Fargo-Moorhead Metropolitan Area Flood Risk Management Project

Draft Adaptive Management and Mitigation Plan

November 2021

US Army Corps of Engineers®
St. Paul District

FM AREA DIVERSION

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DEFINITIONS FOR ABBREVIATIONS AND TERMS USED IN THE AMMP

Abbreviation/Term	Definition
2011 FEIS	Final Feasibility Report and Environmental Impact Statement, Fargo-Moorhead Metropolitan Area Flood Risk Management, July 2011
2013 SEA	Supplemental Environmental Assessment, dated September 2013
2016 MN EIS	Final Environmental Impact Statement by the Minnesota Department of Natural Resources
2019 SEA	Supplemental Environmental Assessment #2
AAHU	Average Annual Habitat Unit
Ac	acre
ADCP	Acoustic Doppler Current Profiler
AMMP	Adaptive Management and Mitigation Plan
AMT	Adaptive Management Team
BWSR	Minnesota Board of Water and Soil Resources
CEQ	Council on Environmental Quality which includes the NEPA Task Force
Corps	St. Paul District, Army Corps of Engineers
DBH	Diameter (of tree) at breast height
DOC	Dissolved Organic Carbon
EPA	U.S. Environmental Protection Agency
GMP	Geomorphic Monitoring Plan
GMT	Geomorphic Monitoring Team
HEP	USFWS Habitat Evaluation Procedures
HSI	Habitat Suitability Index
HU	Habitat Unit
IBI	Index of Biotic Integrity
LOTR	Lower Otter Tail River
MnDNR	Minnesota Department of Natural Resources
MnPCA	Minnesota Pollution Control Agency
MnRAM	Minnesota Routine Assessment Method
NEPA	National Environmental Policy Act
NDDEQ	North Dakota Department of Environmental Quality, previously the North Dakota Department of Health
NDDWR	North Dakota Department of Water Resources, previously the North Dakota State Water Commission
NDGF	North Dakota Game and Fish
NDSWC	North Dakota State Water Commission
Non-Federal Sponsors	City of Fargo, North Dakota; City of Moorhead, Minnesota; and Metro Flood Diversions Authority
NNI	Native, non-invasive Species
NRCS	Natural Resources Conservation Service
OHB	Oxbow-Hickson-Bakke
O&M	Operations and Maintenance
OMRR&R	Operations, Maintenance, Repair, Rehabilitation, and Replacement
Post-construction	Once the Project has received all approvals and is officially operational the status of the Project will be considered post-construction.

Abbreviation/Term	Definition
PRAM	Property Rights Acquisition Mitigation
Project	Fargo-Moorhead Metropolitan Area Flood Risk Management Project
Project Operation	Operation of the Red River Structure, Wild Rice River Structure, and Diversion Inlet Structure in response to a flood that generated a combined Red River and Wild Rice River flow exceeding 21,000 cfs, as measured at the Red River at Enloe, ND, and Wild Rice River at Abercrombie, ND, USGS gages.
Section 404 Permit	Permits issued in accordance with Section 404 of the federal Clean Water Act
SIR	USGS Scientific Investigation Reports
TOC	Total Organic Carbon
USACE	U.S. Army Corps of Engineers
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WCA	Minnesota Wetland Conservation Act
WQM	Water Quality Monitoring Study
WRRDA	Water Resources Reform and Development Act of 2014

INTRODUCTION

The Fargo-Moorhead Metropolitan Area Flood Risk Management Project (Project) was authorized by Section 7002 of the Water Resources Reform and Development Act of 2014 (WRRDA). The purpose of the Project is to reduce flood risk, flood damages, and flood protection costs related to flooding in the Fargo-Moorhead metropolitan area. The Project is led by the St. Paul District, Army Corps of Engineers (Corps), and the non-federal sponsors of Fargo, North Dakota; Moorhead, Minnesota; and the Metro Flood Diversion Authority (collectively Non-Federal Sponsors). The Metro Flood Diversion Authority was formed as the lead Non-Federal Sponsor and is the point of contact for the Non-Federal Sponsors.

The Project is located in the Fargo-Moorhead Metropolitan Area (Figure 1). The Project consists of a 1) diversion channel system and associated infrastructure including, but not limited to: excavated channels, interstate bridges, county bridges, railroad bridges, control structures, and aqueducts; 2) the Southern Embankment including, but not limited to: tie-back embankments, an upstream staging area, levees, and diversion structures for the Wild Rice and Red rivers; 3) In-town levees and floodwalls; and 4) environmental mitigation projects located inside and outside the Project area.

The Project originated as a recommendation from the Final Feasibility Report and Environmental Impact Statement (FEIS), Fargo-Moorhead Metropolitan Area Flood Risk Management, July 2011. As outlined within the FEIS, the Project would have various environmental effects. Some of the identified effects were significant enough to warrant mitigation. These impacts and mitigation needs were updated through the Supplemental Environmental Assessment, dated September 2013 (2013 SEA), and the Supplemental Environmental Assessment #2 (2019 SEA). The Project with all proposed modifications included in the 2013 SEA and the 2019 SEA since the FEIS is referred to as “Plan B.” Based on the current NEPA analysis, environmental impacts requiring mitigation would include impacts to aquatic habitat, riparian forest, and wetland resources. For these impacts, mitigation will be implemented to offset these adverse effects to the greatest extent practicable. Mitigation is also being included to address concerns of state natural resource agencies regarding biological connectivity. Conversely, other resource types or functions were not deemed to have significant impacts but warrant monitoring to ensure impacts stay within those outlined in the NEPA analysis. These include monitoring of river geomorphology, water quality, and fish stranding. Mitigation of nonenvironmental impacts, such as property right mitigation, are not addressed in this document. A property rights acquisition mitigation plan (PRAM) has been developed for the Project and provides details on property rights mitigation.

SUMMARY OF ADAPTIVE MANAGEMENT AND MITIGATION PLAN SECTIONS

The NEPA analysis included impact analyses of changes in habitat quality and quantity. The NEPA analysis also included mitigation measures for to reduce significant adverse impacts. The purpose of this Adaptive Management and Mitigation Plan (AMMP) is to provide a dynamic framework and adaptive approach to monitoring potential impacts over time and mitigation associated with the Project. The AMMP also discusses possible approaches if mitigation measures do not result in projected conditions, or if unforeseen impacts arise from implementation of the Project.

Section 1 provides an overview of the adaptive management and implementation process, including the collaboration process with the Non-Federal Sponsors, Corps, State of North Dakota, State of Minnesota, and federal natural resource agencies.

Section 2 provides an overview of Project impacts and mitigation needs focusing on habitat-based assessments of impacts and mitigation needs for aquatic habitat, forest, and wetland resources.

Section 3 provides an overview of the Project mitigation approach, a summary table of mitigation needs, mitigation accomplished to date, and remaining mitigation needed. Specific mitigation sites have not been fully finalized for all impact needs as the Project design details have not been completed. The Corps has identified several mitigation projects, as described in Section 3, and will continue to refine specific mitigation plans during detailed Project design.

Section 4 describes specific monitoring activities that will be completed pre- and post-construction, performance standards, and triggers for event-specific monitoring and adaptive management. This section also includes overviews on contingency processes where corrective action could be pursued if mitigation proves to be less effective than anticipated.

Section 5 provides the anticipated cost and schedule of monitoring and mitigation efforts.

Section 6 addresses the storage and accessibility of data collected by the monitoring activities.

Collectively, this AMMP will drive the implementation of mitigation, and the data collection and review processes to confirm the effectiveness of the mitigation. Monitoring results will be compared to the environmental changes that would occur due to Project implementation with mitigation to verify whether the impacts of the Project have been appropriately offset. In addition, this AMMP will remain flexible to adapt to the needs of the Project over time. As such, this document is open to change throughout the life of the Project.

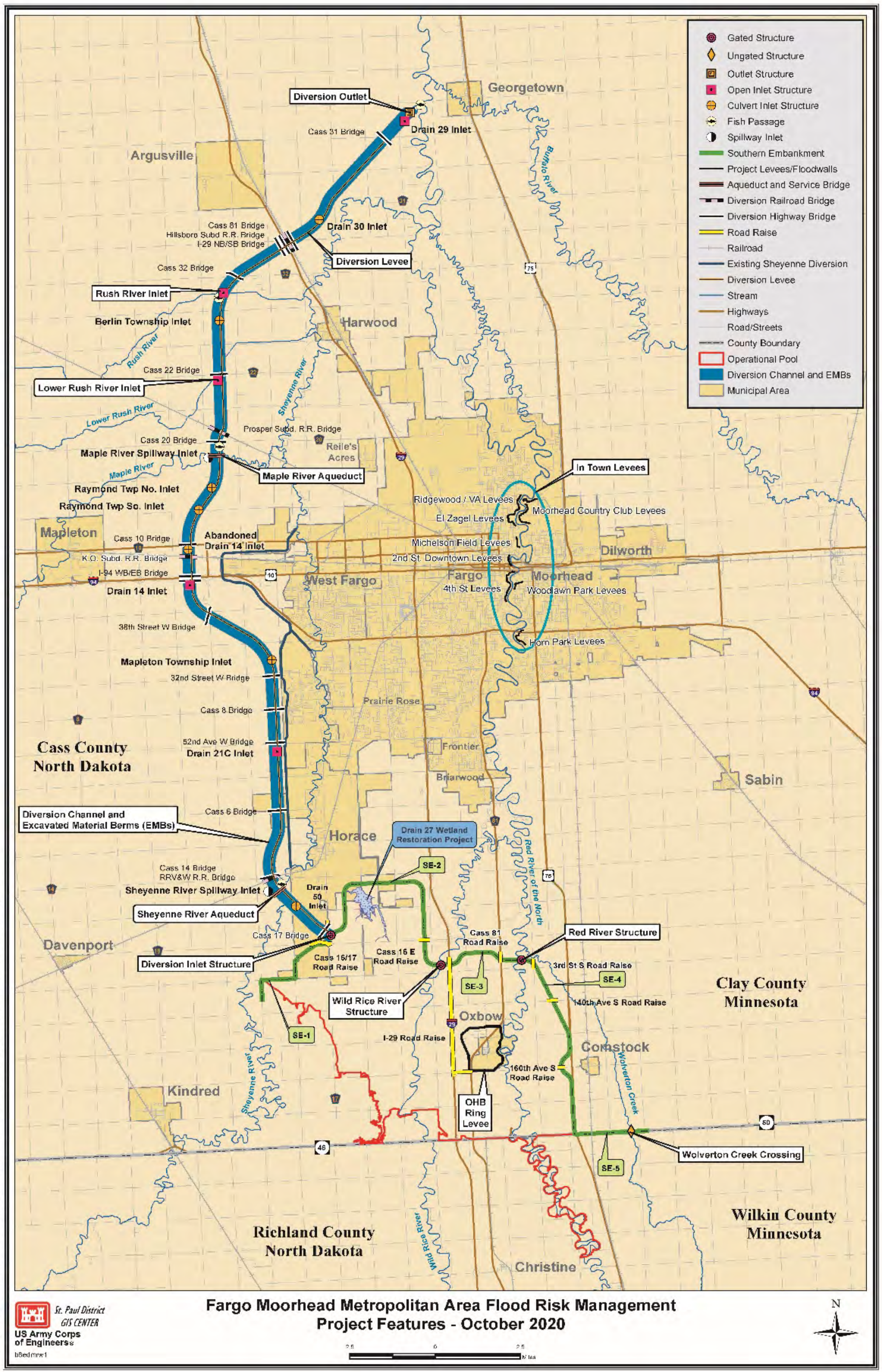

Figure 1. Map of the Project area.

1 OVERVIEW OF ADAPTIVE MANAGEMENT IMPLEMENTATION PROCESS

1.1 Introduction to Adaptive Management Approach

Adaptive management is based upon clearly identified outcomes, as described in environmental documentation, monitoring to determine if the desired outcomes occur, and, if not, facilitating management changes to either meet or re-evaluate the projected outcomes (DOI, 2018). Adaptive Management is a requirement of Minnesota Dam Safety & Public Waters Work Permit number 2018-0819 (“MnDNR Permit No. 2018-0819") and Corps Policy Guidance for those civil works programs that require environmental mitigation. This Adaptive Management and Monitoring Plan recognizes that recommendations generated by the Adaptive Management Approach remain subject to federal and state laws, permit conditions, and the permit amendment/regulatory oversight process is expressly reserved to permitting agencies having jurisdiction over various elements of the Project.

Adaptive management is a “learning by doing” management approach which promotes flexible decision making that can be adjusted when there are uncertainties that will become more defined as outcomes from management actions and other events become better understood (National Academy of Sciences, 2004). It is used to address the uncertainties often associated with complex, large-scale projects. In adaptive management, a structured process is used so that the “learning by doing” is not simply a “trial and error” process (Walters, 1986).

The basic elements of an adaptive management process are: (1) assess; (2) design; (3) implement; (4) monitor; (5) evaluate; and (6) adjust. In practice, adaptive management is implemented in a non-linear sequence, in an iterative way, starting at various points in the process and repeating steps based on improved knowledge.

Application of adaptive management should occur in two phases. A setup phase would involve the development of key components, and an iterative phase would link these components in a sequential process. Elements of the setup phase include stakeholder involvement, defining management or mitigation objectives, identifying potential management or mitigation actions, identifying or building predictive modeling or assessment tools, specifying performance measures and/or risk endpoints, and creating monitoring plans. In addition, values for the monitored measures that would trigger adaptive management should be determined in this phase. The second iterative phase uses these elements in an ongoing cycle of learning about system structure and function, followed by managing based on what is learned from data collected. The elements of the iterative phase include recommendations, follow-up monitoring, collaborative approaches on future actions, and subsequent assessment.

Adaptive management is not necessarily the only decision-making process. Adaptive management provides a systematic methodology that could lead to enhanced benefits and effective outcomes (DOI, 2018).

Adaptive management should not be used where decisions can only be changed in a limited manner or cannot be changed due to permit requirements. Federal permits include the Section 404 Permit, Rivers and Harbors Act of 1899 Sections 9 and 10 Permit, Programmatic Agreement under the National Historic Preservation Act Section 106, U.S. Fish and Wildlife Coordination Act Report compliance, and Prime and Unique Farmlands Protection Act Consultation Compliance. North Dakota permits include Section 401 Permit, North Dakota Sovereign Lands Permit, North Dakota Construction Permits, North Dakota Dewatering Permits, and North Dakota stormwater pollution prevention plan permits. Minnesota permits include MnDNR Permit No. 2018-0819 and Minnesota stormwater pollution prevention plan permits. In addition, the Non-Federal Sponsors have permits and agreements with local agencies and entities that manage land use, flood control, transportation, and utilities along the construction corridor (Local Permits). This AMMP does not address compliance with Local Permits.

The overall adaptive management process generally includes:

- Identification of Project Adaptive Management and Monitoring Plan Participation
- Establishment of Goals, Objectives, and Performance Standards – specifically for those items that are not fully defined in the environmental documentation due to future uncertainties
- Development and Implementation of Monitoring Plans – to determine realization of goals and objectives as defined in the environmental documentation
- Resources Monitoring Team Process – to provide a group of technical experts to review monitoring plan results; compare with goals, objectives, and performance standards; and develop recommendations based upon scientific analyses
- Adaptive Management Team Process – to review the results of the Resources Monitoring Team recommendations to determine "next steps" to achieve goals, objectives, and performance standards
- Consideration of the Adaptive Management Team Recommendations by the Corps and Non-Federal Sponsors
- In accordance with MnDNR Permit No. 2018-0819, the Adaptive Management Team will meet within 30 calendar days of the identification of a trigger set forth in this Adaptive Management and Monitoring Plan and provide a corrective action recommendation within 30 calendar days of the meeting of the Adaptive Management Team.

1.2 Project Adaptive Management and Monitoring Plan Participation

Staff from multiple state and federal resource agencies have been involved in the planning process for the Project dating back to 2009. Agency input has been instrumental in the calculation of Project impacts, the identification and design of mitigation efforts, and the development of monitoring procedures. Individuals that attended meetings on the AMMP eventually became known informally as the Adaptive Management Team (AMT).

Agencies that have participated in AMT meetings include, but are not limited to, the following:

- Corps,
- Non-Federal Sponsors (Metro Flood Diversion Authority, City of Fargo, and City of Moorhead),
- U.S. Fish and Wildlife Service (USFWS),
- U.S. Geological Survey (USGS),
- U.S. Forest Service (USFS),
- Environmental Protection Agency (EPA),
- Natural Resources Conservation Service (NRCS),
- North Dakota Game and Fish (NDGF),
- North Dakota Department of Environmental Quality (NDDEQ), previously the North Dakota Department of Health (NDDoH),
- North Dakota Department of Water Resources (NDDWR), previously North Dakota State Water Commission (NDSWC),
- Minnesota Department of Natural Resources (MnDNR),
- Minnesota Pollution Control Agency (MPCA), and
- Minnesota Board of Water and Soil Resources (BWSR).

Several smaller groups of technical experts were eventually formed to discuss monitoring and adaptive management in greater depth with the intent of providing focused recommendations to the AMT. Those teams included the Geomorphic Monitoring Team, the Water Quality Monitoring Team, and the Biotic Monitoring Team.

1.3 Goals, Objectives, and Performance Standards

Clearly focused and quantitative goals and objectives are essential to adaptive management. They should be logically linked to mitigation actions, performance standards, and monitoring activities. Goals and objectives will be specifically identified during detailed monitoring and mitigation planning.

Performance standards will be used during two adaptive management processes: plan evaluation (evaluation of performance measures and metrics like those described above to predict Project impacts) and assessment of actual plan performance (assessment of performance measures following Project implementation). In many cases, these processes would be the same, allowing predictions to be compared to actual responses.

Performance standards are further discussed in Section 4. This includes metrics for quantifying impacts following Project construction, identification of trigger values that would indicate the need for adaptive management, and how effectiveness of future changes will be measured. These standards have been developed based on the best available information and input from the AMT. Additional data and changes in design may lead to further development or modification of performance standards. At a minimum, the goal of mitigation that has been identified as of the date of the AMMP will be to replace the habitat lost through Project impacts. Future monitoring may include additional minimum goals related to Project impacts, including but not limited to, geomorphology, fish stranding, and invasive species. Performance standards will allow for the evaluation of mitigation effectiveness.

1.4 Development and Implementation of Monitoring Plans

The Council on Environmental Quality (CEQ) NEPA Task Force (CEQ 2003) suggests that the effectiveness of adaptive management hinges upon an effective monitoring program to establish objectives, thresholds, and baseline conditions. This will be achieved through a stepwise process that includes, as appropriate, pre-construction and post-construction studies. It is recognized that Project level monitoring by the Corps during construction may be limited due to the availability of federal funds based on Congressional appropriations; the Non-Federal Sponsors acknowledge that in the event that the Corps does not receive Congressional appropriations, monitoring at the expense of the Non-Federal Sponsors will be required by the permits. Post-project construction monitoring will be a part of Project implementation, with monitoring required from the Non-Federal Sponsors as a part of Project operation and maintenance.

Following the adaptive framework of this document, changes would be monitored over time, and performance of measures would be assessed to determine whether additional avoidance, minimization, or mitigation measures are needed. Post-project monitoring results will provide information that can be compared with pre-project monitoring to assess the extent of impacts from the Project features and evaluate the effectiveness of mitigation. Monitoring activities, including review of results, will be performed collaboratively with the AMT.

Pre- and post-project monitoring is discussed in greater detail below in Section 4. Specific proposed sampling methodologies have been designed with input from the AMT to address the performance standards outlined.

1.5 Resource Management Team Process

Several resource areas have been identified for monitoring and adaptive management through the development of the AMMP. Each of these resource areas is very complex and technical expertise will be needed to assist the AMT in making recommendations. Resource monitoring teams for geomorphology, biotic, wetlands, forests, and water quality will meet when data related to the performance standards/metrics listed in Section 5 have been collected and are ready for evaluation or when adaptive management triggers have been reached. Each team will be responsible for making recommendations to the AMT. It is recognized that any individuals participating on behalf of MnDNR as part of a resource monitoring team will not be providing recommendations and/or ratings, but may provide comments and observations.

In the State of Minnesota, MnDNR is responsible for ensuring any mitigation proposed by the Metro Flood Diversion Authority, which is recommended by the AMT, meets the requirements of Minnesota law and is in compliance with MnDNR Permit No. 2018-0819. Participation by any individuals participating on behalf of MnDNR in a consensus process is not compatible with regulation of the Project by MnDNR. Any determinations on whether mitigation is needed or sufficient under MnDNR Permit No. 2018-0819 is at the sole discretion of MnDNR. MnDNR will use data generated from the AMMP process to determine if any additional mitigation is needed under MnDNR Permit No. 2018-0819. Any mitigation proposed by the Non-Federal Sponsors as a result of a recommendation by the AMT will also be evaluated for compliance with MnDNR Permit No. 2018-0819.

Recommendations from the resource monitoring teams will follow a five-point consensus rating system. Individuals participating in the resource monitoring teams will rate recommendations from 1 through 5 based on the acceptability of the actions being proposed, with a rating of 1 being unacceptable and 5 being full support. Only recommendations that receive ratings of 3 or higher from each individual participating in the discussion can move to the AMT for consideration. This process provides a steppingstone to in-depth discussion. Individuals that provide ratings of 1 or 2 will be asked to provide rationale for those ratings and solutions that could raise their scores to an acceptable level. The intent of the process is to encourage active feedback and resolution of individual concerns. The resource monitoring team will document recommendations that were not fully supported (by members that provide ratings of 1 or 2) prior to submission of the recommendation to the AMT. The documentation of the process would be provided to the AMT, along with the final rating of each member.

1.6 Adaptive Management Team Process

Features of the Project are located solely in both North Dakota and Minnesota and along the Red River channel in both North Dakota and Minnesota. Numerous entities with various interests at several levels of government have been involved in shaping the AMMP, as listed in Section 1.2, Project Adaptive Management Team. It is important to maintain collaboration among these entities to ensure the continued integrity in the adaptive management approach. However, there is also a need to make site-specific implementation recommendations at various locations within the Project area.

The following describes a process that allows for continued collaboration but allows AMT recommendations to be made by a subset of individuals based on input from regulatory and management agencies. The initial AMT participants will be selected by each entity and will discuss recommendations to present to the Non-Federal Sponsors and the Corps (during Project construction) for decisions to change Project implementation or the need for changes to mitigation measures. MnDNR will select its AMT participants, but those individuals selected by MnDNR will not participate in the consensus poll regarding rating or creating recommendations of the AMT, and may, but are not required to, provide opinions and/or comments to proposed recommendations.

Changes to the AMMP will be the result of recommendations from the AMT, using the process described below. It will be each AMT members responsibility to coordinate proposed changes within their own organization and report any concerns to the AMT. Changes AMMP will undergo a similar process to the initial agency approved AMMP in September 2021.

Table 1. Initial Adaptive Management Team Representatives

Adaptive Management Team	
Agency Category	**Entities**
Non-Federal Sponsors	Metro Flood Diversion Authority City of Fargo City of Moorhead
Federal Agencies	Corps USFWS EPA
State of North Dakota	NDDWR NDDEQ NDGF
State of Minnesota	MnDNR (Non-rating observer status) MPCA BWSR

The AMT can use a process for discussion and evaluation of recommendations that includes, but is not limited to the following steps:

- Use the consensus rating tool to determine the position that AMT has regarding support of the recommendations form the resource monitoring teams, such as through the use of a five-point consensus rating system. Under such a consensus rating system, individuals participating in the discussion would rate recommendations from 1 through 5 based on the acceptability of the actions being proposed, with a rating of 1 being unacceptable and 5 being full support. Only recommendations that receive all ratings of 3 or higher would move forward as recommendations for the AMT. This process provides a steppingstone to in-depth discussion. Individuals that provide ratings of 1 or 2 would be asked to provide rationale for those ratings and solutions that could raise their scores to 3 or higher. This information would be used to document items that are not fully supported (by members that provide ratings of 1 or 2) or modify the recommendations.
- The AMT may also bring additional criteria to evaluating recommendations other than those criteria advanced by the science-based technical teams. The AMT may identify essential criteria (including **SMART** – **S**pecific to goal; **M**easurable; **A**ttainable under conditions, capacity, feasibility; **R**elevant to the problem and needs to be done; **T**imely – can be undertaken in time to achieve the goal) / and other filters they agree on for recommendation approval.
- If a recommendation is revised by the AMT in a manner that may impact technical aspects of the recommendation, the AMT may consider requesting the appropriate Resource Management Team's input to assure it still achieves the recommendation goals.

- Recommendations forwarded to the Non-Federal Sponsors and the Corps should include information regarding:
    - Each AMT participant's final rating of the recommendation, including any concerns as appropriate
    - Resources required (personnel, time, costs, and other resources special to Project)
    - Consequences (expected impact or outcome of the action if accomplished)
    - Obstacles (for example: specific conflicts of interest of stakeholders or regulatory requirements or lack of local support that may need to be resolved, or specific lack of resources preventing accomplishment of the action)

The AMT members would have the following responsibilities and commitments.

Responsibilities

- The AMT chair, who will be appointed by the Non-Federal Sponsors, will be responsible for preparing meeting announcements, agendas, and preparing minutes of AMT meetings. Meeting announcements will be required at least 14 calendar days in advance of any meeting, and agendas will be required 7 calendar days prior to the meeting.
- Entity representatives will make every possible effort to attend AMT meetings. In the event that an entity's official representative is unable to participate, the entity or their representative may designate another staff member to serve in that capacity on a substitute basis. If an entity's representative, or designated substitute, does not attend a meeting where a voting matter has been identified in the meeting agenda, votes from that entity will be forfeited.
- The Non-Federal Sponsors are responsible for monitoring and analysis of monitoring data. The Non-Federal Sponsors shall provide individuals with technical expertise, when specific subject-matter expertise is deemed necessary, to present and discuss the analysis of the monitoring data when it is ready for AMT review.
- All entities participating in AMT discussions will be responsible for all costs associated with its participation in AMT meetings and activities.

Commitments

- AMT representatives must be committed to communicate and be willing to share challenges and lessons learned as well as successes
- AMT representatives must strive to create an environment of trust and to foster insightful, non-threatening discussion of ideas and experiences
- AMT representatives must distribute leadership responsibilities and collectively share in the management of the community
- AMT representatives are practitioners, contributing to the community through their experiences, skills, and time
- AMT representatives must agree to be respectful and use appropriate language in group discussions and to listen and respond to each other with open and constructive minds

- AMT representatives must not be afraid to respectfully challenge one another by asking questions
- AMT representatives must openly express their agency's objectives when working to promote them
- AMT representatives must participate to the fullest extent possible
- AMT representatives must commit to search for opportunities for consensus or compromise and for creative solutions
- AMT representatives must contribute to an atmosphere of problem solving rather than stating positions
- AMT representatives must attempt to build on each member's strengths and help each other improve areas in need of further development

AMT recommendations must support the continued operation of the Project to protect the communities in North Dakota and Minnesota from flooding. It is recognized that specific operational considerations may be modified; however, as a fundamental portion of the AMT charter, the ability to operate the Project in accordance with existing permits must and shall be maintained to provide for public health and safety. The AMT will meet within 30 calendar days of the triggers identified in Section 4 of this document and corrective actions will be identified within 30 calendar days of that meeting. This will ensure that actions move forward in a timely manner.

The AMT will also meet within 90 calendar days after every Project operation has been completed to discuss any adjustments needed to the AMMP. For proposes of the AMMP, Project operation means that the gates on the Red River and Wild Rice Control Structures have been lowered to divert the Red and Wild Rice Rivers into the staging area and diversion channel.

1.7 Consideration of the Adaptive Management Team Recommendations by Non-Federal Sponsors and the Corps

As discussed in Section 1.1, adaptive management should not be used where recommendations conflict with permit requirements. It is recognized that adaptive management is a condition of MnDNR Permit No. 2018-0819. Therefore, the AMMP would not be used for implementation of specific permit conditions, including but not limited to permit conditions in the Section 404 Permit, Rivers and Harbors Act of 1899 Sections 9 and 10 Permit, Programmatic Agreement under the National Historic Preservation Act Section 106, U.S. Fish and Wildlife Coordination Act Report compliance, Prime and Unique Farmlands Protection Act Consultation Compliance, North Dakota Sovereign Lands Permit, North Dakota Construction Permits, North Dakota Dewatering Permits, and permits and agreements with local agencies and entities that manage transportation and utilities. With respect to these permit-related decisions, changes would be developed by consultation with the permit agencies and the Corps and Non-Federal Sponsors prior to completion of Project construction and with the Non-Federal Sponsors post-construction.

For all non-permit related decisions, recommendations from the AMT will be considered in a collaborative manner to develop changes in implementation methods, monitoring protocol, performance standards, and, if necessary, objectives and goals. Prior to completion of Project construction, the collaborative process will occur between the AMT, the Corps, and Non-Federal Sponsors. The decision will be made by the Non-Federal Sponsors and the Corps. Post-construction, the collaborative process will continue to occur between the AMT and the Non-Federal Sponsors with the decisions being made by the Non-Federal Sponsors.

2 PROJECT IMPACTS AND MITIGATION NEEDS

The previous NEPA documentation for the Project evaluated potential impacts to a wide range of resource types. The FEIS and the subsequent SEAs from 2013 and 2019 are source documents for this AMMP which set forth the discussion of impact quantification and rationale for impacts warranting mitigation. Project designs were compared with aerial photographs, available data, and in-field observations to estimate the amount, quality, and value of potential habitats impacted by all Project features. The Corps reviewed this information, collaborated with agency partners, and made a final determination on whether or not these losses warranted mitigation. Based on those conversations, the Corps determined to require mitigation for lost aquatic riverine habitat; wetlands; and forests. In addition, MnDNR permit 2018-0819 required that mitigation for fish passage take place at Drayton Dam and that any impacts to geomorphology, fish stranding, and cold weather impacts at the aqueducts also be monitored and mitigated, if necessary.

Since completion of the FEIS, impacts and mitigation needs were updated for several key reasons. Project designs and operations updated from those previously assessed in the FEIS were evaluated in the subsequent SEAs. In addition, collection of additional field data has allowed for a better understanding of both existing habitat quantity and quality. Finally, the North Dakota and Minnesota state permitting processes have included more detailed monitoring and/or mitigation requirements.

Corps policy requires that any potential mitigation planning considers habitat quality as part of the impact determinations. The FEIS estimated habitat quality based on best available information at that time. For example, as described in the FEIS, the quality of floodplain forest impacted was quantified by using a series of USFWS Habitat Evaluation Procedures (HEP) habitat models. These models were used to compute an average habitat suitability index (HSI) score between 0.0 and 1.0 to measure habitat quality. From the qualitative and quantitative determinations, the standard unit of measure, the Habitat Unit (HU), is calculated using the formula: HSI score x acres impacted = HUs.

Another aspect to assessing lost habitat and mitigation needs is how conditions could change over time within impact areas. Mitigation value could also change over time. For example, floodplain forest mitigation must consider that it takes a considerable amount of time for floodplain forest to grow and mature to full functionality. To characterize habitat changes over time, HUs are calculated for target years and averaged over the life of the Project (50 years) to determine what is known as the Average Annual Habitat Units (AAHUs).

Given the uncertainty with whether habitat conditions might generally improve or degrade in the future, or to what magnitude such changes would occur, the FEIS and subsequent SEAs assumed that conditions would remain constant over time when assessing impacts. It is recognized that habitat conditions likely will not remain constant. However, this approach hopefully minimizes the potential to either underestimate or overestimate potential Project impacts to aquatic and terrestrial habitat. For assessing mitigation benefits, consideration was given as to how long it may take habitat restoration projects to reach full effect.

The above approach was used to estimate habitat quality and mitigation needs for forests and wetland resources. However, habitat mitigation needs will be influenced by available opportunities and requirements of the North Dakota and Minnesota permits for the Project. The following represents the Project impact and mitigation needs updated through the current design.

2.1 Aquatic Habitat

Impacts have been quantified through collection of pre-project fish and invertebrate data, resulting in Index of Biotic Integrity (IBI) scores. The original plan was to compare IBI scores before and after construction to verify resulting impacts. IBI scores were also to be generated for mitigation sites to help quantify the amount of mitigation created compared to the habitat lost through construction. This approach has been discontinued for two primary reasons. First, this approach is not consistent with the State of Minnesota's determination of mitigation needs via the MnDNR Dam Safety & Public Waters Work Permit (permit # 2018-0819) for lost aquatic habitat within their state. This will include any post-project monitoring needs. Second, mitigation for lost aquatic habitat in North Dakota will be mitigated via a combination of habitat restoration and fish passage implementation. Because of the challenge of quantifying fish passage benefits and combining them with benefits of site-specific mitigation, these mitigation needs will be met through a mutual agreement with the State of North Dakota. This agreement will be formalized with the State of North Dakota once the design and operation of features along the Project diversion channel near completion and a clearer understanding of mitigation needs can be established.

The IBI scoring system had previously been generated in the Red River Basin back in the 1990s to describe general biotic conditions (EPA 1998). This was used in the FEIS to estimate habitat quality, impacts and mitigation needs. However, the NDDoH subsequently developed both a fish and macroinvertebrate IBI for Red River Basin tributaries (NDDoH 2011a; 2011b). These two IBIs were utilized to calculate IBI scores for all rivers except the Red River. The Red River only utilized a specific fish IBI to calculate habitat quality for sites on this river. The reason is due to limitations with 2017 invertebrate sample collection and the resulting questionable invertebrate data for the Red River. For pre-project data collected to date, the NDDoH provided the IBI scoring results.

Impacts to aquatic habitat were quantified by calculating HUs, with the IBI scores identified above as the habitat quality. The IBIs calculate habitat condition to a score between 0.0 and 1.0, and are then multiplied by the impact area to calculate an amount of habitat lost via impact. This approach noted the potential HUs present within any newly constructed river channels to facilitate routing flow through Project features (e.g., water control structures, aqueducts, etc.).

Aquatic habitat lost through the latest Project designs, and associated proposed mitigation needs, are presented in Table 2.

Table 2. Aquatic habitat footprint impact areas being mitigated and corresponding habitat units for aquatic impacts by Project feature, updated for the most recent design.

Impact	Footprint Area (ac)	IBI Score*	Habitat Units (HUs) Lost
Red River Structure	12.9	0.52	6.7
Wild Rice River Structure	7.8	0.44	3.4
Sheyenne River Aqueduct	8.0	0.54	4.3
Maple River Aqueduct	10.0	0.57	5.7
Total	38.7		20.1

*IBI scores are an average of fish and invert IBI scores for 2012 and 2017 at the footprint sampling site. The Red River structure uses fish only given some of the challenges with sampling invertebrates on the Red River. Fish IBI scores are also higher than Invertebrate IBI for the Red River, providing a more conservative estimate.

2.2 Floodplain Forest

Some forested areas would need to be cleared for construction of the Project. Forest areas impacted by construction of Project features total 139 acres for the current design. The FEIS outlined a habitat evaluation process for existing floodplain forest in the Project area, which identified a habitat suitability factor of 0.51. This suitability factor is assumed to not have changed as no major changes have occurred in the areas forest composition or structure that would result in appreciable alteration of that suitability factor. Thus, 0.51 is applied to the acres impacted to identify the habitat units for lost forest habitat and the targeted amount for mitigation.

In terms of habitat conditions over the next 50 years, woodland extent, structure, and composition is assumed to remain fairly similar to existing condition. While habitat value for individual species may change over time as natural setback/succession processes occur on these established tracts, the overall habitat value for the riparian woodland community would remain essentially the same and be rated as fair with a HSI of 0.51.

The assumed HSI for an established floodplain forest is 0.51. It is also assumed that it could take a full 50 years for a created forest to reach its full functioning level. Over a 50-year planning horizon (the standard for the Corps planning activities), assuming a starting HSI of 0 and an ending HSI of 0.51, this amounts to an average HSI value of 0.25. Thus, approximately 283.4 acres of floodplain forest habitat would be needed to generate the 70.9 Habitat Units of mitigation needed to offset Project impacts.

Table 3. Estimated floodplain forest mitigation need based on forest habitat lost.

Impact	Footprint Area Lost (ac)		Existing Habitat Quality Score	Habitat Units Lost		Created Forest Habitat Quality Score	Mitigation Needs (ac)	
	ND	MN		ND	MN		ND	MN
Forest	124	15	0.51	63.2	7.7	0.25	252.8	30.6
Total	**139**		**0.51**	**70.9**		**0.25**	**283.4**	

2.3 Wetlands

Wetland areas would need to be filled or modified for construction of the Project. This includes areas for the diversion channel, southern embankment, and Oxbow-Hickson-Bakke (OHB) ring levee. The wetland impacts for the diversion channel and OHB are addressed by parallel Section 404 permitting efforts (referenced below). Wetland impacts for the remaining portions of the Project will be assessed through a Section 404(b)(1) analysis and mitigated appropriately. Wetland impacts for the Project are provided in Table 4. Minnesota Routine Assessment Method (MnRAM) wetland functionality assessment was used to determine mitigation for the Project. It was later decided that MnRAM is not a preferred method in Minnesota so mitigation in that state will follow the ratios in the Minnesota Wetland Conservation Act (WCA). Mitigation would target no net loss of wetland impacts.

Table 4. Estimated wetland impact based on current footprint of the Project.

Wetland Type	Wetland Impacts by Type					
	ND Ditched Wetlands	ND Non-Ditched Wetlands	ND Total Wetlands	MN Ditched Wetlands	MN Non-Ditched Wetlands	MN Total Wetlands
Farmed Seasonally Flooded Basin	0.44	1199.63	1200.07	0.40	15.40	15.80
Shallow Marsh	28.66	51.95	80.61	-	2.99	2.99
Shallow Open Water	-	4.97	4.97	-	-	-
Wet Meadow	73.56	93.06	166.62	16.73	0.83	17.56
Column Total	**102.66**	**1349.61**	**1452.27**	**17.13**	**19.22**	**36.35**
Total	**1488.62**					

2.4 Geomorphology

Potential effects to waterways, bank stability, erosion, and sedimentation within and outside the existing channel and floodplain (including newly inundated areas) have been discussed at length in the FEIS (geomorphic impacts discussion including Section 5.2) and subsequent SEAs. These impacts and related monitoring are also described in Section 3.3 and Appendix B of the MnDNR Final Environmental Impact Statement (2016 MN EIS), dated May 2016. Potential future conditions impacts were also outlined in geomorphic assessment reports completed by WEST

Consultants in 2012 and 2019. As outlined in the FEIS, the 2016 MN EIS, and the WEST reports in 2012 and 2019, no significant adverse impacts are anticipated. The Project would not likely have a significant effect on stream stability and geomorphology throughout the potentially impacted/affected environment. Multiple features were incorporated to reduce the frequency at which the Project would operate in the future. This was done specifically to minimize potential adverse effects to multiple resource types, including geomorphology. With the updates to the Project operations in the 2019 SEA, no significant adverse effects are anticipated, and no mitigation was proposed. However, geomorphic conditions will be monitored as a part of the AMMP (outlined in Section 4.4). The monitoring plan for geomorphology has been developed, and will be revised over time, as needed, to capture any new concerns. Pre-Project geomorphic monitoring was conducted in 2010/2011, 2018, and 2020. The scopes of work for the pre-Project geomorphic monitoring were developed through a collaborative effort with participating agencies.

2.5 Invasive Species Management

Preventing the spread of invasive species is always a concern during the construction of projects as equipment and materials are transported from other areas. To avoid the spread of invasive species (including Red River and its tributaries that are infested by zebra mussels), contractors will need to prepare an invasive species management plan prior to construction. All equipment that would be in contact with infested waters must be decontaminated prior to entering the water and before leaving the site. Methods for decontamination could include one or more of the following methods: a) Drain and treat all water from equipment; 2) Remove all visible aquatic remnants of plants, seeds, or animals; 3) Remove mud and soil; and/or 4) Hand scrape or power wash with hot water of at least 140° Fahrenheit for at least 10 seconds or use another acceptable treatment method. To avoid the spread of existing invasive vegetative species within the construction boundaries, the plan would delineate existing weed infested areas and include methods to: a) Minimize disturbance; b) Clean equipment before leaving the infested areas; and/or c) Separate stockpile and removed vegetation piles from the infested areas as compared to the non-infested areas. Soil placed in water bodies would not include solid wastes, hazardous materials, or aquatic invasive species.

Construction within Minnesota will require that contractors prevent the spread of invasive species based on MnDNR publication, "Best Practices for preventing the spread of aquatic invasive species;" Minnesota Administrative Rules Chapters 84D and 6216 which address aquatic, terrestrial, and vegetative invasive species; and U.S. Department of Agriculture publication "A guide to Nonnative Invasive Plants Inventoried in the North by Forest Inventory and Analysis" (2017, C. Olson and A. Cholewa).

Construction totally within North Dakota will requires that contractors prevent the spread of invasive species based upon North Dakota Century Codes 4.1-47-02 and 36-26 which address aquatic, terrestrial, and vegetative invasive species; and, within Cass County, additional compliance with *Identification and Control of Invasive and Troublesome Weeds in North Dakota* by North Dakota State University. Within the construction boundaries of the diversion channel construction project, invasive and/or non-native species control would consist of a combination of mowing, burning, disking, and/or mulching or approved use of biocontrol and/or herbicide treatments developed for each invasive or non-native species.

Construction projects that extend into both Minnesota and North Dakota, such as along the Red River, will require compliance with all of the above regulations and guidance.

2.6 Aquatic Connectivity

Previous Project plans and resulting analyses identified potential impacts to biological connectivity and proposed mitigation actions to offset these impacts (2011 FEIS; 2013 SEA). As discussed in the 2019 SEA, Plan B further reduces adverse impacts to connectivity. As outlined within the SEA, the disruption to upstream connectivity in the Red River system would generally be about 10-14 days whenever the Project operates, which would only occur for floods with a combined discharge of greater than 21,000 cfs on the Wild Rice River and Red River upstream of the dam (approximately a 20-year event). As stated in the 2019 SEA, "While disruptions to connectivity would still occur with Plan B modifications, it is most likely that these disruptions would be infrequent enough, short enough in duration, and early enough in the season that broad, measurable, long-term impacts to Red River fish communities would not be expected.". No additional mitigation in addition to the minimization measures for impacts to connectivity is required by the Corps. Not all resource agencies concurred with this interpretation of impacts.

MnDNR, as a part of its permitting process, is requiring construction of Drayton Dam fish passage. The Project is moving forward as a requirement of MnDNR permit 2018-0819. The permit states that: "The Permittee shall work with DNR on the design of the Drayton Dam Project to ensure that it satisfies the mitigation requirements of this permit." USACE and the Non-Federal Sponsors have worked continuously with MnDNR over the years to develop Drayton Dam fish passage Project designs. This has recently included a design workshop and several phone conversations and email exchanges to complete Project designs in preparation for a contract advertisement in the near future. The Drayton Dam Project designs have essentially included most, if not all, DNR design requests relevant to fish passage and include the most current design standards that MnDNR uses on its own fish passage projects.

While significant impacts to connectivity were not identified due to construction/operation of the aqueducts on the Maple and Sheyenne Rivers, there is uncertainty around this conclusion. Monitoring activities, including evaluation criteria, are discussed below to help confirm if the aqueducts are functioning adequately for biological connectivity.

3 PROJECT MITIGATION

The following discussions outline the mitigation approach to meet the mitigation needs identified in Section 2 of this AMMP.

Tables 5 through 8, at the end of this section, provide a summary of mitigation needs, mitigation accomplished to date, and remaining mitigation needs. These tables will be updated over time in subsequent versions of the AMMP and will demonstrate where the Corps and the Non-Federal Sponsors are in relation to meeting their mitigation commitments.

A database for tracking Project mitigation observations and monitoring data is in development. The database will be accessible to the Corps, the Non-Federal Sponsors, AMT, and resource monitoring team members.

3.1 Aquatic Habitat

Mitigation approaches will be developed based upon the location of the resources and the geographical extent of the impacts in Minnesota and North Dakota. MnDNR permit 2018-0819 mandates mitigation to be completed for impacts to aquatic habitat in waters of the State of Minnesota. This includes half of the lost aquatic habitat on the Red River. All remaining lost aquatic habitat (including the remaining half of lost Red River habitat) occurs within the State of North Dakota and is addressed separately.

3.1.1 Aquatic Habitat Mitigation in Minnesota

Restoration of the Lower Otter Tail River (LOTR) has been considered by a number of resource agencies in recent years. The LOTR forms the headwaters of the Red River. Sections of this river, which flows entirely within Minnesota, have been channelized for flood control purposes below Orwell Dam, near Fergus Falls, Minnesota. There is a large extent of habitat that could be considered for restoration, including several meander bends that have been disconnected from the main channel. Restoration measures potentially include reconnecting isolated oxbows, bank stabilization, reconnecting the river to the floodplain, grading, and other features to recreate more natural and stable river habitat. However, constraints to future restoration projects include limitations due to potential increased water surface elevations and landowner participation from properties adjacent to the Project.

Per condition 27 of the MnDNR permit 2018-0819 for the Project, "The Permittee shall fund the Lower Otter Tail Restoration Project to a dollar amount that would ensure replacement of all ecological resource values and functions of the public waters impacted by the Project. Ecological resource values will be calculated by the DNR…" The MnDNR determined that \$8.28M would be the appropriate amount of funding to offset aquatic habitat impacts.

3.1.2 Aquatic Habitat Mitigation in North Dakota

In the State of North Dakota, extensive work and collaboration has been done to identify potential river restoration projects to serve as mitigation for Project impacts. This has included meetings and site visits with natural resource agencies, county representatives, watershed coordinators, and other stakeholders. To date, the best candidate projects for aquatic habitat mitigation focus on the Sheyenne River and include components listed below. For additional description on the Sheyenne River mitigation, see Attachment A.

Restoration of the Sheyenne River Oxbow

A meander bend of the Sheyenne River within the Project area has experienced a meander bend cutoff. This cutoff is located between Horace and West Fargo, North Dakota, immediately to the east of Sheyenne Street/Highway 17. The Project under consideration includes reconnecting the isolated oxbow, potentially with additional channel work, grading, and other features to recreate more natural river habitat. The area is relatively small, and a project would need to work within potential constraints of the adjacent highway and residences. The restoration of this meander would not be able to take place until after the Project is operational to avoid potential impacts to water surface elevations. While the amount of mitigation that could be credited here is small, it does provide an opportunity for some direct aquatic habitat mitigation on an impacted water body within North Dakota.

Improve Connectivity in the Sheyenne River

Two existing flood risk management projects near the Fargo metropolitan area have resulted in unfavorable natural resource conditions in the Sheyenne River. The existing Horace to West Fargo Diversion includes a culvert structure that restricts high flow through the natural Sheyenne River channel and diverts flows over a baffle structure into a 7+ mile long diversion channel. The Horace to West Fargo Diversion flows into the West Fargo Diversion. The West Fargo Diversion is a 6.5+ mile diversion channel that operates when gated structures near Interstate 94 and 12th Avenue North are closed to divert water around West Fargo. The structures used to operate the projects inhibit fish passage and decrease connectivity. Restoration would include the removal and modification of existing structures. Removal of the gated structures would substantially improve connectivity throughout the natural channel, while modification of the diversion inlets would also improve passability for fish. The existing projects provide flood risk management and modifications to any of the structures would need to take place after the Project is operational (to ensure that existing flood risk management benefits are sustained) and the Letter of Map Revisions (LOMR) floodplain mapping is complete. Other connectivity improvement projects would consider methods to modify or remove a low-head dam that exists adjacent to a railroad bridge just north of where Main Avenue West crosses the Sheyenne River in West Fargo.

The Sheyenne River Oxbow Restoration is the best candidate for aquatic mitigation in North Dakota. Restoration of the oxbow is in-kind with impacts from the Project, but restoration of the oxbow alone would not be enough to offset the aquatic impacts in North Dakota. Discussions with the State of North Dakota have indicated that there is strong interest in also pursuing connectivity improvement projects to offset aquatic footprint impacts. Use of connectivity for mitigation of lost habitat is challenging in that it is difficult to quantify exactly "how much" connectivity must be restored to offset a certain loss of habitat. Improving connectivity in the Sheyenne River channel would have clear ecological benefits. A whitepaper on the Sheyenne River restoration measures listed above has been prepared by the Corps and describes the projects in further detail (Attachment A).

The North Dakota resource agencies and the local governments protected by the existing diversion channels have expressed their support of the Sheyenne River channel improvements, with the understanding that implementation would not occur until after the Project is operational and the LOMR process is complete. The State of North Dakota strongly supports these two projects to fulfill the mitigation needs for lost aquatic habitat in the State of North Dakota. The Corps and Non-Federal Sponsors will work with North Dakota agencies to continue Project coordination and document support.

3.2 Forests

Forest impacts and mitigation needs are outlined above in Table 4. The Project results in a need for approximately 70.9 habitat units of mitigation, which equates to 283 acres of newly created floodplain forest.

Work and collaboration to date has resulted in 13 acres (3.3 HUs) of forest mitigation already implemented (Table 8). Construction is currently underway on an additional 72.34 acres (18.1 HUs) of forest mitigation at the former site of the Oxbow Country Club. It is estimated an additional 198 acres (49.5 HUs) will be needed for mitigation. There are many other opportunities for implementing floodplain forest mitigation. The Non-Federal Sponsors have acquired several properties along the Red River and other tributaries that would be suitable for the establishment of floodplain forest. Additional coordination with the resource agencies and Non-Federal Sponsors will occur to prioritize, select, and design specific sites. These sites will be added to Table 8 as the designs become more defined.

In addition to the activities outlined above, forestry mitigation will include, based on agency input, the following actions:

- As outlined in the paragraph above, mitigation will be implemented based on the habitat analysis performed in the original FEIS. Based on this habitat analysis, a 2.1:1 mitigation ratio would be applied for floodplain forest impacts.

- Floodplain lands that are currently in agricultural production or were previously the site of building sites acquired along the rivers will be planted with native tree species. This would include restoring native floodplain forest and herbaceous vegetation. These areas would also provide wildlife habitat. Monitoring will be performed, as outlined in the next section, to verify floodplain forest response is as needed.

- The Corps would develop site restoration plans, including tree planting areas, and clearing, treatment, and management schedules for forest mitigation sites. A combination of direct seeding and seedling trees would be used as needed. Sites would be managed for effective forest growth. Sites may be protected and managed into perpetuity by an agreement for management as a wildlife management area by the MnDNR or NDGF.

- A forest restoration plan will be prepared with input from the Forest Resource Group and will be included as an appendix in a later version of the AMMP.

3.3 Wetlands

Wetland impacts are addressed through US Army Corps of Engineers Permit No. NWO-2013-1723-BIS for the diversion channel and OHB ring levee. Wetland impacts for the Southern Embankment were addressed through the environmental impact analysis in the FEIS and subsequent SEAs and in more detail in this AMMP.

3.3.1 Wetland Impacts Addressed in the US Army Corps of Engineers Permit No. NWO-2013-1723-BIS

Wetland impacts are outlined above in Table 4. Wetland losses due to the diversion channel will be mitigated via wetland replacement that will occur within the constructed diversion channel. These mitigation requirements have been outlined in US Army Corps of Engineers Permit No. NWO-2013-1723-BIS issued to the Non-Federal Sponsors on December 14, 2016, and modified on September 29, 2020. Wetland mitigation for the diversion channel will be addressed through this permit and therefore limited description will be provided in this AMMP.

3.3.2 Wetland Impacts Addressed in the US Army Corps of Engineers Permit No. NWO-2014-0236-BIS

Wetland impacts due to the construction of the OHB ring levee are being mitigated via wetland restoration at the Forest River and Oxbow Country Club sites, as well as the purchase of wetland credits through the Ducks Unlimited In-Lieu Fee Program. Wetland mitigation for the OHB ring levee is addressed in Army Permit No. NWO-2014-0236-BIS and therefore limited description has been provided in this AMMP.

3.3.3 Wetland Impacts from the Southern Embankment and Associated Infrastructure

Wetlands impacted through the construction of the Southern Embankment, which total approximately 261.7 acres, will be mitigated separately from those identified above. Ditched wetland losses will be mitigated with the creation of similar wetlands through the construction of the Project. The remaining wetland mitigation in North Dakota and Minnesota will be accounted for in each of the states separately. Mitigation for the 19.2 acres of non-ditched wetland impacts in Minnesota will be purchased as wetland credits. The remaining non-ditched wetlands in North Dakota that require mitigation total 142 acres. For a summary of all wetland impacts associated with the Project, see Table 4.

There is a clear difference between the functions provided by the impacted wetlands. Early in Project planning, it was decided amongst the agencies that a function-based approach was appropriate for determining compensatory mitigation requirements. MnRAM was used for determining compensatory mitigation requirements for impacts. The results of the MnRAM analysis suggested that farmed seasonally flooded areas be mitigated at a 0.88 acres of wetland credits for every 1 acre of impact, while all other wetland types be mitigated at a 1:1 ratio. However, Minnesota WCA rules set minimum replacement ratios that cannot be reduced based on a functional assessment. In addition, there are no state-adopted procedures or policies for using a functional assessment method to determine wetland replacement ratios.

Mitigation for the Southern Embankment wetland impacts in North Dakota would occur in the "Camel Hump" area where the Southern Embankment extends northward between the Diversion Inlet and the Wild Rice River Structure. Hydraulic modeling has indicated that this area will be prone to flooding more frequently after the Project is constructed. This will make the area less desirable for farming and presents an opportunity for wetland restoration along Drain 27. It is anticipated that the Drain 27 Wetland Restoration Project will provide enough wetland credits for the remaining mitigation needs in North Dakota. A contract for the Project is anticipated to be awarded in late 2021 or early 2022 with construction occurring in 2022.

For the nearly 19.2 acres of non-ditched wetland impacts estimated to occur in Minnesota, wetland mitigation credits will be purchased to offset the impacts. The Project proponents intend to collaborate with BWSR, and the purchase of wetland credits will use the ratios consistent with the Minnesota WCA (1:1 for ag land impacts, 2:1 for non-ag land impacts).

Agency representatives have noted that wetland replacement would incidentally result in wildlife habitat replacement when discussing the potential mitigation needs for wildlife habitat losses.

3.4 Aquatic Connectivity

Previous Project plans and resulting analyses identified potential impacts to biological connectivity and proposed mitigation actions to offset these impacts (2011 FEIS; 2013 SEA). With Plan B the adverse impacts to connectivity have been reduced even further. As stated in the 2019 SEA, "While disruptions to connectivity would still occur with Plan B modifications, it is most likely that these disruptions would be infrequent enough, short enough in duration, and early enough in the season that broad, measurable, long-term impacts to Red River fish communities would not be expected." No mitigation for aquatic connectivity impacts is required by the Corps.

The MnDNR permit for the Project requires their concerns for biological connectivity be addressed. Per condition 27 of MnDNR permit 2018-0819, "Within five (5) years of permit issuance and no later than the start of construction of the Red River Structure, the Permittee shall have a legally binding commitment to fund the Drayton Dam Project, and construction shall have commenced within this same time period. The Drayton Dam Project, which includes the removal of the existing dam and construction of a rock arch rapids, shall serve as partial mitigation for impacts of the Project on the ecology of the Red River, including impacts to connectivity, fish passage, and aquatic resources. The Permittee shall work with DNR on the design of the Drayton Dam Project to ensure that it satisfies the mitigation requirements of this permit."

Drayton Dam is a low-head dam on the lower Red River at Drayton, North Dakota. It is the last fish barrier on the mainstem Red River within the United States. Several other low-head dams on the Red River have been retrofitted with rock rapids fishways to facilitate fish movement. Drayton is the last location without fish passage. It is also the most downstream dam within the United States that operates as a barrier to the watershed.

Plans and specifications have been prepared for fish passage at Drayton Dam with input from the AMT. Fish passage experts, including the MnDNR, were directly involved in developing the design of this Project.

3.5 Additional Considerations to Minimize Impacts and Mitigation Needs

Coordination with agency members during preparation of the 2019 SEA identified additional considerations to minimize impacts of the Project. The following recommendations will be performed to minimize adverse effects related to the Project:

- To the extent practicable, vegetation clearing activities would be done so as to avoid affecting nesting individuals.

- To the extent practicable, tree clearing on forested land would occur during the winter months in order to avoid impacts to listed bird species during their nesting and rearing periods.

- Wetland mitigation sites constructed for the Project are only anticipated in North Dakota, as wetland credits will be purchased in Minnesota. Wetlands would be managed for invasive species. Invasive and/or non-native plant species would be controlled for three full growing seasons at floodplain forest mitigation sites. Control would consist of mowing, burning, disking, mulching, biocontrol and/or herbicide treatments, as needed. By the third growing season, any planted areas one-half acre in size or larger that have greater than 50 percent areal cover of invasive and/or non-native species would be treated (e.g., herbicide) and/or cleared (e.g., disked) and then replanted with appropriate non-invasive plants. The areal cover percentage was arrived at through discussions with the resource agencies, most recently revisited in March 2020.

- When construction activities are complete, disturbed areas would be seeded with native plant species or other plant species per Project plans and specifications. After native species have been planted, the areas would be monitored and managed to maintain the native vegetation.

- The Non-Federal Sponsors would be responsible for noxious weed control on the whole Project as part of the Operations, Maintenance, Repair, Rehabilitation, and Replacement (OMRR&R).

Impact Tables

Table 5. Aquatic habitat impacts and mitigation.

Aquatic Riverine Habitat Impact	Habitat Lost (HUs)	Mitigation
Red River Control Structure	6.7	Mitigation on the Lower Otter Tail River was directed by the MnDNR as a permit condition for impacts within MN.
Wild Rice River Control Structure	3.4	Mitigation for all aquatic impacts in ND, including shared impacts on the Red River, will be provided through the removal/modification of flood risk management features and restoration on the Sheyenne River. Restoration would not occur until after the Project is operational.
Sheyenne River Aqueduct	4.3	
Maple River Aqueduct	5.7	
Total Aquatic Mitigation Need:	20.1	

Table 6. Forest impacts and mitigation.

Impact	Footprint Area Lost (ac)		Existing Habitat Quality Score	Habitat Units Lost		Created Forest Habitat Quality Score	Mitigation Needs (ac)	
	ND	MN		ND	MN		ND	MN
Forest	124	15	0.51	63.2	7.65	0.25	252.8	30.6

Table 7. Non-ditch wetland impacts and mitigation

Wetland Type	Diversion Channel Wetland Impacts	Mitigation	Southern Embankment Wetland Impacts (acres)	Mitigation
Farmed Seasonally Flooded Basin	1034.39	All wetland impacts associated with the construction of the Diversion Channel will be mitigated by the creation of wetlands within the Diversion Channel itself.	180.64	Mitigation for impacts ND were accounted for via mitigation projects and wetland credit purchases described in Table 8. Wetland mitigation in MN will be met by the purchase of credits.
Shallow Marsh	49.62		5.32	
Shallow Open Water	-		4.97	
Wet Meadow	61.68		32.21	
Total Acres	**1,145.68**		**223.14**	

Mitigation Tracking

Table 8. Project Mitigation Tracker

Mitigation Type	Site/Project Name	Site Location	Construction	Acres	Habitat Units	Description
Aquatic Habitat	Lower Otter Tail River Restoration	Breckinridge, MN	TBD	*	*	The MnDNR has determined that $8.28M will be provided by the Non-Federal Sponsor to fulfil permit condition
	Sheyenne Oxbow Restoration	West Fargo, ND	TBD	2	**	Restoration of oxbow adjacent to Co Rd 17.
	Sheyenne Connectivity	West Fargo/Horace, ND	TBD	TBD	**	Improved connectivity associated with Sheyenne River Flood Control Project
Forest	Red River site	Oxbow, ND	2017	13	3.3	Restoration of ag row crop area with modifications to hydrology.
	Oxbow Country Club	Oxbow, ND	Construction: 2022	72.34	18.1	Restoring wetland of a historic Red River oxbow.
	TBD	TBD	Varies	198	49.5	Floodplain forest areas are being prioritized. Sites will be determined by AMT.
Wetland	Diversion Channel	Fargo, ND	Construction: 2022	TBD	TBD	Amount of mitigation dependent on impacts of final design.
	Oxbow Golf Course	Oxbow, ND	Construction: 2021 Establish veg: 2026	18.8	12.26	Restoring wetland features for an old Red River oxbow. Includes: 10.62 acres of wet meadow/ shallow marsh; 8.18 acres of upland buffer
	Forest River	Briarwood, ND	Complete	6	6	Restoration of wetlands near Briarwood, ND
	DU In-Lieu Fee Credits	NA	NA	NA	17.27	Purchased for work on OHB
	Drain 27 Wetland Restoration	Stanley Township, ND	Construction: 2022 Establish veg: 2027	320	169.8	Mitigation for wetland impacts for the Southern Embankment and Associated Infrastructure in ND
	MN Wetland Bank Credits	NA	NA	NA	23.03	The purchase of wetland credits may occur at several iterations. The first purchase of 0.5 credits is anticipated in August of 2021.
Connectivity	Drayton Dam Modification	Drayton, ND	Construction: 2022/2023	*	*	Mitigation to fulfil MnDNR permit condition

*The MnDNR prescribed this mitigation as a permit condition.

**Mitigation amount needed for impacts within North Dakota will be developed through the AMMP with North Dakota and the Corps/Sponsors. This agreement will be formalized with correspondence.

4 MONITORING, PERFORMANCE STANDARDS, AND TRIGGERS

Monitoring methodologies, performance standards, and adaptive management triggers will be used to better characterize pre-project conditions for key resources, identify changes following Project implementation, verify resulting Project impacts, and verify whether mitigation is offsetting these Project impacts.

Monitoring and adaptive management of resources impacted by the Project and mitigation projects is the responsibility of the Non-Federal Sponsors.

Monitoring

Monitoring helps capture the state of a resource at a particular point in time and can help to track changes that a resource experiences. Monitoring methodology and frequency have been collaboratively established with input from natural resource agencies.

Monitoring activities will be focused on key resources of concern. These include:

- Connectivity Mitigation for Aquatic Habitat (mitigation)
- Floodplain Forest (mitigation)
- Wetlands (mitigation)
- Aqueduct Connectivity (resource of concern)
- Geomorphic (resource of concern)
- Water Quality (resource of concern)
- Fish Stranding (resource of concern)

Monitoring for aquatic habitat, floodplain forest, and wetlands is associated with impacts warranting mitigation. Geomorphic and water quality impacts were not deemed to be significant and therefore no mitigation was required. Geomorphology and water quality will be further monitored prior to and after Project construction to verify these assumptions. Similarly, fish stranding following Project operations was not considered as a significant impact but will be monitored, with potential mitigation needs pending results.

Monitoring plans were developed for each resource based on the information available at the time this AMMP was written. The monitoring approaches outlined below will need to remain flexible to adapt to changing conditions (either pre- or post-project); alternative technologies or techniques that become available for monitoring; and refinement of specific Project features or mitigation actions. Revisions to monitoring plans would require AMT approval. In addition, many of the monitoring schedules may overlap with each other. Where this occurs, it is highly recommended that the resource agencies attempt to coordinate field surveys concurrently so that data can be compared and utilized efficiently.

Pre-construction monitoring efforts are led by the Corps and the Non-Federal Sponsors. Following construction, monitoring and adaptive management would be the responsibility of the Non-Federal Sponsors as a requirement of Project operation and maintenance. Monitoring results will be shared with the AMT when the data is processed and ready for distribution.

Performance Standards

Performance standards are measurable criteria set to help determine the success of mitigation efforts. Where specified, monitoring can be concluded once performance standards are met. If performance standards are not met within a defined amount of time, adaptive management of that resource or alternative mitigation options may be necessary.

Corps regulations require that projects develop and use criteria for determining ecological success of mitigation and to ensure Project impacts are offset. The metrics used to measure impacts and mitigation effectiveness are described below. Even with the use of metrics, it is recognized that conclusions on Project impacts and mitigation success will need to include detailed review of data and collaboration amongst the AMT. Even then, opinions may differ on the questions at hand. However, the discussion below provides guidance on the metrics that will be used to verify Project impacts and mitigation effectiveness. These metrics will provide the primary measure of whether or not mitigation has proven effective.

Triggers

Triggers are predetermined values that serve as thresholds for specific actions or further evaluation of a resource. Triggers fall into one of two categories: 1) monitoring triggers or 2) adaptive management triggers.

Monitoring triggers are events that cause additional monitoring to occur. For this Project, several monitoring triggers have been identified in particular resource areas for significant flood events. Pre-project monitoring triggers will help to expand the baseline data so there is a better understanding of existing flood impacts which are more suitable for comparison after Project operation. After Project construction, monitoring triggers will provide data that can help to assess the actual impacts of the Project. Resource areas with monitoring triggers are identified in the text below.

Adaptive management triggers are measurable changes to a resource that leads to a defined response or further evaluation. Evaluation will consider monitoring data and any additional underlying circumstances that could have influenced the triggers to be met. The result of evaluation may lead to modification of a particular feature, changes in the management of a resource, or even no action if it is determined that changes were the result of something other than the Project. Adaptive management triggers for the Project can be found in the resource area descriptions in the text below.

4.1 Aquatic Habitat and Connectivity

Mitigation needs for lost aquatic habitat in waters of Minnesota have been directed by MnDNR via their permit. In a letter dated May 19, 2021, the MnDNR indicated that funding of $8.28M toward restoration of the Lower Otter Tail River was the appropriate amount of mitigation necessary to offset aquatic impacts in Minnesota. In the same letter, the MnDNR also determined that monitoring will not be required on the Lower Otter Tail River.

Mitigation needs for lost aquatic habitat in waters of North Dakota will be accomplished via a set of projects on the Sheyenne River. This includes restoration of a Sheyenne oxbow and improvements in biotic connectivity via modification to the Sheyenne River Flood Control Project, as well as a small dam in West Fargo. As outlined above, the State of North Dakota has agreed that this is adequate mitigation for aquatic habitat losses in their state. However, to confirm these projects are effectively working, monitoring activities will be performed. These monitoring activities will be done in concert with evaluation of whether fish are able to effectively move across the Sheyenne aqueduct which is immediately upstream of the Sheyenne connectivity mitigation project. The exact monitoring activities are still under discussion, and may include a combination of netting, hydroacoustic observations, radio telemetry, and other techniques. The specifics will be added to this subsection once identified and approved by the AMT.

The following discussion on the Sheyenne River mitigation project will include an overview for evaluation of connectivity through the Sheyenne River and Maple River aqueducts. These are similar discussions, with Sheyenne aqueduct performance critical to the effectiveness of the Sheyenne River mitigation project.

PERFORMANCE STANDARDS AND METRICS

Red River Structure Monitoring Activities

The Non-Federal Sponsors will observe average cross section velocities through the Red River Structure at discharges close to 2,900 cfs, 8,100 cfs, and 10,700 cfs, which are equal to the 50%, 10%, and 5% annual exceedance probability flows, respectively, through the Red River Structure, as reported in the 2019 SEA. A reasonable surrogate for determining Red River Structure discharges prior to operations is the USGS gage on the Red River at Hickson, ND. This is to verify velocities that generally align with those identified in the 2019 SEA (approximately 2 fps at a discharge of 10,700 cfs). These results will be coordinated and discussed with the Biotic Resource Management Team and the AMT to determine if any additional actions are warranted. Given the general consistency of results from both computer modeling and physical modeling for the Red River Structure, it is unlikely that actual velocities will differ substantially from those predicted.

Minnesota Mitigation

Standards and metrics associated with aquatic habitat for impacts and mitigation in Minnesota will be done in accordance with the MnDNR and associated Project permit. This includes restoration on the Lower Otter Tail River and will include direct collaboration on design with the MnDNR. Because these actions will ensure that impacts are offset, no monitoring is proposed at this time for this aquatic habitat mitigation.

North Dakota Mitigation

Sheyenne Mitigation and Aqueduct Connectivity Evaluation Methodology

Habitat benefits of the Sheyenne Mitigation Project will be evaluated to confirm an acceptable level of improvement for offsetting lost aquatic habitat in North Dakota due to the Project. This will be done in concert with an evaluation of connectivity through the Maple River and Sheyenne River aqueducts also to be constructed as a part of the Project.

Participation and Timing

The evaluation will be performed by the Project Non-Federal Sponsors as a part of the AMMP and the Project's O&M requirement. Resource agencies (i.e., NDGF, MnDNR, and USFWS) will be invited and involved with this process to the full extent they are willing/able to do so. Note that the precise timing of an evaluation will be dependent on completion of construction. At this time, the aqueducts would not be completed and functioning until 2025. Sheyenne River Mitigation will not be constructed until the entire Project is operational and the LOMR process is complete. Given this timing, and the fact that an evaluation of both the mitigation and aqueduct will likely be strongly related, full evaluation may not occur for seven to eight years, or more. With likely improvements in science and technology to track and observe fish in turbid environments, the proposed methodology here can and should be revisited as the timing for evaluation draws closer. The following is intended to provide an overview of an evaluation process and a commitment by Non-Federal Sponsors to evaluate the effectiveness of the mitigation project and confirm whether or not the aqueducts are effectively passing fish. Note that designs are not currently available for any of these features, which is part of the reason why the following methods are proposed and not finalized.

Goals and Objectives of Mitigation

Goal 1: Improve connectivity on the lower Sheyenne River

Objective 1.1: Remove instream structural features to restore in-channel connectivity

Objective 1.2: Improve connectivity through diversion channels through installation of nature-like fishways across upstream control weirs

Key Questions to Answer:

- Are resulting hydraulics at rock rapids similar to what was designed?
- Do fish enter the Sheyenne aqueduct bypass channels, especially with the rest of the channel open?
- Do fish reach the rock rapids?
- Do fish successfully pass the rock rapids?

- Do fish pass the concrete weir adjacent to the railroad bridge north of Main Avenue West in West Fargo?
- Do IBI metrics in project area improve with improved connectivity?

<u>Performance Standards to Measure Success</u>

- Where instream structures are removed, return the channel to the same dimensions and channel substrates as adjacent areas upstream and downstream.
- Rock rapids fishways in bypass channels that would be implemented for the Sheyenne River Mitigation Project will employ the latest design standards for rock ramp fishways. Successfully meeting this standard means maintaining the following design criteria. This will be done to the fullest extent allowed by site hydraulics. This includes:
    - <3% slope down centerline of fishway
    - <0.7ft drop between individual rock boulder weirs
    - Use of alternating sine wave weirs
    - Boulder pools between weirs of at least 3ft of depth
    - Pool widths should be at least 30ft between the widest points of alternating sine waves
    - No smooth sills should extend above adjacent rock at the crest maintain upstream water elevations
- If a rock rapids fishway is used at the weir near the Main Avenue West railroad bridge, achieve and maintain the exact same design criteria as those outlined above for rock ramp fishways in the bypass channels.

<u>Monitoring Activities</u>

Methods discussed here are preliminary and need to be developed further based on what the final design of the mitigation project will be. Effort also will be made to incorporate evaluation of connectivity across the Sheyenne River aqueduct with evaluation of Sheyenne River mitigation effectiveness. Potential integration of those two efforts is discussed later.

Pre-Project

Fish Collection. Anecdotal observations have noted fish presence in the Sheyenne River Flood Control Project diversion channels. If practicable, perform cursory monitoring to confirm fish use of the diversion channels and presence below existing weirs on the West Fargo Diversion, and Horace to West Fargo Diversion. This will include notes for species diversity and size. Sampling should occur in or near the weir tailrace during springs when the diversion channels have been conveying water. Sampling could include seining or electroshocking. Sampling should occur bi-weekly during the period April through June during at least one event prior to Project construction.

IBI Methodology. An evaluation of river health via IBI methodology has already been performed pre-project with observations from 2012 to 2017. This included measurements of both fish and macroinvertebrate IBI. Observations were made at several points on the lower Sheyenne River, including areas relatively close to the proposed oxbow restoration. At this time, no further pre-project data is recommended.

Post Project

These future studies are described generally; detailed experimental designs will be developed in consultation with agency partners during preparation of plans and specifications for project implementation. The monitoring noted would most likely be a part of a broader evaluation of connectivity across the Sheyenne River aqueduct. As these designs are not yet available, and construction is several years away for Sheyenne River fish passage mitigation, a revised study plan will be developed. It is likely that technology improvements in the technique outlined would want to be captured with the final study design.

Field Survey of Fish Passage Structures. For any rock ramp fishway, perform surveys every five years post-construction to ensure the above design criteria performance standards are maintained. These structures are within the area of protection and should not experience flows above a 2-year flood event. As such, post flood surveys should not be needed.

Passive Adaptive Management Monitoring: IBI Methodology. Utilize the Index of Biotic Integrity protocol (fish and macroinvertebrate) to survey locations on the Sheyenne River. Protocol for use will be that used previously in 2012 and 2017 with the IBI assessment for the Sheyenne and other rivers of concern in the Project area. Locations will be the same as those surveyed in 2012 and 2017. This should include a minimum of two sampling events after the Sheyenne River fish passage mitigation project has been completed. This should likely happen at least two years following completion of the Sheyenne River mitigation project. Results will help reflect on the effectiveness of fish passage of both the mitigation project, as well as the aqueducts, on improving river health in the area.

Passive Adaptive Management Monitoring: Fish Capture. Fish capture sampling in the tailwater of at least one of the bypass channel rock rapids fishways will provide information on the species composition and size structure of fish below the fishway. Fish passing through the fishway will also be monitored with capture nets placed at the upstream exit of the rock rapids fishway. Results will not be compared to any specific performance targets and will be made as a cursory evaluation of fish occurrence and use around the structure. Sampling should occur bi-weekly during the period of April through June during at least one seasonal period post-project construction. Final methods will be developed closer to Project implementation.

Goal 2: Restore Sheyenne River aquatic habitat via oxbow restoration
Objective 2.1: Return flow through identified historic oxbow and return the channel to likely dimensions pre-disturbance, maintaining long-term stability

Key Questions to Answer:

- Is oxbow functioning as natural channel?

Performance Standards to Measure Success

- Return flow to the historic channel and maintain channel stability.

Monitoring Activities

Post Project

Geomorphology. Utilize geomorphic assessments, using the protocol outlined in the Geomorphic Monitoring Plan (Attachment B), to confirm that the channel is stable and functioning as a natural channel. This should include a minimum of two sampling events after the oxbow restoration project has been completed. This methodology can be revised in the future if simpler methods would be adequate to confirm channel stability.

AQUEDUCT EVALUATION AND ASSOCIATED TRIGGERS

Biological connectivity through the Project aqueducts is important for river health and function. Connectivity through the Sheyenne River aqueduct is especially critical to work in concert with the Sheyenne River connectivity mitigation project. Following is the evaluation approach for aqueduct connectivity.

Goals and Objectives of Aqueduct Design

Goal: Maintain connectivity on the lower Sheyenne and Maple Rivers through the planned Project features

Objective: Maintain the ability for the full range of species and size diversity to move through the aqueducts at a level similar to existing conditions

Key Questions to Answer:

- Are resulting hydraulics in the aqueducts adequate to allow fish passage?
  - Are velocities generally adequate to allow fish passage across the majority of flow conditions?
  - Are roughness elements incorporated adequate to promote velocities pattern that promote effective fish movement?
- Do fish of all species and sizes enter the aqueduct?
- Do most fish that enter the aqueduct exit the upper end of the aqueduct?

Triggers to Measure Impact Levels

The following criteria are in draft and will need refinement. Criteria need to be appropriately developed in-line with the capabilities of available methods and technologies. In particular, the ability to make biological measurements makes similar criteria difficult to employ.

The Corps and the Non-Federal Sponsors will coordinate during the development of the design concept for the aqueducts to maintain connectivity. This will likely include some form of the following:

- Fish that arrive at the downstream end of the aqueduct are able to successfully pass for flows up to the 50 percent annual flow event.
- Maintain water velocities conducive to biological connectivity up to project operation.
- Incorporate roughness elements in the aqueduct of similar design/pattern as that outlined in the Corps/Non-Federal Sponsors physical flume study of the Maple River aqueduct.

Monitoring Activities

At this time, the aqueduct design concepts have not been fully developed. The Sheyenne River and Maple River aqueducts across the diversion channel will be designed to convey winter flows through the aqueducts and control ice formation to prevent ice from impeding the hydraulic capacity or performance of the system and to resist ice and debris without damaging, reducing capacity, or reducing function of the aqueducts (October through April). At each aqueduct, flows will be measured to determine the flows upstream of the spillway into the diversion channel, flows entering the aqueduct, and flows exiting the aqueduct.

The most specific methods for monitoring fisheries conditions in the aqueduct will be developed with agency input as aqueduct designs progress. Some methods that are being considered include the use of an acoustic doppler current profiler (ADCP), fish collection, hydroacoustic monitoring systems (e.g., DIDSON or ARIS camera), Passive Integrated Transponder (PIT) tagging, and acoustic tagging.

Mitigation Contingency

Should monitoring suggest that Sheyenne River mitigation or either aqueduct performance is not meeting the mitigation Performance Standards, or triggers are met, the Non-Federal Sponsors will meet with natural resource agencies to discuss whether modifications to Project features are possible, or if additional mitigation is needed to further offset Project impacts.

- Features such as rock rapids at the existing Sheyenne River diversions channels could be relatively easy to modify. If field surveys reveal fish passage features fall out of the design criteria, the Non-Federal Sponsors will modify Sheyenne fish passage structures to meet design criteria.

- If the Sheyenne oxbow channel restoration is no longer stable, the Non-Federal Sponsors will meet with the resource agencies to consider on-site modifications to improve channel stability and on-site habitat conditions.

- Final determinations on acceptability of the effectiveness of the Sheyenne River mitigation project, and whether any there are any additional mitigation needs, would ultimately fall to agreement between NDGF and the Non-Federal Sponsors. All resource agencies would be able to provide input on that decision.

- Modifications to the aqueducts could be much more difficult if performance triggers are not met. If this occurs, the Non-Federal Sponsors will meet with the natural resource agencies to discuss potential options to address the issue. This could include modifications such as addition or alteration of the roughness elements. It could also include additional mitigation actions to improve fish passage elsewhere on the Sheyenne River. The scope and scale of potential actions due to aqueduct triggers is much more difficult to project and will have to be dealt with as it arises.

4.2 Floodplain Forest Habitat

The majority of baseline data needed to quantify existing habitat value of floodplain forest impact areas has been collected (please see Appendix F of 2011 FEIS). No additional floodplain forest surveys are planned prior to construction. Following construction, monitoring will be performed to determine the condition of these habitat types and the overall effectiveness of their mitigation.

Vegetation will be monitored annually for the first five years following planting using stratified random sampling. At each randomly generated point within the areas planted, plots of 0.01 acre will be surveyed according to Corps standard forest inventory procedures. An average of at least one plot per acre will be surveyed. Tree survival and composition will be monitored every ten years.

The goal of the floodplain forest habitat is to provide the area and quantity needed to offset the loss of forest habitat through footprint impacts. The following performance standards will be used to measure when forest mitigation has reached full effectiveness. The metric will be the habitat unit adjusted for quality over time against when the standards below are met.

Forest Performance Standards:

1 Restore native floodplain forest and herbaceous vegetation. The floodplain forest should include green ash, cottonwood, black willow, hackberry, quaking aspen, American elm, American basswood, and bur oak.

2. Restore stand density with an average of 300 trees per acre over 80 percent of the mitigation site(s) with diameter at breast height (DBH) of 2 inches within 10 years if using

seedling plantings, direct seeding, or natural seeding. This tree density is typical for the Red River Basin floodplain forest in the Project vicinity. If using container trees, an average of 90 trees per acre over 80 percent of the mitigation site(s) with diameter at breast height (DBH) of 4 inches within 10 years.
3. Restore floodplain forest community with a target species composition of at least 10 percent by number of individual trees to be bur oak and hackberry, with the rest a mix of green ash, cottonwood, black willow, boxelder, American elm, and American basswood.
4. Allow some regeneration of native herbaceous plants, shrubs, and trees from locally produced propagules on 20 percent of the mitigation land area, to create diversity in forest and herbaceous vegetation in the mitigation area.
5. Protect and manage the site(s) in perpetuity.

Trees will be replanted as needed to meet the target vegetation cover. Invasive, noxious and/or non-native species will be controlled for three full growing seasons. Control will consist of mowing, burning, disking, mulching, biocontrol and/or herbicide treatments, as needed. By the third growing season, any planted areas one-quarter acre in size or larger that have greater than 50 percent areal cover of invasive and/or non-native species will be treated (e.g., herbicide) and/or cleared (e.g., disked) and then replanted with trees.

The monitoring results will be compiled, interpreted, and described in letter reports. The monitoring reports will be provided to the AMT. The AMT will decide if additional forest monitoring is needed at the conclusion of the five-year monitoring period for floodplain forest.

The monitoring approach identified above is targeted for establishing new forests. As the forest sites age, monitoring beyond the first five years, if recommended by the AMT, may be adjusted to evaluate mature forests. At that point, forestry monitoring may be performed using St. Paul District's Forest Inventory Phase II Protocol (available upon request), adapted as needed for monitoring in the Project area.

In addition to the monitoring activities outlined above, forest monitoring will include, based on agency input, the following actions:

- Monitoring Plan: Sites would be monitored for tree survival annually for five years, then tree survival and composition at ten years. Tree survival and composition would be monitored every five years thereafter until it can be demonstrated that value of the forest habitat lost has been replaced through mitigation. The Non-Federal Sponsors would be responsible for providing this justification and receiving approval from the AMT.

- Adaptive management would be used to manage the mitigation sites. Monitoring would include measurement of the performance standards and the implementation of corrective actions would be carried out if the standards were not being met.

4.3 Wetland Habitats

A wetland delineation has been conducted along the alignments for the diversion channel and Plan B Southern Embankment. A MnRAM functionality assessment had been performed to determine mitigation needs in North Dakota. This information was used to verify the mitigation approach for these wetlands. Surveys of the diversion channel will be performed after construction to verify that the wetland type and function present are offsetting wetland areas lost through construction.

Post-construction monitoring shall be conducted annually to determine the type, quality, and amount of wetlands created as compensatory mitigation for the unavoidable impacts. The purpose of the monitoring is to provide information to determine if the site is successful in meeting its performance standards. The monitoring period for wetlands shall be five years. This period may be shortened if the monitoring reports demonstrate that the mitigation site(s) has met vegetation and hydrology performance standard(s) in two consecutive reports and the AMT concurs that additional monitoring is not required.

Monitoring reports shall be concise and effectively provide the information necessary to assess the status of the compensatory mitigation project. Monitoring shall commence the first full growing season after completion of construction (construction includes earth moving, excavation, and other physical work as well as planting and seeding), approximately May 1. Best Management Practices will be employed between planting and the start of monitoring. Annual monitoring reports shall be submitted on or before December 31 for each of the required monitoring years and will be provided to the AMT.

Monitoring reports shall contain the following information and any additional information necessary to evaluate the performance of the mitigation site:

1. Name of party responsible for conducting the monitoring and the date(s) the inspection was conducted;
2. A brief paragraph describing the mitigation acreage and type of aquatic resources authorized to compensate for the aquatic impacts;
3. Written description of the location of the compensatory mitigation project including information to locate the site perimeter(s) and coordinates of the mitigation site (expressed as latitude, longitudes, UTMs, state plane coordinate system, etc.);
4. Dates the compensatory mitigation project commenced and/or was completed;
5. Short statement on whether the performance standards are being met;
6. Summary data, including photo documentation, to substantiate the success and/or potential challenges associated with the compensatory mitigation project;
    a. All plant species along with their percent cover, identified by meandering through each vegetative community, including upland buffers, and list commonly encountered, or dominant and co-dominant, species observed. In addition, the

presence, location, and percent areal cover of invasive, noxious and/or non-native species in any of plant communities will be noted

   b. Vegetation cover maps at an appropriate scale will be submitted for each reported growing season
   c. Photographs showing all representative areas of the mitigation site taken at least once each reported growing season during the period of July 1 to September 30. Photographs will be taken from a height of approximately five to six feet from at least one location per acre. Photos will be taken from the same reference point and direction of view each reporting year. Location of the photographs should be mapped on a GPS unit
   d. Surface water and groundwater elevations in representative areas. The location of each monitoring site will be shown on a plan view of the site
   e. Precipitation data to address the 50 percent chance or "normal growing season." Can use the following website: http://agacis.rcc-acis.org/

7. Maps showing the location of the compensatory mitigation site relative to other landscape features, habitat types, locations of photographic reference points, transects, sampling data points, monitoring well locations, and/or other features pertinent to the mitigation plan;
8. A summary of the amounts and type of wetlands restored, enhanced, and created at the mitigation site identified by wetland plant community types based on Wetland Plants and Plant Communities of Minnesota and Wisconsin (Eggers and Reed);
9. Dates of any recent corrective or maintenance activities conducted since the previous report submission;
10. Specific recommendations for any additional corrective or remedial actions; and
11. If non-compliance activities are occurring on the site, the activity will be noted, photographed, and mapped on a GPS unit. Best professional judgment would be used to determine if the activity is not compliance with easement or mitigation site plan.

The final monitoring report shall also include a wetland delineation completed in accordance with the *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Great Plains Region*.

Over two-thirds of the wetlands that are impacted are seasonally flooded wetlands or farmed wetlands; these wetlands have very poor function. It is not environmentally preferable to compensate for impacts to degraded wetlands by deliberately providing degraded compensatory mitigation projects. A compensation project should result in high quality wetlands that provide optimum functions within its landscape context, taking into account unavoidable constraints. Even though the wetlands impacted by the Project are generally highly degraded, they should be mitigated for by restoring equal acres of wetland or by restoring functions that are lacking in the Red River Basin watershed. Wetland mitigation in North Dakota will be evaluated with a functional assessment tool (MnRAM) to factor in wetland quality and functional value and ensure that mitigation is adequate.

In addition to the monitoring activities outlined above, wetland monitoring will include, based on agency input, the following actions:

- Adaptive management would be used to monitor any project-specific mitigation sites. Monitoring would include measurement of performance standards and the implementation of corrective action measures if the standards were not being met.

- The MnRAM wetland assessment method or other agreed upon methods would be used to assess the adequacy with which the mitigations replaced lost wetland function.

The goal of the wetland mitigation is to the area and functional value to offset the loss of such habitat through footprint impacts. It is anticipated that all wetland impacts in Minnesota will be mitigated through the purchase of wetland banking credits and therefore performance standards for those banks have already met those established by BWSR and the Minnesota WCA. The following performance standards were developed in coordination with North Dakota natural resource agencies and will be used to measure when wetland mitigation has reached the appropriate functional value. The metric will be the acre meeting functional value as measured by MnRAM.

Wetland Performance Standards:

Definitions:

InNN**:** invasive and/or non-native plant species

NNI**:** native, non-invasive plant species

Relative areal cover**:** the proportion (percentage) of the total absolute areal cover by an individual plant species, or group of plant species (e.g., hydrophytes), within a reference area or plot; sum of all proportions equals 100 percent

Wet Meadow/Wet Prairie

Fresh (wet) meadows, sedge meadows, wet prairies, and seasonally flooded plant communities (Type 1 and Type 2 wetlands) will be monitored separately and shall each achieve a species composition that includes 10 or more species of native/non-invasive grasses, sedges, ferns, rushes and/or forbs by the end of year 5. Relative areal cover of native, non-invasive species (NNI) versus invasive, non-native species (InNN) of ≥60% NNI and relative areal cover by hydrophytes of ≥70%. Alternatively, a MnRAM vegetative diversity and integrity score of “high quality” by the end of year 5 would also satisfy this performance standard.

Marsh

Shallow and deep marsh plant community types shall be combined. Marsh plant community types with a species composition that includes 6 or more native OBL hydrophytes and any floating or submergent species by the end of the 5th full growing season. The threshold for relative areal cover NNI versus InNN should be 50 percent. A MnRAM vegetative diversity and integrity score of “high quality” for each these plant communities will also satisfy this performance standard.

Upland Buffer

Restored tallgrass prairie in the upland buffer with a species composition that includes 15 or more species of native non-invasive grasses, sedges, rushes, forbs and/or ferns, with approximately 80 percent or greater areal coverage of the total buffer area having NNI species by the end of year 5.

Hydrophytes

Relative areal cover by hydrophytes shall be more than 50 percent within the wetland communities of the mitigation site.

Invasive Species

Invasive and/or non-native plant species will be controlled within each wetland mitigation site. Control could include mowing, burning, disking, mulching, biocontrol and/or herbicide treatments. By the third growing season, any areas one-quarter acre in size or larger that have greater than 50 percent areal cover of invasive and/or non-native species would be treated (e.g., herbicide) and/or cleared (e.g., disked) and then reseeded. Follow-up control of invasive and/or non-native species shall be implemented as stated above.

Hydrology Performance Standards:

The minimum wetland hydrologic criteria for wetland hydrology are 14 or more consecutive days of inundation or saturation during the growing season with a 50 percent chance (or more) annual probability of occurrence.

- Hydrology will be measured within each wetland type.
- The number of monitoring wells and/or staff gauges necessary for monitoring the hydrology of a compensation site varies with size and complexity of the site. For the Drain 27 mitigation site, staff gauges will be installed between elevations 899 – 901 at four different locations. Shallow groundwater monitoring wells will be installed at elevations 906.5 and 908 at three separate transect locations.
- The frequency of water level readings must be sufficient to determine whether performance standards are met.

- Duration of monitoring hydrology at compensation sites is generally two growing seasons but can be increased or decreased due to site-specific conditions and goals/objectives.
- Monitoring wells should be installed and data collection begun as soon as frost is out of the ground. If this is not feasible, monitoring wells should be installed, and data collection begun as early in the growing season as possible. The "growing season" for a particular monitoring year is determined in accordance with the *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Great Plains Region.*
- Staff gauges with cameras can be used to record water level readings.

4.4 Geomorphic

The Red River and tributaries are dynamic river systems that naturally show movement of their mobile boundaries. The Geomorphic Monitoring Team (GMT) collaboratively developed comprehensive Geomorphic Monitoring Plan (GMP), which is included as Attachment B to this AMMP. The bullet points below present a brief summary of the GMP. Because this AMMP contains only a summary of the GMP, in the event the language in the GMP and this AMMP are in conflict, the GMP shall govern, unless otherwise agreed to by the AMT.

- Purpose: Ensure the Project does not result in detrimental geomorphic impacts relative to the pre-project dynamics of the system and the reference reaches and if such impacts occur to implement beneficial mitigation measures.

- Goal: Monitor streams in the Project area vicinity for geomorphic changes and, if geomorphic changes are deemed by the GMT to have been caused by the Project, to identify Project operation adjustments and/or mitigation measures to meet established GMT and Project goals.

- Geomorphic Assessment Locations and Methods (future efforts can be adjusted as appropriate by the GMT and AMT):
    - Monitor 39 Geomorphic Monitoring Stations (GMSs) pre-Project (with locations shown in Figure 2) and at least 42 GMSs post-Project.
    - Collect cross-sectional data at long-term monitoring cross sections.
    - Collect longitudinal profiles within the extents of each geomorphic monitoring station.
    - Leverage bathymetry with/from other sampling efforts in the Project vicinity when available to assess channel bed conditions especially outside the monitoring stations.
    - Collect both instream and bed and bank sediment samples in new GMS locations or where significant changes are apparent with respect to the historical data.
    - Complete Rosgen Level II assessments while also collecting data for select Rosgen Level III worksheets as the standard Level III assessment is not entirely applicable

to the Red River. Assessments should be completed by practitioners with at least ten years of experience in riverine geomorphic measurements and analysis.

- Conduct specific gage analysis for all USGS gages in the Project vicinity.
- Evaluate changes in surveyed cross section geometry.
- Evaluate changes in surveyed longitudinal profile.
- Evaluate bank movement, sinuosity, channel (meander) migration and erosion rates, and meander amplitude and frequency using aerial photography. Aerial imagery is currently collected every three years and can be used to capture trends in the land surface, including use and observations of impacts from the Project and other causes. The GMT will recommend appropriate intervals for post-Project aerial imagery collection.
- Evaluate trends in sedimentary features (in-stream sediment bars), changes in large woody debris (LWD), and changes in riparian vegetation type.
- Evaluate the degree of channel incision.

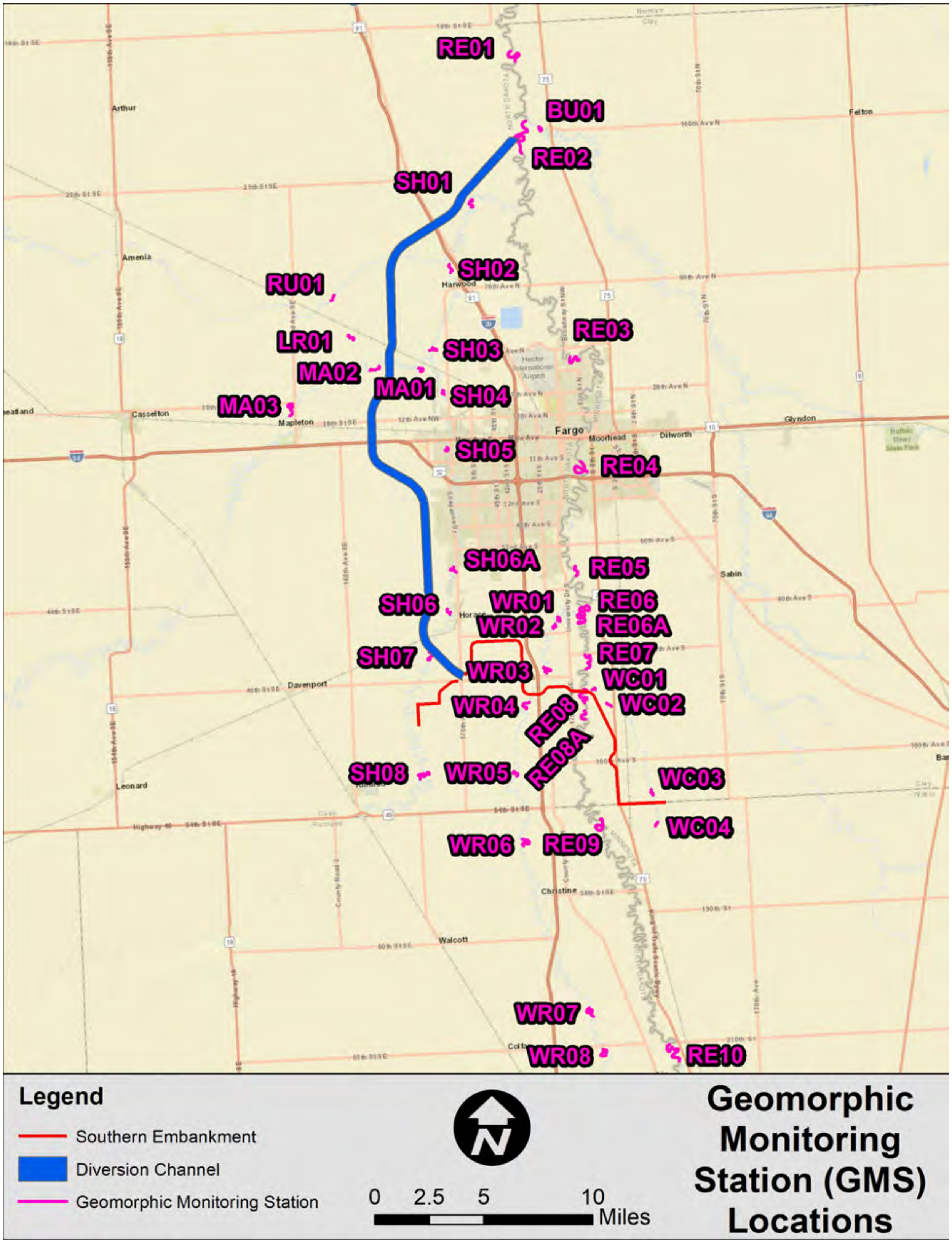

Figure 2. Geomorphic Monitoring Station Locations.

Geomorphic adaptive management triggers were discussed with the AMT and GMT during a series of meetings spanning April through June 2021. The selected adaptive management triggers are data-driven and technically justified and establish triggers that, if exceeded, require additional action to be taken by the GMT and AMT. These actions are detailed in the attached Geomorphic Monitoring Plan. An overview of the selected geomorphic adaptive management triggers is presented in the following paragraphs. It is noted that if it is the GMT's judgment that other significant change is occurring throughout the system and is not being captured by the currently established triggers, the GMT can recommend to the AMT that additional action is needed without exceedance of one of the pre-established geomorphic triggers.

Geomorphic Adaptive Management Trigger 1: Entrenchment Ratio

Table 9 displays the Entrenchment Ratio triggers for each stream in the Project vicinity. The methodology that will be used to calculate Entrenchment Ratios in post-Project geomorphic assessments for the purposes of comparing to these action triggers is outlined in the Geomorphic Monitoring Plan attachment.

Table 9: Entrenchment Ratio Action Triggers by Stream

Stream	Action Trigger
Buffalo River	<2.3
Lower Rush River	<2.3
Maple River	<2.3
Red River	<2.3
Rush River	<2.3
Sheyenne River	<2.3
Wolverton Creek	<1.8
Wild Rice River	<2.3

Geomorphic Adaptive Management Trigger 2: Bank Height Ratio

Table 10 displays the Bank Height Ratio triggers for each stream in the Project vicinity. The methodology that shall be used to calculate Bank Height Ratios in post-Project geomorphic assessments for the purposes of comparing to these action triggers is outlined in the Geomorphic Monitoring Plan attachment.

Table 10: Bank Height Ratio Action Triggers by Stream

Stream	Action Trigger
Buffalo River	>1.4
Lower Rush River	>1.5
Maple River	>1.3

Red River	>1.4
Rush River	>1.6
Sheyenne River	>1.5
Wolverton Creek	>2.2
Wild Rice River	>1.4

Geomorphic Adaptive Management Trigger 3: Bank Line Location

Triggers that would require the GMT and AMT to take further action regarding changes in bank line locations are outlined below:

- In the event any member of the GMT or AMT receives a complaint from the public stating that the Project is causing increased bank line movements in areas not within the immediate vicinity of a monitored cross section, the GMT member who is the recipient of the complaint and a Non-Federal Sponsor representative 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 and notify the GMT of the complaint and their screening analysis. If bank line movement appears to have occurred, the GMT shall meet to 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 Project
  - If the result of the Project, the recommended corrective action

- Post-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 will be further investigated by the GMT. The GMT will 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 Project
  - If the result of the Project, the recommended corrective action

Geomorphic Adaptive Management Trigger Exceedance

In the event a geomorphic adaptive management trigger is exceeded, the Geomorphic Monitoring Plan identifies specific actions the GMT will take. Generally, the GMT will first evaluate whether the trigger exceedance is attributable to the Project and, if possible, to what degree. If attributable, the GMT will then evaluate whether the impact is detrimental to stakeholders. If attributable and detrimental, the GMT will provide one or more recommended corrective actions for consideration to the AMT that are commensurate with the detrimental level of impact and with the level of attribution to the Project. The GMP has established a collaboration process and timelines for working through any trigger exceedance so as to allow for a maximum of 60 days to elapse between trigger notification and recommendation.

- Protocols and Standards:
    - A number of protocols are defined in the GMP related to all areas of geomorphic assessment, including calculation of entrenchment ratios, calculation of bank height ratios, determining aerial imagery-derived bank line locations, collecting survey data, analyzing sediment samples, and conducting Rosgen assessments.
    - Data will be made available in the RIVERMorph format and stored by the Non-Federal Sponsors in an electronic repository accessible by all GMT and AMT members via a web interface. The current storage location for this data is the Aconex site (https://us1.aconex.com/Logon).

- Geomorphic Assessment Schedule:
    - Pre-Construction: A total of three pre-construction geomorphic assessments were conducted. Another pre-operation sampling event may occur during construction if a large flood event occurs. The three pre-construction geomorphic assessments were conducted in 2010/2011, 2018, and 2020. The GMT adapted the survey plan used in 2010/2011 with additional and revised cross section survey locations, longitudinal profiles, and overbank deposition assessments for a more complete pre-construction geomorphology monitoring survey plan that was implemented in the 2018 collection and further refined for the 2020 collection. After the 2021 assessment is completed, the GMT and AMT will refine the GMP as appropriate.
    - Post-Construction: Conduct a total of three initial post-construction geomorphic assessments at five-year intervals following completion of Project construction. If no significant changes are noted after these initial three assessments, the assessment frequency may be reduced if the GMT and AMT deem that to be appropriate. If the Project is operated (which will occur only if the combined inflows at the USGS gages at Abercrombie and Enloe exceed 21,000 cfs, equivalent to slightly less frequent than a 5% annual exceedance probability event), a geomorphic assessment will occur as soon as possible following the event and the GMT may recommend the use of a post-operation assessment as a substitute for a regularly-scheduled geomorphic assessment. After the third initial post-

construction assessment is completed, the GMT and AMT will refine the GMP as appropriate.

- Communications:
  - AMT will be notified of all GMT meeting times, dates, agendas, and meeting notes.
  - GMT members are responsible for informing the AMT of upcoming personnel changes and provide an agency authorized alternate or replacement upon retirement or reassignment.
  - GMT will be notified by the AMT and/or Sponsors of geomorphic issues or concerns identified outside of the regular monitoring process as soon as possible.

4.5 Water Quality

A Water Quality Monitoring (WQM) Study has been set up to provide a baseline for water quality conditions and to monitor changes during and after Project construction.

The primary objective of this study is to sample and analyze water quality within the Project area before, during, and after construction to assess river response to the Project. Gages included in the WQM Study are to be monitored in a consistent manner. Statistical analyses of the data (e.g., load and trend analysis) are to be reported to the Corps, the GMT, and the AMT. Secondary objectives of this study are to leverage existing flow data, water quality data, personnel expertise, and on-going water quality programs within general Project area as the WQM Study foundation. The existing water quality data network will be used to fill in any data gaps for records collected before, during, and after construction to aid in assessing river response to the Project. The study personnel will proactively learn and share their understanding of the system and the monitoring network during the phased WQM Study to allow for betterment of future scopes-of-work under this program. The WQM Study is planned to be phased into three separate agreements with an initial three-year termed agreement started in FY 2019. The second agreement is planned to be adapted from findings of the first study and the construction progress and is planned to be executed at the contract end of the first agreement for an additional four years. The third agreement, again adapted as needed, is planned to be executed at the conclusion of the second agreement for an additional five years. At a minimum, it is anticipated that the third phase of the WQM Study will include a trend analysis comprising data collected during all three planned phases of the WQM Study.

Ten sampling locations are part of the monitoring program. Five locations are on the Red River of the North (Halstad, Georgetown, Harwood, Fargo, and Hickson), two locations on the Sheyenne River (Kindred and Harwood), two locations on the Wild Rice River (Abercrombie and St. Benedict), and one location on the Maple River (Below Mapleton). During times of normal flow conditions (i.e., non-flood event), a standard sampling protocol will be followed (eight samples per year).

All ten sites are sampled for major ions, trace metals, nutrients, TOC, DOC, bacteria, pesticides, and suspended sediment. Three sites on the Red River of the North (Georgetown, Fargo, and Hickson) include continuous water quality monitors for water temperature, specific conductivity, pH, and dissolved oxygen.

Water Quality Flood Event Monitoring Triggers

During flood events, a more frequent sampling protocol will be followed. For the Maple and Sheyenne Rivers, a "flood event" is defined as occurring when the National Weather Service's forecasted peak flow at either the Maple River or Sheyenne River gage (shown in Table 1) exceeds the 10% annual chance exceedance (ACE) event flow. The 10% ACE definition of a flood event for these river systems was selected based on a review of hydraulic modeling results that indicated that flows begin to inundate the floodplain during events of this size. For the Wild Rice and Red Rivers, a flood event is defined as occurring when the summation of forecasted flows exceeds 21,000 cfs at the Wild Rice and Red River gages, as indicated in Table 11.

Table 11. Monitoring Triggers for Defining a Flood Event

River System	WMS Study Gage	Flow Threshold (cfs) for Flood Event
Maple River	Below Mapleton (05060100)	6,280
Sheyenne River	Kindred (05059000)	4,190
Red River and Wild Rice River	Summation of Flows at: Enloe (0505152130) and Abercrombie (05053000)	21,000

Annual workshops are planned to keep stakeholders informed and allow for adaptive management of the monitoring regime. USGS Scientific Investigation Reports (SIRs) are expected at the end of the pre-project, construction, and post-construction periods. A Final SIR will compute trends and loads using R-QWTEND statistical analysis package.

4.6 Invasive Species Monitoring

Invasive species management is related to aquatic species and vegetative invasive species. During construction and post-construction, spread of invasive species at wetlands and other landscaping areas will require construction in accordance with specific criteria for Minnesota and North Dakota for aquatic and terrestrial invasive species, as described in Section 2.5.

Aquatic Invasive Species Monitoring

During construction and post-construction, contractors will operate in accordance with an approved aquatic invasive species management plan. The plan would require equipment that would be in contact with infested waters to be decontaminated prior to entering the water and before leaving the site. Methods for decontamination could include one of the methods described in Section 2.5. Use and cleaning of equipment will be monitored and documented when equipment enters or leaves the water body.

Zebra mussel monitoring plates on the Red River Structure and Wild Rice River will be monitored on an annual basis. Mussel counts will be recorded and shared with the AMT to provide informal information to the resource agencies. No triggers or response actions would result from this data.

Vegetative Invasive Species Monitoring

Post-construction vegetative invasive species monitoring would occur in areas planted with native species, including wetlands habitats. The monitoring results will be compiled and described in monitoring reports to be provided to the AMT. Non-forested wetland habitat monitoring in the Diversion Channel will occur annually until the invasive and non-native species performance standards listed below are met for two consecutive years. The forest habitat would also be monitored for invasive and non-native species at the fifth and tenth year following planting, and every five years thereafter until the invasive and non-native species performance standards are met for two consecutive monitoring events.

Performance Standards:

By the third going season, areas one-quarter acre in size or larger that have greater than 50 percent areal cover of invasive and/or non-native species will be treated and replaced with native species in non-forested and forested habitats.

A combination of vegetation control methods would be used including, mowing, burning, disking, and/or mulching; or, if appropriate, biocontrol and/or herbicide treatments.

4.7 Fish Stranding

Fish stranding will be evaluated following Project operations. The evaluation will be for areas of the upstream staging area that are not otherwise flooded under without Project conditions. Please reference Figures 1, 2 and 3 in Attachment C. These provide inundation areas for both With and Without Project for the 4%, 2% and 1% annual flood probability. Maps provided in Attachment C and associated shapefiles will be the reference point for floods at or below the referenced magnitude (e.g., floods between the 4% and 2% will reference the 2% map with transects occurring in areas flooded with the Project that would not be flooded without).

The evaluation will be performed by the Non-Federal Sponsor as a part of the AMMP and the Project's O&M requirement. The Biotic Resource Monitoring Team will be contacted prior to or at the onset of Project operation and coordination will continue as waters recede. Team members will be invited to participate in field activities and will be involved with this process to the full extent they are able. Note that the precise timing of an evaluation will be dependent on hydrology and Project operations. Flexibility will be needed to perform the evaluation at an optimal time.

Monitoring fish stranding will use a two staged approach. The first is a Reconnaissance Stage to quickly evaluate if a fish stranding/kill event has occurred (MnDNR defines this as a Consequential Fish Kill). If the Reconnaissance Stage identifies a stranding/kill event, the second stage is a Detailed Evaluation Stage to quantify/enumerate fish loss.

Note that a separate discussion is included in a later section for fish that may become trapped in the Drain 27 wetland mitigation complex. A separate sampling and rescue effort will be employed to remove fish from this feature and return them to the Wild Rice or Red Rivers.

- <u>Reconnaissance Stage</u>:
  When the Project operates, this first stage will be performed as water is receding from the upstream staging area. This stage will have a two-part, phased approach. The cumulative level of effort will be approximately one day, broken across approximately two half-day events.

  <u>Reconnaissance Stage, Phase 1</u>

  - Observe "field" sites within the upstream staging area. These are intended to be agricultural fields and other broad, open areas. Effort will be made to survey these areas within seven days of them generally being drained following Project operations, though flexibility is needed given that field conditions could be difficult for access and sampling.
  - Perform windshield surveys to quickly view areas and consider if there's an obvious fish stranding event.
  - Periodically along travel routes, and/or based on the windshield surveys, do on-site walking surveys in select areas where fish may be likely to strand.
  - It is assumed this phase would take approximately a half-day. Figure 4, 5, and 6 in Attachment C provide a suggested route to perform windshield surveys (based on the magnitude of flood). Staff will allocate enough time to walk areas of specific interest. This should include frequent stops along areas of concern (e.g., areas where dead fish may collect). Identified paths in Figures 4, 5 and 6 in Attachment C could also be used for walking assessments (along field edges and roadside ditches, or into fields if access available), but these will ultimately need to be adapted based on field conditions and access or available rights-of-entry.

- Fish collected will be identified, measured when practical, and photographed. Data will be recorded on datasheets.

o <u>Reconnaissance Stage, Phase 2</u>

- Observe “drainage path” sites for receding waters both along natural waterways and new drainage swales established in the staging area. These are intended to be corridors of flow where fish would presumably find their way back to the Red or Wild Rice Rivers, or down the diversion channel. Focus areas likely would include the borrow pit and borrow ditch (the dashed line in Figures 4, 5, and 6 in Attachment C), and potentially drainage swales within the staging area. Access to the borrow ditch would be available between the toe of the embankment slope and the borrow ditch where there will be a bench for maintenance access. Assessment could also occur in other drainage areas, such as the swale leading to Drainage Ditch 27 and the drainage network leading to the borrow pit.
- Agency representatives will be consulted to finalize the locations based on site access, field conditions and how the draining process has progressed. Based on modeling of the staging area, it is anticipated that Reconnaissance Phase 2 would occur from 4 to 8 days following Reconnaissance Phase 1 but is entirely dependent on conditions with that particular flood event.
- Focus areas to stop and observe along drainage areas could include riffle-type locations, willows, beaver dams, etc. These areas tend to collect fish.
- Fish collected will be identified, measured, and photographed. Data will be recorded on datasheets.

<u>Triggers that Require Second Stage Evaluation</u>

The following are identified as the triggers requiring a detailed evaluation (what MnDNR has defined as a Consequential Fish Kill).

- 5 Lake Sturgeon of any size OR
- 5 Channel Catfish >24” OR
- 10 Walleye >15” OR
- 10 other sport fish of public value as defined by Minnesota Rule 6133.0080, of the “Quality” size class or larger as defined by Gabelhouse 1984.

If triggers are met in Reconnaissance Phase 1, a detailed evaluation of the same broader staging area would occur. Similarly, if triggers are met in Reconnaissance Phase 2, a detailed evaluation of the drainage corridors would occur for areas leading from the staging area to the Red or Wild Rice Rivers, or diversion channel.

Results of the two Reconnaissance stages will be coordinated within a day of completion with NDGF, MnDNR, and USFWS.

- Detailed Evaluation Stage:
  - If a trigger is met, perform a detailed evaluation of either the broader staging area which would not have been inundated under the without Project conditions and/or the drainage paths leading out of the staging area.
  - Detailed evaluations will follow the protocol employed in American Fisheries Society Special Publication 35 (Southwick and Loftus, 2017). Evaluations of the broader staging area would generally follow the protocol for lakes sampling; evaluations for drainage paths would follow the protocol for rivers/streams sampling.
  - The Corps and the Non-Federal Sponsors will work with agencies and external experts to develop a sampling approach with a practical number of transects for estimation of total fish stranding/kill. Sampling must be able to be completed within 1-3 days for a crew of two people. Considerations to sampling approach should include field conditions, property access, and other factors that could influence access or efficiency for data collection. As such, transect number and location needs to be flexible and may only be partially planned in advance of the flood. Consideration will be given to aerial surveys via drone technology as a potential tool for data collection, especially for detailed evaluations. While there are many limitations to doing the surveys remotely, techniques and technology will continue to improve and could be a viable option by the time fish stranding surveys would be needed (e.g., 2027 and beyond).

Number of Fish Stranding Evaluation Events
If the Project operates three times and the reconnaissance field surveys do not result in triggers for a Consequential Fish Kill, then it will be assumed that the Project does not result in substantial fish stranding and stranding evaluations will cease. This standard would be applied to both areas considered in the Reconnaissance phase (e.g., field sites and drainage path sites). Note that if the first three events are all small or similar sized events (e.g., 30-year events or less) the Non-Federal Sponsors will collaborate with the AMT to confirm if future monitoring should consider one more event if that event will be significantly different (e.g., a 50- or 100-year event). Also note that if the Project has operated three times without incident and no monitoring is planned, yet a fish kill or fish stranding is reported by the public or resource agency after a subsequent event, then the Non-Federal Sponsors will respond with a reconnaissance level investigation and move to the detailed evaluation phase if triggers are met.

Mitigation

Southwick and Loftus (2017) provides the technical approach to estimate numbers of fish lost due to stranding. They also provide guidance on applying monetary values on lost fish, based on species and size. This can be applied to estimate a monetary loss. The MnDNR and NDGF have agreed that restitution values for lost fish in the staging area will be split 50/50, with monetary values defined by Minnesota Rule 6133.0080. MnDNR retains statutory authority to assess penalties for fish kills in Minnesota resulting from project operations. In addition to a payment for lost fish, both states have expressed an interest in modifying field conditions, if possible, to minimize risk for future stranding events. This could range from a relatively easy, low-cost exercise (e.g., debris removal from culverts) to a much more expensive effort to improve drainage (e.g., extensive grading or upgrading culverts). If a Consequential Fish Kill occurs, the Non-Federal Sponsors will work with agency partners to identify the best approach to address the issue for the current fish mortality event, as well as in future years, using the monetary value of fish loss as a reference point or guide. This will need to include how any monetary payment is divided up between the states.

Drain 27 Wetland Complex

This wetland complex drains portions of the upstream staging area and includes a weir to maintain minimum water elevations during most years. This provides hydrology to support a wetland community implemented for mitigation, but also provides a barrier fish may not move downstream over. Fish could become trapped within this feature following floods. In addition, common carp that become trapped would likely uproot vegetation, limiting the ecological effectiveness of the mitigation feature.

Following operation of the Project, sampling will be done within the wetland to assess fish presence. A two-stage approach will be used, with an initial stage to determine fish presence, and a second to remove fish and transport back to the Red River. Exact gear types and triggers for moving to a fish removal operation are still under development. Depending on location and conditions, this potential sampling could include electroshocking, fyke or trap netting, or other methods. The evaluation will be performed by the Non-Federal Sponsors as a part of the AMMP and the Project's O&M requirement. The AMT will be invited and involved with this process to the full extent they are willing/able to do so. The timing of this evaluation can be more flexible but should be performed within 30 days of the end of Project operations.

Specific gear types and level of effort will be fine-tuned in collaboration with the AMT once the wetland complex is built. Initial sampling is intended to take approximately a day to assess fish presence within the wetland. This could include a minimum of two hours of run-time for electrofishing; a set number of seine hauls; or set number of overnight fyke-sets.

Triggers that Require a Fish Removal Operation

Triggers will follow with those outlined above for fish stranding. These will need refinement and finalization. These will be based on the following level of effort:

- 1 hour of electroshocking
- 5 overnight sets of a fyke or trap net
- Other

Triggers for the above effort

- 5 Lake Sturgeon of any size OR
- 5 Channel Catfish >24" OR
- 10 Walleye >15" OR
- 10 other game fish as defined by the North Dakota 2020-2022 Fishing Proclamation, of the "Quality" size class or larger as defined by Gabelhouse 1984.

If the above triggers are met with the given level of effort, a fish removal operation will commence. If this occurs, it will continue via active sampling (e.g., shocking or other) until fewer than five of the target species (any size) are collected for the same level of effort for given gear types listed above. If a different active or passive collection method is used, the Non-Federal Sponsors will work with the AMT to develop a similar endpoint.

Any live fish collected during a removal operation will be transported and returned to the Red River using typical methods (e.g., stock truck or similar). The Non-Federal Sponsors will coordinate with the resource agencies on the appropriate transport methods. All results of the collection effort will be recorded and reported to the AMT.

The exception to the fish removal identified above is if the fish collected are common carp or any other invasive fish. If the only fish collected outside of the defined triggers are common carp or other invasive fish, the AMT will identify the best approach to manage/remove and dispose of remaining fish. This may occur outside of the specified 30-day window, and could include water level management, continued physical removal, chemical treatment (rotenone), predator fish stocking, or other actions.

4.8 Drayton Dam

Drayton Dam will be constructed as a MnDNR permit requirement for this Project. As directed in condition 27 of MnDNR permit 2018-0819, the design of the Drayton Dam Project was collaboratively worked on with the MnDNR, in addition to other resource agencies, to ensure effective fish passage. The design incorporates the best available design parameters for slope, weir alignment, pool depth, and head-loss across boulder weirs.

Monitoring Activities

Though not required in the permit, velocities through the Drayton Dam Project will be measured after the Project is complete, as requested by the DNR, to capture the “as-built” condition for water movement through rock ramps. Measurements will be taken in resting pools between weirs and in gaps between boulders across the entire cross-section. Measurements will occur within one year of Project completion and will be limited to a single sampling effort. Additional monitoring of the fish passage, or any modifications to the structure based on velocity or other observations, would be addressed in state and local permits, such as the individual Drayton Dam permit from the MnDNR.

4.9 Additional monitoring needs

Coordination with agency members during preparation of the 2019 SEA identified additional monitoring concerns for the Project. These include needs for species or biota of special concern, and invasive species. Monitoring will include the following activities:

- Bald eagle nests would be monitored every spring through the completion of all construction. The Project area would continue to be monitored during the upcoming years to ensure that no new nests would be impacted by Project construction.

- Similar to eagle surveys, there would be raptor nest surveys completed in the spring of the year preceding construction within or near any affected wooded areas.

- Monitoring would be completed on an annual basis in accordance with the OMRR&R and AMMP.

5 Costs and Schedules

5.1 Monitoring Schedule and Costs

Table 12 provides a summary of what monitoring has been completed and a tentative plan for additional monitoring prior to or during Project construction. Because of uncertainties with the Project schedule, annual funding, field conditions, and the results of earlier surveys, the need and timing of additional survey work could shift. Note that two of three events of aquatic biotic/habitat surveys have been completed for impact areas; all three geomorphic assessments have been completed. The schedule for surveys of aquatic habitat mitigation sites will be developed once mitigation plans are finalized.

Schedules for individual mitigation projects will be developed as they are designed and constructed. A general summary of the timing and information that will be collected for each category of mitigation project is provided in Table 12; additional description can be found in Section 4.

Table 12. Estimated scheduled for pre- and post-construction Project monitoring. The number and timing of events for aquatic habitat mitigation sites will be set once the mitigation plans are finalized.

Monitoring Event	**Year**	**Status**
Geomorphic Assessment (Pre-construction, first round)	2010/2011	Completed with report finalized in October 2012
Geomorphic Assessment (Pre-construction, second round)	2018	Completed with report finalized in September 2019
Geomorphic Assessment (Pre-construction, third round)	2020	Monitoring complete, report anticipated in fall 2021
Geomorphic Assessment (Pre-Project, Event)	Event dependent	Report to AMT within 1 year of completion of field investigation effort. (*USACE Until 24 OCT 2024; Sponsor 25 OCT 2024 and beyond.)*
Geomorphic Assessment (Post-Project, first round)	Within 1 year of Project Completion	Future TBD: Report final within 2 years to establish Post-FMM Project conditions.
Geomorphic Assessment (Post-Project, second round)	+ 5 years after Round 1	Future TBD: 2nd Post-Project Assessment
Geomorphic Assessment (Post-Project, third round)	+ 10 years after Round 1	Future TBD: 3rd Post-project Assessment. GMT initiate meetings to evaluate within 90 calendar days of finalization of third post-project Geomorphic Assessment Report. GMT provides summary and recommendations to AMT within 180 days.
Inspect Zebra Mussel Monitoring Plate at Red River and Wild Rice Structures	Annually	Future TBD: Once the structures are constructed annual inspections will begin.

Monitoring Event	Year	Status
Water Quality Monitoring (Pre-construction) w/ Flood Event Monitoring	FY 2019-2022	3-year-term, ongoing. Monitoring Plan adaptable following evaluation of first-term monitoring assessment. Including Flood event 2020.
Water Quality Monitoring (Construction) w/ Flood Event Monitoring	FY 2022-2026*	4-year term; Re-assess, evaluate, adapt.
Water Quality Monitoring (Post-Construction) w/ Flood Event Monitoring	FY 2026-2031*	5-year term; Re-assess, evaluate, adapt.
Aquatic Biotic/Habitat, first round	2011 & 2012	Completed
Aquatic Biotic/Habitat, second round	2017	Completed
Sheyenne Fish Observation in Diversion Channels	2025*	To be performed at least one year prior to construction (2027 or later)
Drayton Dam Velocity Measurements	2024	A single monitoring event will be conducted after construction to capture as-built conditions
Red River Structure Velocity Measurements	TBD	Average cross section velocities at the Red River Structure will be measured at discharges close to 2,900 cfs, 8,100 cfs, and 10,700 cfs
Floodplain Forest, Post-Construction	2010-2031*	Forest mitigation areas will be monitored annually for the first 5 years after planting.
Wetlands, Post-Construction	2010-2031*	Wetland mitigation areas will be monitored annually for the first 5 years after planting or once criteria has been met.
Eagle/Raptor Monitoring	Annual	Raptor surveys will occur in the Project area until construction is complete.

*Timing dependent on field conditions, logistical concerns, etc. Timing may shift as needed.

The schedule for post construction surveys will be set once the Project is largely constructed.

Table 13 provides an estimate for pre- and post-construction monitoring costs. Specific line-item costs have not been included for observations for fish stranding or floodplain forest success as these activities would be likely be a relatively small efforts accomplished by the Non-Federal Sponsors. Invasive species monitoring will be included as a component of both forestry and wetlands monitoring. The estimate below will be revised as Project costs are updated to reflect current dollars as well as any necessary changes. Note that monitoring estimates for mitigation sites could increase or decrease depending on the number, location and type of mitigation and monitoring sites ultimately selected.

Table 13. Estimated monitoring costs for the AMMP.

Project Phase	Studies	Cost (in 2020 dollars)
Pre-Project	Sheyenne Fish Observation in Diversion Channels	$50,000 (per year)
Pre-Project	Geomorphic Assessment (only if an event sufficient to initiate Project operations, if the Project were complete, occurs, since all regularly scheduled pre-Project monitoring is complete)	$1,000,000 (per event)
Pre-Project	Water Quality Monitoring Term #1 (covering water years 2019-2022). Report delivered to AMT in 2023. Included 2020 Flood event enhanced monitoring. May also include an additional flood event if occurs prior to 30 Sep 2022.	$1,000,000 (for all 3 years)
Pre-Project and Construction	Water Quality Monitoring Term #2 Report delivered to AMT in 2027 covering water years 2023-2026. Effort may be adjusted by AMT after evaluation of Term #1 data.	$1,333,333 (total estimate for all four years at pre-construction monitoring levels)
Construction and Post-Project	Water Quality Monitoring (Term #3). Report delivered to AMT in 2032 covering water years 2027-2031. Effort may be adjusted by AMT after evaluation of Term #2 data.	$1,666,666 (total estimate for all 5 years at pre-construction monitoring levels)
Post-Project	Geomorphic Assessment (3 rounds and re-evaluation). Currently anticipate assessments conducted in 2027, 2032, and 2037, with reports delivered to the AMT the following year. Timing of assessments beyond 2037 dependent upon AMT and GMT evaluation after 2037 assessment report is completed.	$1,000,000 (per round)
Post-Project	Geomorphic Post-Flood Event Assessment (only in the event Project operations occur)	$1,000,000 (per event)
Post-Project	Field Surveys of Rock Rapids Fishways (Sheyenne mitigation) to ensure maintaining design criteria.	$10,000 (per event). Assumes each event monitoring two rock rapids fishways.
Post-Project	Sheyenne River IBI Observations.	$100,000 (per event)
Post-Project	Aqueduct Acoustic Doppler Current Profiler	$10,000 (per event, per aqueduct)
Post-Project	Fish Stranding Stage 1 (Recon)	$15,000 per event (includes Phase I and II).
Post-Project	Fish Stranding Stage 2 (Detailed Evaluation)	$25,000 per event (includes Phase I and II).

Project Phase	Studies	Cost (in 2020 dollars)
Post-Project	Drain 27 Fish Removal	$25,000 per event
Post-Project	Velocity measurements at the Red River Structure	$5,000 (per event)
Post-Project	Velocity measurements at Drayton	$15,000
Post-Project	Forest Monitoring (annually for first 5 years)	$50,000 (per event)
Post-Project	Forest Monitoring (every 10 years or following major flood)	$50,000 (per event)
Post-Project	Diversion Channel Wetlands Monitoring (5-10 years)	$200,000 (annually)
Post-Project	Drain 27 Wetland (5 years)*	$65,000 (annually)
Post-Project	Inspect Zebra Mussel Monitoring Plate at the Red River and Wild Rice River Structures	$500 (annually)

* This period may be shortened if the monitoring reports demonstrate that the mitigation site(s) has met its vegetation and hydrology performance standard(s) in two consecutive reports and the AMT concurs that additional monitoring is not required.

** Table does not include costs for items still needing further development, such as potential fish observations through the Sheyenne aqueduct and adjacent areas of the Sheyenne mitigation project.

The Non-Federal Sponsors will be responsible for funding long-term operation and maintenance, including the monitoring costs and unforeseen mitigation needs that may arise due to Project operation. On June 10, 2021, the Metro Flood Diversion Authority and Cass County Water Resource District (CCJWRD) entered into a Master Indenture of Trust with the Bank of North Dakota serving as Trustee and the City of Fargo serving as Fiscal Agent. The Master Indenture of Trust establishes and controls multiple funds and accounts for the Project, including but not limited to the Operations and Maintenance Fund that will be used to fully fund operations and maintenance of the throughout the life of the Project. The Operations and Maintenance Fund is funded through a variety of revenue sources (as more fully set forth in the Master Indenture of Trust), including sales and use taxes from the City of Fargo and Cass County in North Dakota that would be in excess following payment of debt obligations issued for the capital cost of the Project, the imposition and levy by CCJWRD of Fargo-Moorhead Flood Risk Management District No. 1 maintenance levy upon benefitted lands in North Dakota, and the Storm Water Maintenance Fee collected within the City of Moorhead, Minnesota, and funds from Clay County, Minnesota.

6 Data Storage

The AMMP will generate substantial amounts of data, information, and reports over time. The data and subsequent reports should be accessible and shared to avoid redundancy and analysis purposes as well as stored as part of the monitoring record and for future data needs. The Corps and the Non-Federal Sponsors will work with the AMT to develop a repository for this information. This will likely be a web-based system, providing access to summary reports and potentially raw data. All AMMP work products will be shared with the AMT when requested.

As discussed in Section 4.4 and more extensively in the Geomorphic Monitoring Plan, the current storage location for geomorphic monitoring data is the Aconex site maintained by the Non-Federal Sponsors. The Aconex site can be accessed here: https://us1.aconex.com/Logon.

A database is being developed to track Project impacts, mitigation sites, and monitoring. Information the database would contain includes a brief overview of each project phase/feature, access to files and maps, inspection notes and schedules. The platform would allow photos and notes to be uploaded from the field. The database would be accessible to the Corps, the Non-Federal Sponsors, and agency team members.

References:

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White Paper

Proposal for improving Sheyenne River connectivity and aquatic habitat for mitigation of aquatic impacts associated with the Fargo-Moorhead Metropolitan Area Flood Risk Management Project.

June 2021

Background

The Red River basin in eastern North Dakota and western Minnesota has a long history of flooding due to the unique hydrology and topography of the area. The US Army Corps of Engineers (USACE) completed the Final Feasibility Report and Environmental Impact Statement (FEIS) for the Fargo-Moorhead Metropolitan Area Flood Risk Management Project (FMM Project) in July 2011. The Project was later authorized by Congress in the Water Resources Reform and Development Act of 2014.

Detailed engineering and design conducted since the completion of the FEIS have resulted in modifications to the FMM Project. This resulted in a Supplemental Environmental Assessment (SEA) in 2013, with the most current designs and associated impacts outlined in SEA #2 in 2019.

The FMM Project will include various environmental effects, some substantial enough to warrant mitigation. This document outlines a proposal to fulfill mitigation needs for specific impacts to lost aquatic habitat resulting from the project in the State of North Dakota. Other mitigation needs (e.g., wetlands and forest habitat) are outlined in the project's Adaptive Monitoring and Management Plan.

Aquatic Habitat Impacts

Construction of FMM Project will result in adverse impacts to riverine aquatic habitat. In many cases, major features must be built "in the dry," in areas disconnected from river flows. Once construction of the features is substantially completed, the rivers would be re-routed through the newly constructed channel and features. Existing river channel that is filled, excavated, or abandoned was considered in the calculation of aquatic habitat impact. Aquatic habitat impacts requiring mitigation are primarily associated with the gated control structures on the Red and Wild Rice Rivers (the Red River Structure and the Wild Rice River Structure), and the aqueducts (river bridges) that allow the Sheyenne and Maple rivers to cross the FMM Project's diversion channel.

Table 1. Location and amount of lost riverine aquatic habitat associated with the FMM Project that will be mitigated.

Riverine Aquatic Impact Location	Acres Lost
Red River Structure (MN/ND)	12.9
Wild Rice River Structure (ND)	7.8
Sheyenne River Aqueduct (ND)	8.0
Maple River Aqueduct (ND)	10.0
Total	**38.7**

Mitigation Strategy

Minnesota

Mitigation needs for aquatic habitat impacts associated with waters of Minnesota caused by the FMM Project are outlined in the Minnesota DNR Dam Safety & Public Waters Work Permit (Permit # 2018-0819). Specifically, Condition 27 of that permit outlines how mitigation will be handled for Minnesota waters.

Condition 27 includes USACE/sponsorship coordination with the DNR to set the mitigation needs to address impacts, including both amounts and location of mitigation. About 6.5 acres of lost aquatic habitat occur within Minnesota (half of the impacts on the Red River). USACE is working with Minnesota DNR to implement mitigation projects, likely on the Lower Otter Tail River, to offset these losses.

North Dakota

USACE had lengthy discussions with agency partners searching for potential mitigation actions in North Dakota. This included restoration of habitat on the Bois de Sioux, as well as other rivers. However, candidate sites are nearly non-existent, primarily due to the lack of available real estate. Land owners, particularly near the project area, are hesitant or unwilling to provide real estate to implement mitigation projects. This has made it extremely difficult to mitigate lost aquatic habitat in North Dakota.

Previous discussions with North Dakota resource agencies identified a desire to improve habitat connectivity (e.g., fish passage) and whether projects that improve connectivity could serve as mitigation. While the comparison of direct habitat loss is difficult to make compared to a functional improvement like connectivity, the improved habitat quality is something that could be used to mitigate for habitat losses resulting from the FMM Project.

Several potential fish passage/connectivity projects were discussed with North Dakota resource agencies. One with substantial interest focused on the lower Sheyenne River. Connectivity in this area has been substantially reduced due to several features constructed previously, many of which were built as part of the Sheyenne River Flood Control Project (SRFCP) in the 1990s. This river reach is extremely attractive from a mitigation standpoint because:

- The river reach is located near the project impacts, and within the FMM Project area
- The Sheyenne River is the largest tributary to the Red River in North Dakota, and provides valuable habitat to many species
- The real estate necessary to implement mitigation is owned by local government
- The connectivity impairments are immediately adjacent to the Red River; resolving these impairments improves connectivity for fish migration between the two rivers.

In addition to connectivity improvements, there is also a disconnected oxbow on the Sheyenne River adjacent to County Road 17 between West Fargo and Horace. Accessibility and real estate don't appear to be a problem, and the site would provide roughly three acres (1,750 lineal feet) of restored habitat.

Overview of Existing Connectivity Impairments on the Sheyenne

The SRFCP is a federal project authorized in the 1986 Water Resources Development Act. The SRFCP was designed and constructed by USACE, becoming operational in 1993. The project is owned and operated by the Southeast Cass Water Resource District. The pertinent features associated with the SRFCP and the proposed FMM Project are in Figure 1. The SRFCP consists of the following key features:

- Weir structure across the river at upstream end of the Horace to West Fargo Diversion Channel (HWFDC)
- Culvert and baffle structure adjacent to the weir structure at the upstream end of the HWFDC
- Sheet pile weir structure across the river at upstream end of the West Fargo Diversion Channel
- Gated structure on the river just upstream of I-94
- Gated structure and pumping station on the river near 12th Ave

Figure 1. Overview of the Sheyenne River Flood Control Project (SRFCP) and associated features of the Sheyenne mitigation project.

At the upstream end of the HWFDC, flow is split when flow in the natural channel reaches approximately 1,100 cfs. Flow that continues along the natural channel must pass through the culvert and baffle structure. The percent of flow entering the HWFDC via the HWFDC inlet structure fixed-crest weir increases as the total river flow increases. Under current conditions there is very little freeboard provided by the natural channel banks for the 1/100 Annual Excedence Probability (AEP) event.

At the upstream end of the WFDC, flow is split when the flow in the natural channel reaches approximately 700 to 750 cfs. Flow that continues along the natural channel must pass through a gated culvert structure just upstream of I-94. The existing SRFCP operation & maintenance plan calls for this gated culvert structure to be closed if either the local water surface elevation reaches 898.93 feet (which corresponds to a flow of approximately 900 cfs) or the water surface elevation at the downstream end of the SRFCP near the 12th Avenue North gated culvert structure and pump station reaches 890.94 feet. Soon after the gated structure just upstream of I-94 is closed, the downstream gated structure near 12th Avenue North is closed. These gated structures have been closed a high percentage of the time, especially in recent wetter years. It was estimated that from 2012 to 2019, the gates for this project were closed around 900 days. This is about 32% of the all days during that period. Further review suggests the gates may have been closed about 42% of days from March through November; and about 48% of days March through June. A flow analysis has been attached to this document to demonstrate the frequency of flow exceedance for the project area, including an analysis of how Devils Lake pumping influences those flows. This provides context in understanding flow frequency and distribution for the existing Sheyenne project, as well as conditions with the mitigation project proposed below.

Fish passage and other biologic connectivity are impacted by the SRFCP. Six miles of natural channel are hydraulically severed when the gated culvert structures near I-94 and 12th Avenue North are closed. Bank instabilities resulting from the relatively quick drop in water elevations immediately after closure of these gates and the poor water quality that develops with an extended closure degrade the habitat value and function in this six mile reach of natural channel. Connectivity along the natural channel is also hindered at the culvert and baffle structure adjacent to the HFWDC inlet structure since the baffle slot is subject to blockage by debris and high velocities occur through the submerged box culverts. The culvert structures, even when those with gates have their gates open, produce adverse light and velocity conditions for fish passage. Fish that are drawn up the diversion channels are faced with challenges getting back into the natural channel. The WFDC inlet structure likely passes some fish, but the flow conditions are not what they should be to pass fish over a wide range of flow conditions. Sedimentation has made the fish passage structure at the HWFDC inlet structure inaccessible at low to moderate flows in the HWFDC.

Outside of SRFCP, other barriers also exist on the lower Sheyenne River. Review of aerial imagery identifies a low-head dam immediately north of the railroad bridge crossing on the Sheyenne River in West Fargo (between Main Street and 12th Avenue). This dam is often inundated, but would be a barrier to fish during periods when not flooded out. It is not immediately known who the owner of the dam is, or its historical purpose.

Another issue is a number of existing bridges and box culverts on the Sheyenne in the project area. Some of these could be a partial barrier to fish, particularly at higher discharges. While these do not appear to be as significant of a barrier as the items outlined above, they could further restrict fish movement.

Collectively, fish in the lower Sheyenne and Red Rivers cannot reliably access the Sheyenne River above Horace, ND, particular during periods of higher river flow which often coincides with important migration periods.

Proposed Connectivity Improvements

To achieve habitat improvements and meet mitigation needs for lost aquatic habitat in North Dakota due to the FMM Project, USACE is proposing modifications to the SRFCP to improve connectivity. The Southeast Cass Water Resource District and the cities of West Fargo and Horace are in support of this proposed mitigation project, provided they continue to receive flood protection as provided by the SRFCP. To accomplish this requires a delicate balance of hydraulic design in concert with the broader FMM Project.

The required modifications to the SRFCP are provided here:

- Modifications to the HWFDC Reach (see Figure 2)
    - Remove the Sheyenne River culvert and baffle structure adjacent to the HWFDC inlet structure
    - Maintain the HWFDC inlet structure fixed-crest weir elevation and width, and retrofit with rock rapids to allow fish passage out of the HWFDC back into the Sheyenne River
    - The resulting slight decrease in water surface elevation at the split location due to removal of existing culvert and baffle structure will slightly increase the flow at which the flow split first occurs.
- Modifications to the WFDC Reach (see Figure 3 and Figure 4)
    - Remove the Sheyenne River gated structure just south of I-94
    - Remove the Sheyenne River gated structure and pump station just north of 12th Ave North
    - Lower the WFDC inlet weir invert to limit flow in the Sheyenne River between I-94 and 12th Ave North to 700 cfs up through the Sheyenne River Standard Project Flood (SPF) event
    - Lowering of the WFDC inlet structure weir will increase the frequency of flow being diverted into the WFDC, but removal of the gated structures assures that there will always be flow along the natural channel
    - Design/update the rock rapids below the crest of lowered WFDC inlet structure to allow fish passage out of the WFDC back into the Sheyenne River
    - The increase in frequency of flow into the WFDC will be determined by first getting a USGS flow measurement at the existing-condition threshold point (confirm/revise the estimated 650 cfs threshold) and then performing detailed modeling and design of the lowered WFDC inlet structure to determine the new threshold flow.
    - Design of the lowered WFDC inlet structure will be an iterative effort that considers the benefits of no longer closing off the natural channel through West Fargo, the increase in the frequency of flow into the WFDC, and the cost of the WFDC inlet structure modifications.
- The design of the rock rapids will likely employ similar designs to recent rock rapids projects (e.g, 3% overall slope; localized water surface elevation drops between stone arch weirs of about 0.5' or less).
- **Modifications to the SRFCP cannot be constructed until the broader FMM FRM Project construction is complete and operational and levee certification is achieved; flood protection currently provided by the SRFCP must be maintained at all times**

The following would also be completed with the broader FMM Project to facilitate the modifications outlined above:

- Modifications to the SRFCP will not be completed by the P3 Developer. This will be a USACE and/or Local Sponsor project.
- The FMM Project's Sheyenne River aqueduct structure will begin diverting water into the Diversion Channel at 1,200 cfs, with a maximum flow through the aqueduct of 1,500 cfs. It is not anticipated that this limit will significantly affect habitat or geomorphic function.
- The FMM Project's Maple River aqueduct structure will begin diverting water into the Diversion Channel at 1,700 cfs, with a maximum flow through the aqueduct of 3,500 cfs. It is not anticipated that this limit will significantly affect habitat or geomorphic function.
- Emergency positive closure will be added to the downstream side of both Sheyenne and Maple aqueduct structures to prevent exceeding the maximum flows. The positive closures would only operate in events in excess of 500-year annual exceedance flows or in an emergency situation.

Outside of the SRFCP modifications, two other items will be considered for connectivity improvements on the Sheyenne River. First, the low-head dam immediately north of the railroad bridge in West Fargo will be investigated (Figure 5). If at all feasible, the dam will be removed or retrofitted with a rock rapids fishway similar to design as other recent fishways in the region.

The second item is future consideration for improvements to bridges and box culverts on the Sheyenne River between the Sheyenne River aqueduct and the mouth of the river. Some of these bridges and culverts could be a partial barrier to fish, particularly at higher discharges. While re-designing or retrofitting several such crossings would be difficult, local officials will consider fish friendly crossings with future road/bridge improvements when these needs arise.

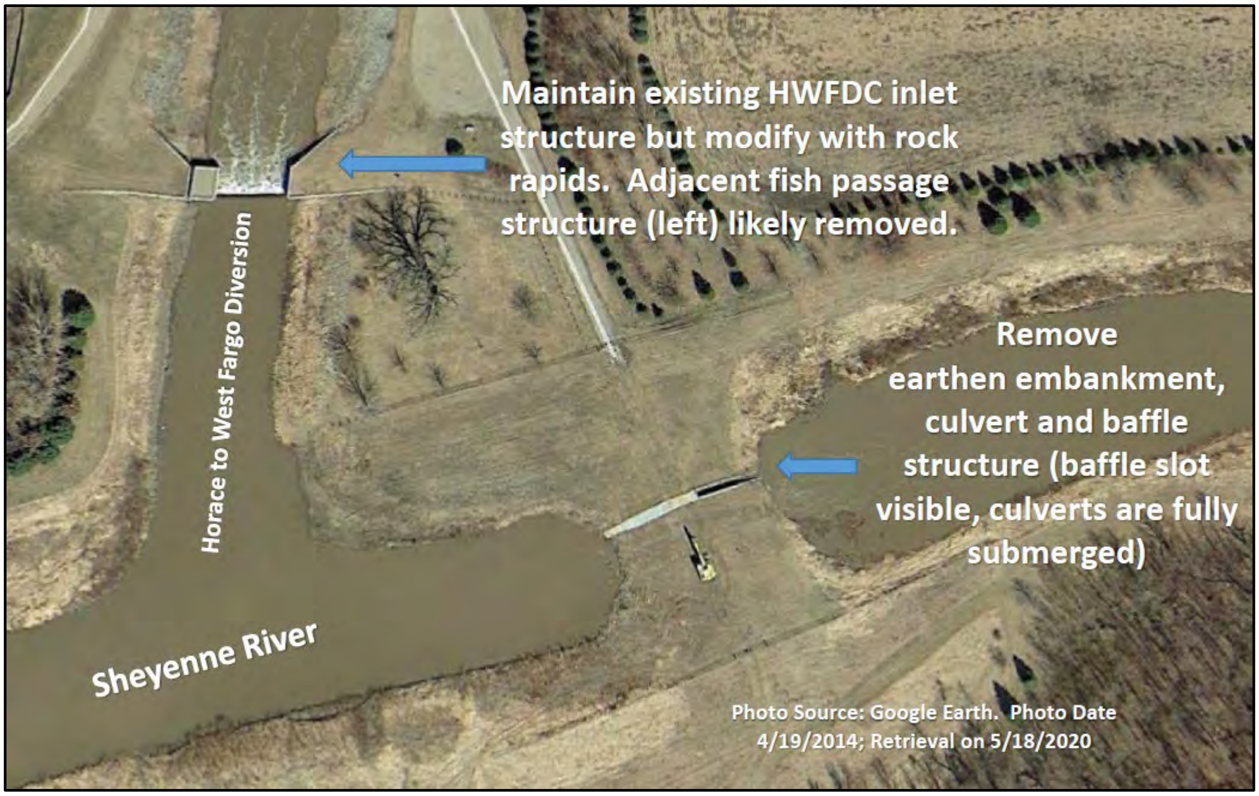

Figure 2. Overview of Sheyenne River connectivity improvements near Horace, ND.

Figure 3. Overview of Sheyenne River connectivity improvements near I-94 in West Fargo, ND.

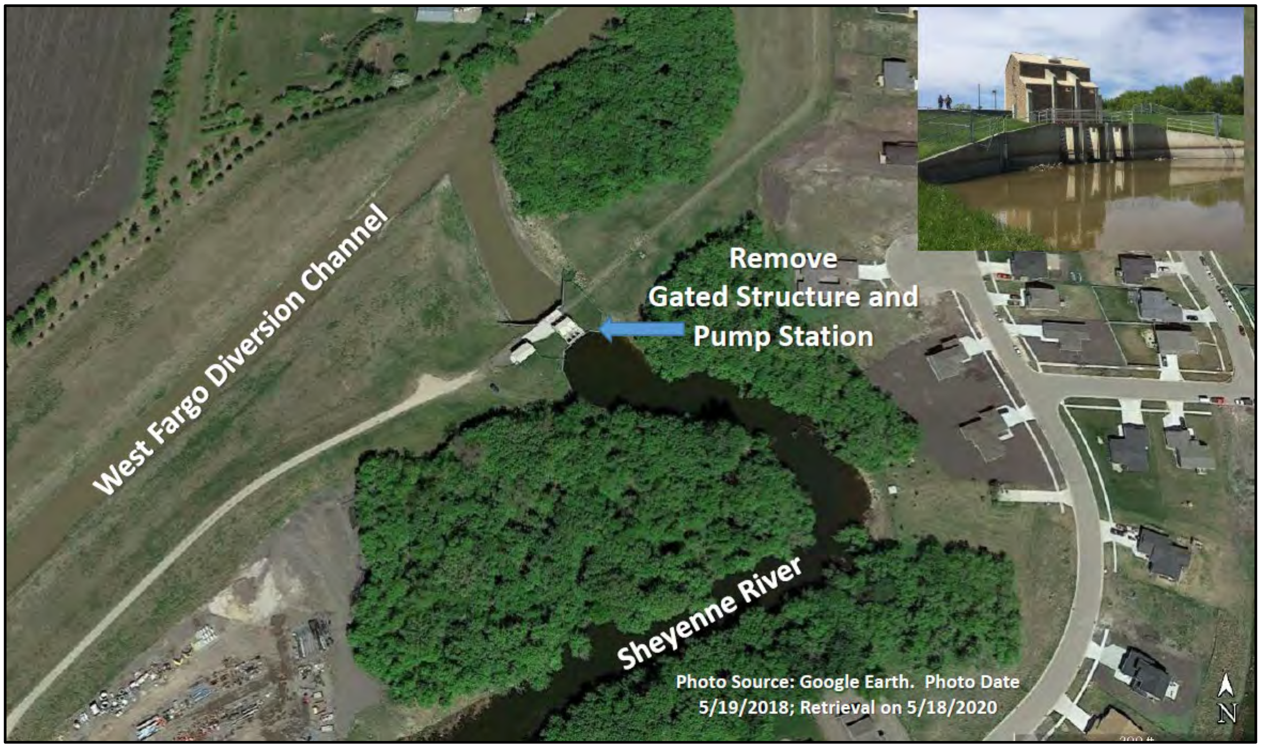

Figure 4. Overview of Sheyenne River connectivity improvements near 12th Avenue in West Fargo, ND.

Figure 5. Location of low head dam for fish passage considerations on the Sheyenne River in West Fargo, ND.

Overview and Proposed Action for Sheyenne Oxbow Restoration

The Sheyenne River oxbow in question is adjacent to County Road 17 between West Fargo and Horace, North Dakota (Figure 6). The proposed restoration would be to excavate both oxbow ends to reconnect the oxbow, and potentially excavate oxbow depth to maintain needed conveyance. Consideration would be given to whether erosion or stability protection is needed for the adjacent County Road 17, or adjacent properties. The Sheyenne River would be “plugged” with an overflow weir to direct flow into the oxbow. The plug may be at a low enough elevation where flood flows may also move through the reach to be abandoned.

Figure 6. Overview of propose oxbow restoration on the Sheyenne River near Horace, ND. Photo source: GoogleEarth May 14, 2020 (Imagery Date 5/19/2018).

Project Benefits

"The Sheyenne River is one of the most biologically diverse rivers in North Dakota and is the 4th longest river in the state, meandering approximately 600 miles. Fifty-three fish species and 12 mussel species occur within the Sheyenne River watershed (DeLorme 2011; Delorme et al. 2019; Peterka 1978; as cited in USFWS 2018). Many of these fish species are known to be migratory, including walleye, sauger, channel catfish, and several redhorse species. The Sheyenne River is listed as a Class 1 River, meaning it is classified as a highest-valued fishery resource in North Dakota (USGS 1978, as cited in USFWS 2018). Currently the lower Sheyenne River is almost impassable. The reconnection efforts described above would reconnect over 100 miles of Sheyenne River habitat (USFWS 2018). This would extend from the Red River to the next most upstream low-head dam, which is the upstream of Horace, ND. The Sheyenne River is the largest Red River tributary in North Dakota, so this reconnection would provide a substantial improvement for fishery resources in the Sheyenne River, as well as Red River fishes that use the Sheyenne River for seasonal needs.

Connectivity would be achieved through fish movement both in the Sheyenne River Channel, as well as potential fish movement through the required, adjacent HWFDC and WFDC. The attached flow analysis provides context to how frequently river discharge will meet thresholds where flows would be passed down through the HWFDC and WFDC. Regardless of river discharge, the mitigation will strive to promote connectivity across almost all river flows.

The oxbow restoration would restore about three acres (1,750 lineal feet) of Sheyenne River previously abandoned. This would provide some habitat of the same type lost due to the project.

Mitigation Credit

Use of fish passage/connectivity as a mitigation strategy for direct loss of aquatic habitat presents a unique challenge of accounting. It's difficult to gage how the level of functional improvement directly compares to lost physical habitat space. While some ecological models and other tools are beginning to explore these possibilities, the reality is that it remains difficult to directly compare how much functional improvement offsets a loss of river habitat.

Note that USACE policy directs the Corps to offset significant habitat losses to the fullest extent practicable, while trying to avoid or minimize both over- and under-mitigating for a significant effect. Corps policy recommends the use of habitat models for such quantification, with adaptive management and monitoring to help ensure mitigation is working. Such quantification would be difficult in this case. Yet the need remains for the Corps to be able to document when mitigation has been fulfilled.

This issue has been discussed with the State of North Dakota, including the Department of Game and Fish, Department of Environmental Quality, as well as the State Water Commission. This group mutually agreed that implementation of the project features outlined above (both fish passage and oxbow restoration), in concert with other benefits that will be obtained from the Drayton Dam Fish Passage Project (which will also be implemented as a part of project mitigation activities) would adequately offset the loss of aquatic habitat within the State of North Dakota. This include the loss of habitat associated with the Red River Structure, Wild Rice River Structure, Sheyenne River aqueduct, and Maple

River aqueduct. This loss is approximately 32 to 33 acres, but could vary slightly as the design efforts progress.

Documentation Process

USACE policy requires measurements to demonstrate, to the extent practical, that habitat losses have been fully mitigated. That cannot be realistically done in this instance at this time. In lieu of this, USACE proposes an agreement with the natural resource agencies in North Dakota that the proposed Sheyenne River mitigation project adequately offsets the losses of aquatic habitat.

USACE will transmit to the Department of Game and Fish, and Department of Environmental Quality, a letter with this white paper outlining the Sheyenne River mitigation efforts, and request concurrence from each agency that the project fulfills the mitigation need for lost aquatic habitat in the State of North Dakota. This coordination is not a legally binding agreement, but an agreement of understanding that this specific mitigation need in North Dakota has been fulfilled. USACE can then use this coordination to document completion of this mitigation need, and provide for vertical reporting within our agency should concerns arise over adequate levels of mitigation for this impact.

Environmental Compliance

The proposed mitigation actions discussed herein would undergo its own environmental compliance review. This would include public review pursuant to the National Environmental Policy Act, as well as considerations for Clean Water Act, Endangered Species Act, National Historic Preservation Act and other statutes. The action would consider needs for CWA 404 and 401 Water Quality Certification, and necessary permits from the North Dakota State Water Commission.

Sheyenne River above the Sheyenne Diversion near Horace, ND

Flow Duration Curve Update

September 2020

Addendum No. 1

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1 Monthly Flow Duration

This addendum was added to the *Sheyenne River above the Sheyenne Diversion near Horace, ND Flow Duration Curve Update* report in response to a request from the FMM project team for monthly flow duration information at the Sheyenne River above the Sheyenne Diversion near Horace, ND gage. Specifically, the project team requested the approximate percent time of exceedance for two discharges, 1,100 cfs and 650 cfs, for each month of the year. These two discharges correspond to the threshold at which flow begins to enter the Horace to West Fargo Diversion Channel and the West Fargo Diversion Channel, respectively. This information is presented in Table 1 for 1992-2020 and 1952-2020, the two time periods analyzed for the flow duration curve update.

Table 1. Monthly percent time of exceedance for 1,100 cfs and 650 cfs, Sheyenne River above the Sheyenne Diversion Channel near Horace, ND

Month	Approximate % Time of Exceedance			
	1992-2020		1952-2020	
	1,100 cfs	650 cfs	1,100 cfs	650 cfs
January	< 0.1	< 0.1	< 0.1	< 0.1
February	0.5	1.6	0.3	0.8
March	12	23	8	15
April	50	66	33	45
May	39	64	20	35
June	25	55	11	25
July	17	45	8	22
August	7	26	3	11
September	3	23	1	8
October	4	24	2	10
November	2	14	1	6
December	< 0.1	1	< 0.1	0.5

Figure 1 through Figure 12 display the flow duration curve for each month for the periods 1992-2020 and 1952-2020. For all plots, the y-axis was limited to a maximum of 1,500 cfs to highlight the range of discharges of greatest concern to the project team. For all months, the curve computed for the period 1992-2020 plots above the curve computed for the period 1952-2020. This is due to a relatively wet period occurring over the last 30 years as well as the effects of pumping from Devils Lake, which has been occurring since 2005.

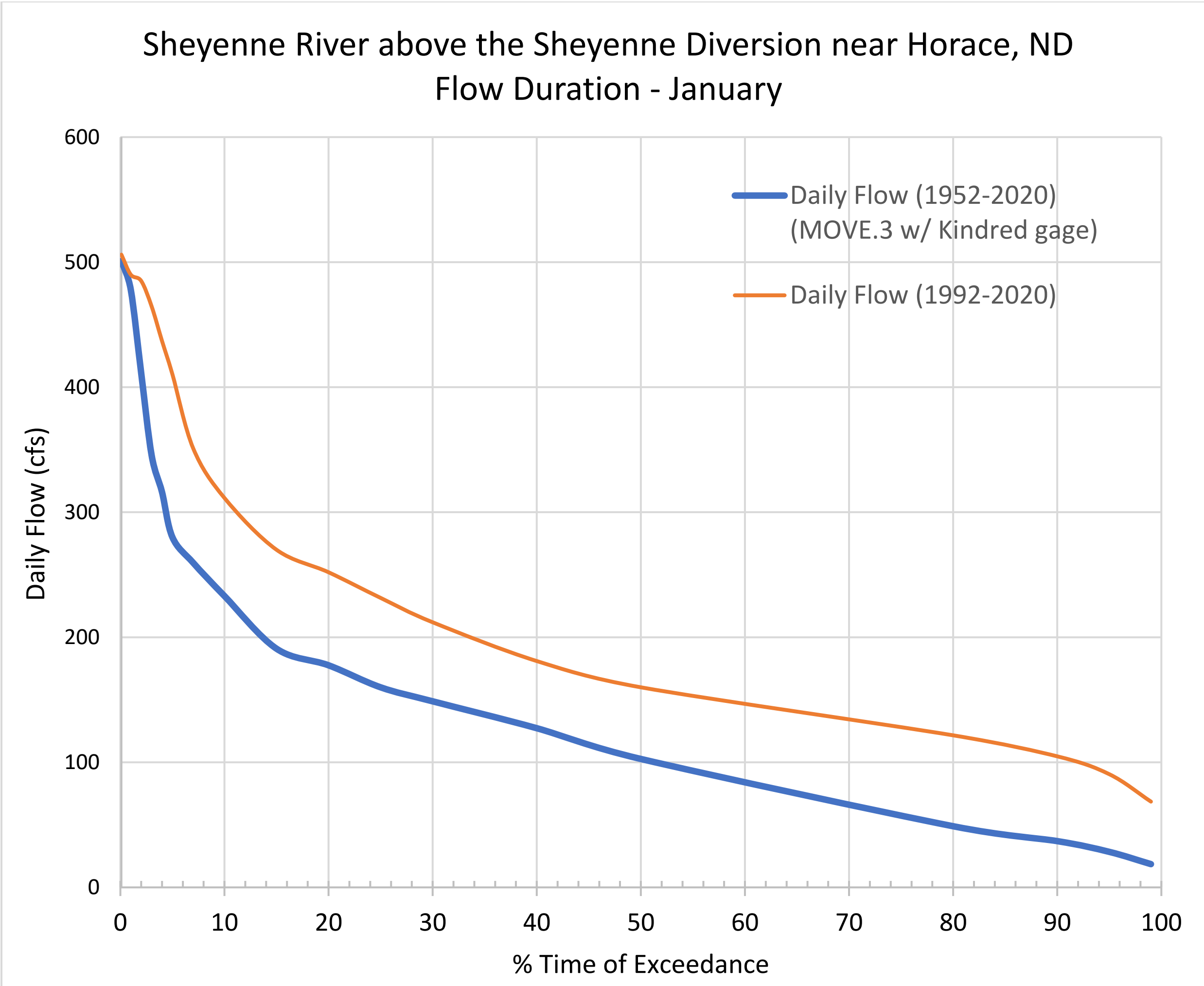


Figure 1. January flow duration curve, Sheyenne River above the Sheyenne Diversion near Horace, ND

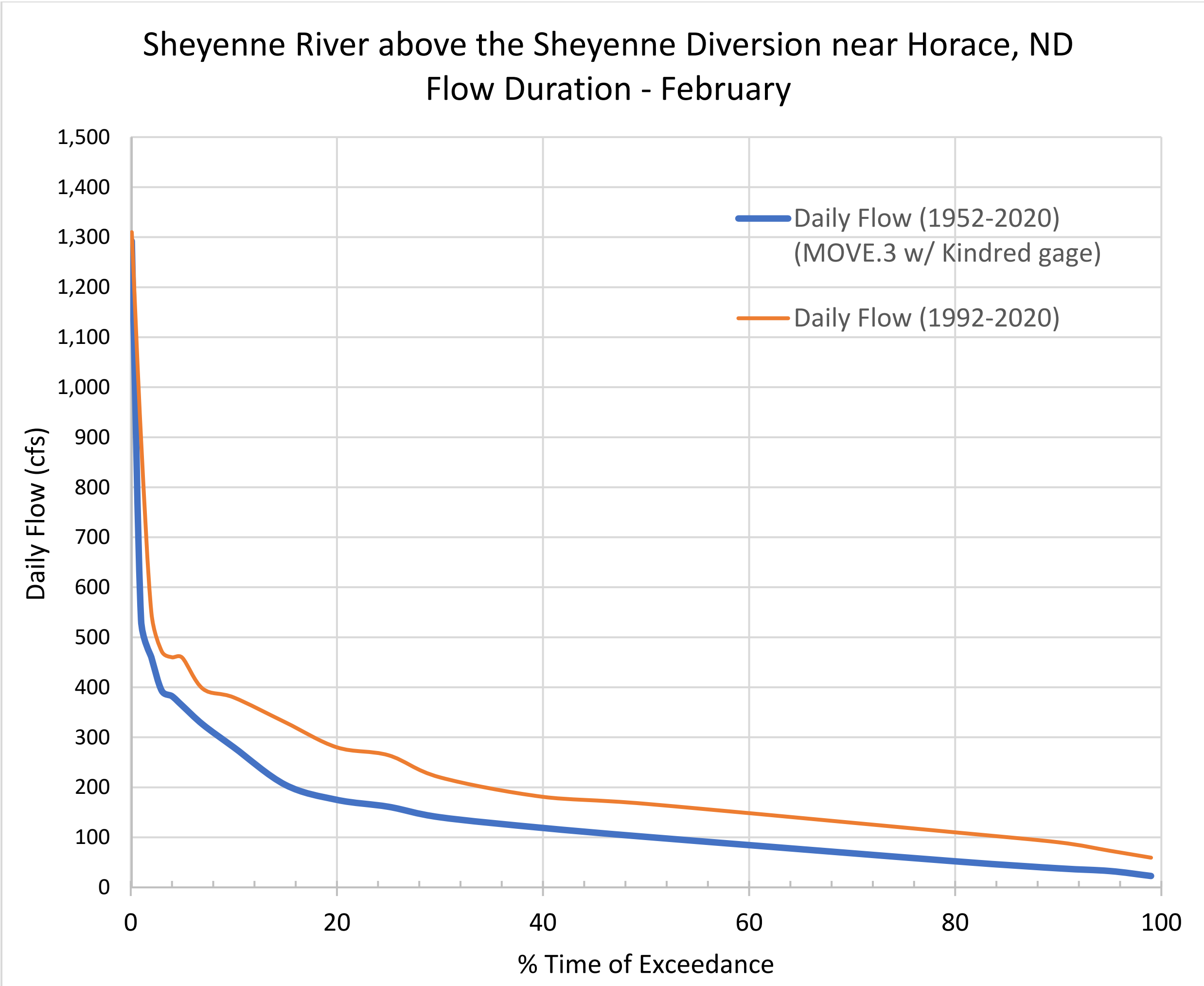


Figure 2. February flow duration curve, Sheyenne River above the Sheyenne Diversion near Horace, ND

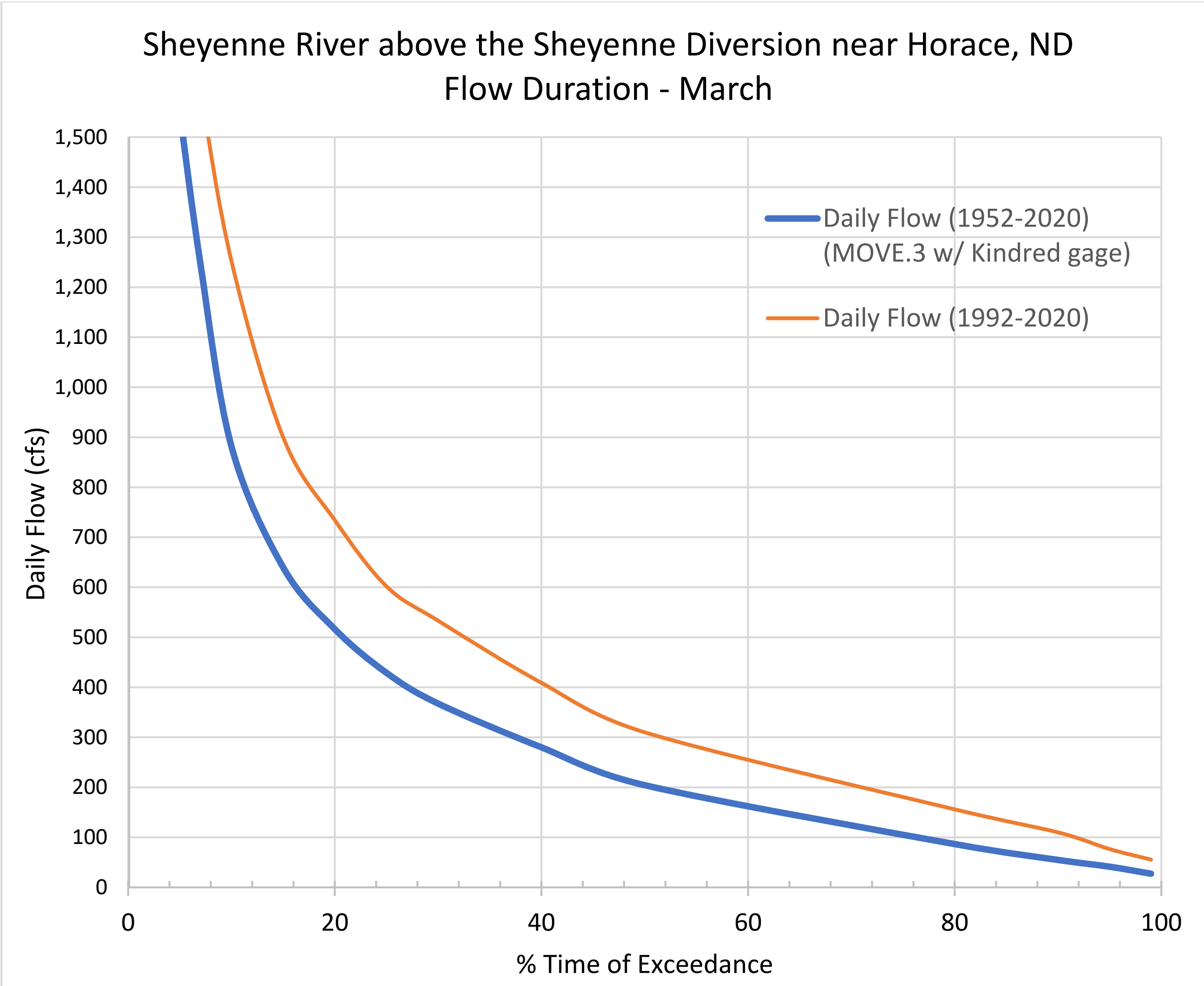


Figure 3. March flow duration curve, Sheyenne River above the Sheyenne Diversion near Horace, ND

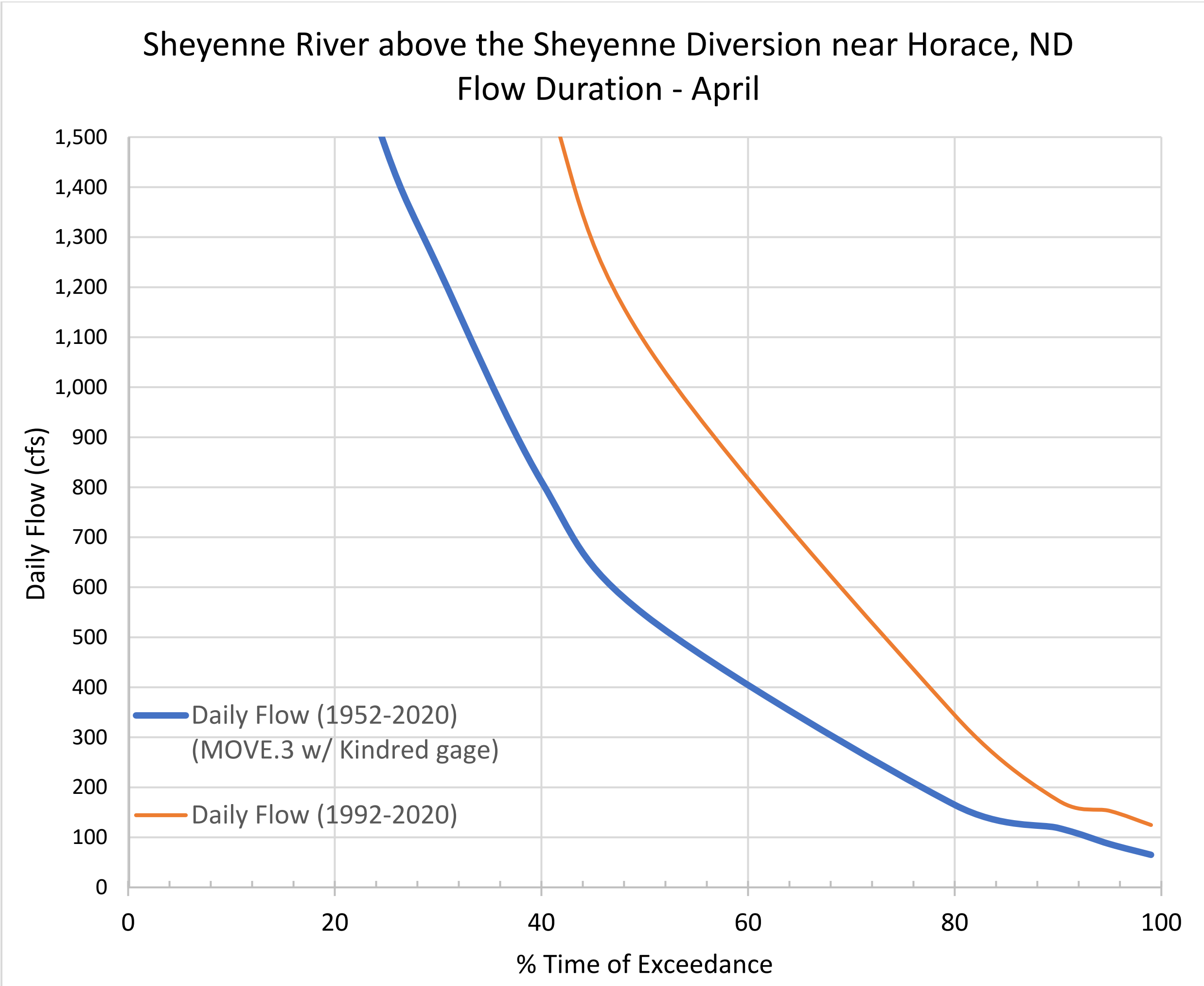


Figure 4. April flow duration curve, Sheyenne River above the Sheyenne Diversion near Horace, ND

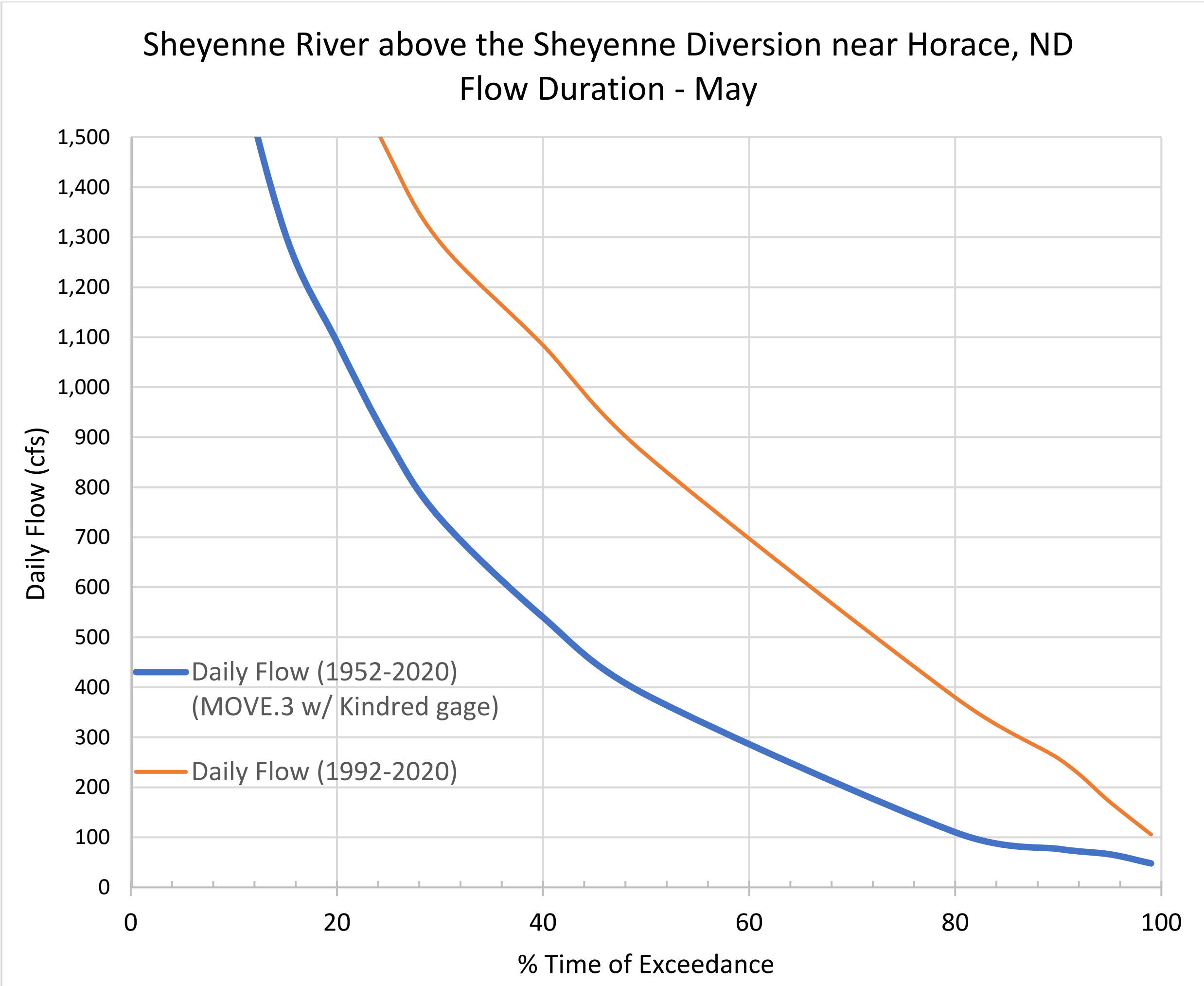


Figure 5. May flow duration curve, Sheyenne River above the Sheyenne Diversion near Horace, ND

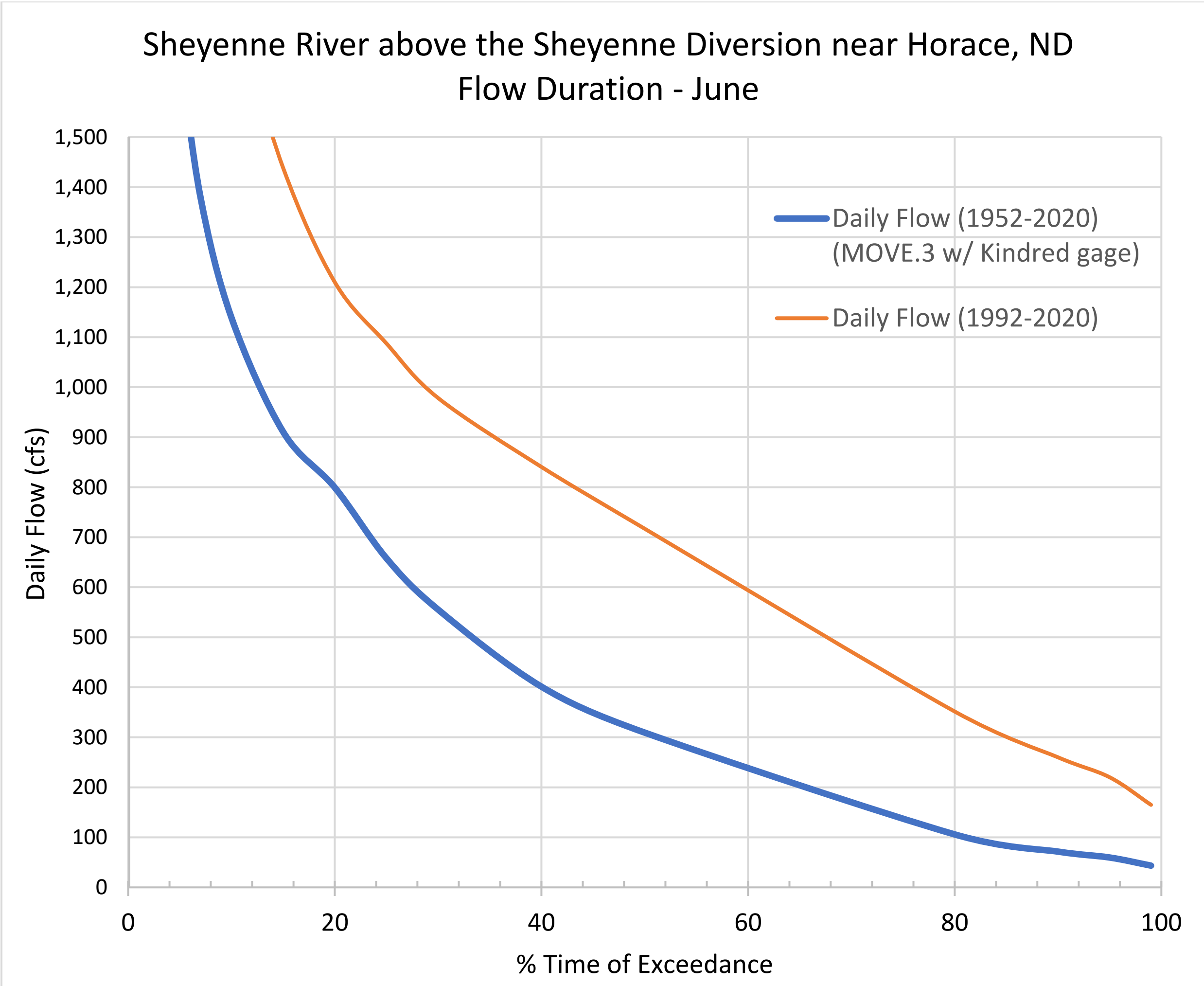


Figure 6. June flow duration curve, Sheyenne River above the Sheyenne Diversion near Horace, ND

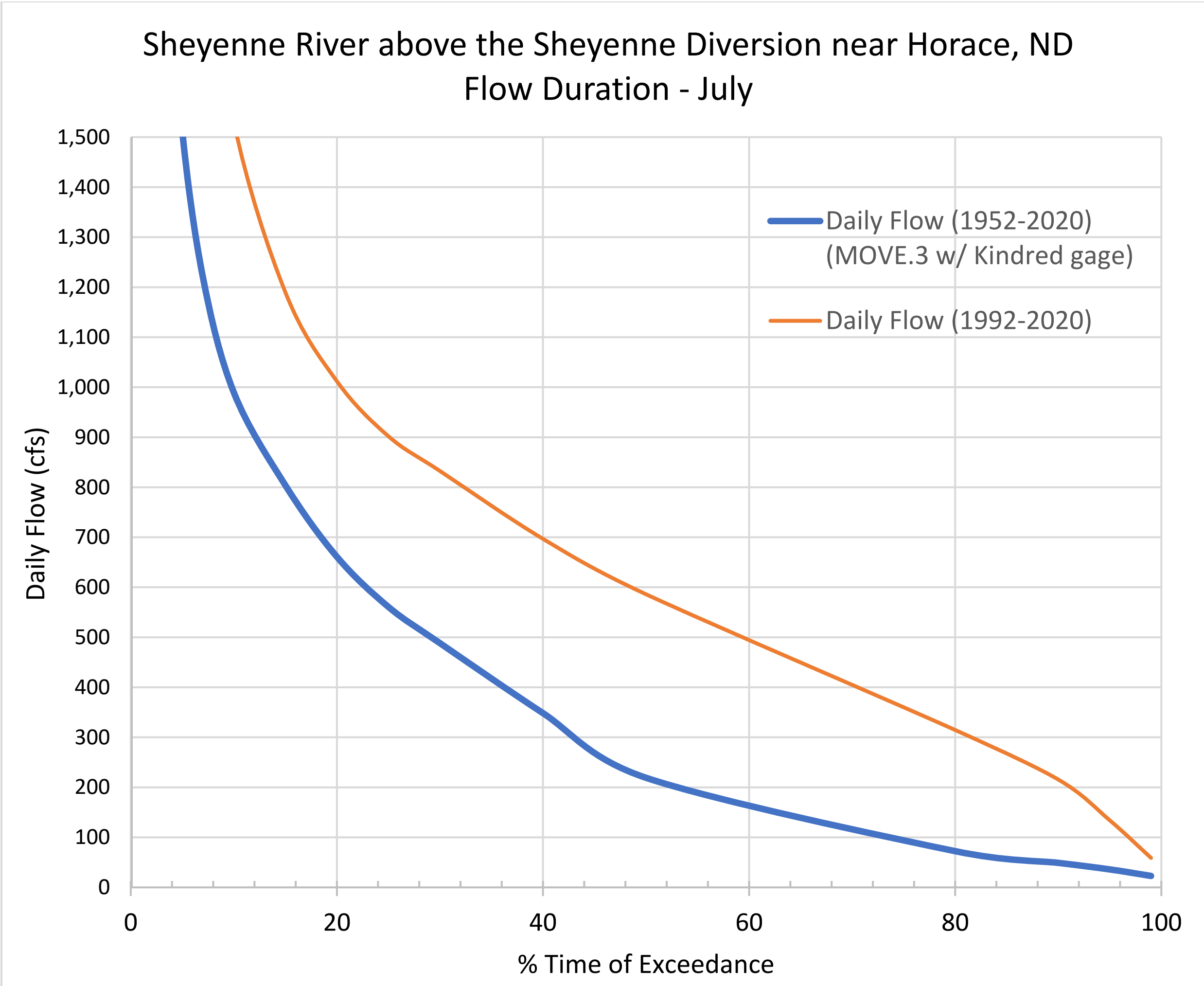


Figure 7. July flow duration curve, Sheyenne River above the Sheyenne Diversion near Horace, ND

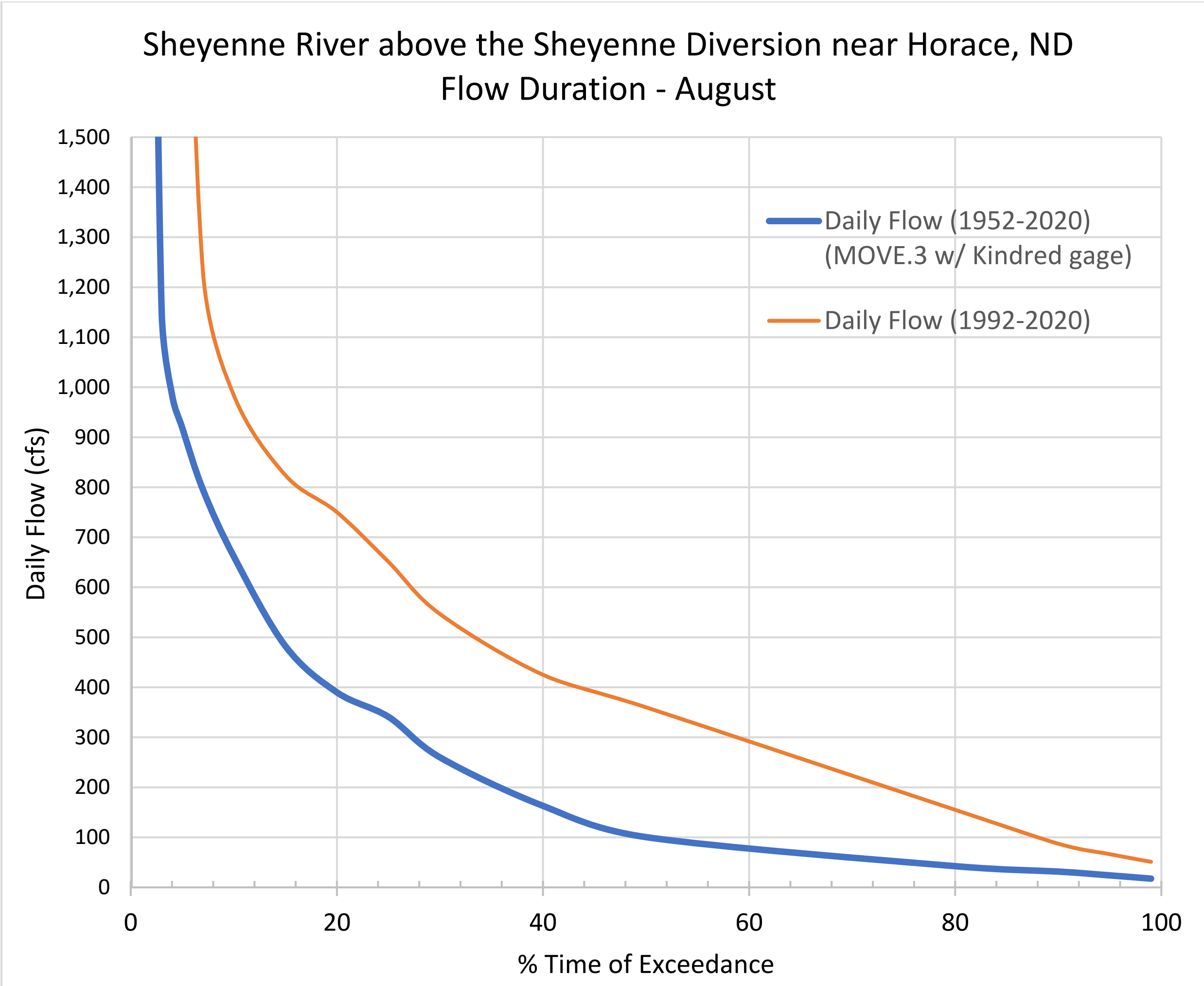


Figure 8. August flow duration curve, Sheyenne River above the Sheyenne Diversion near Horace, ND

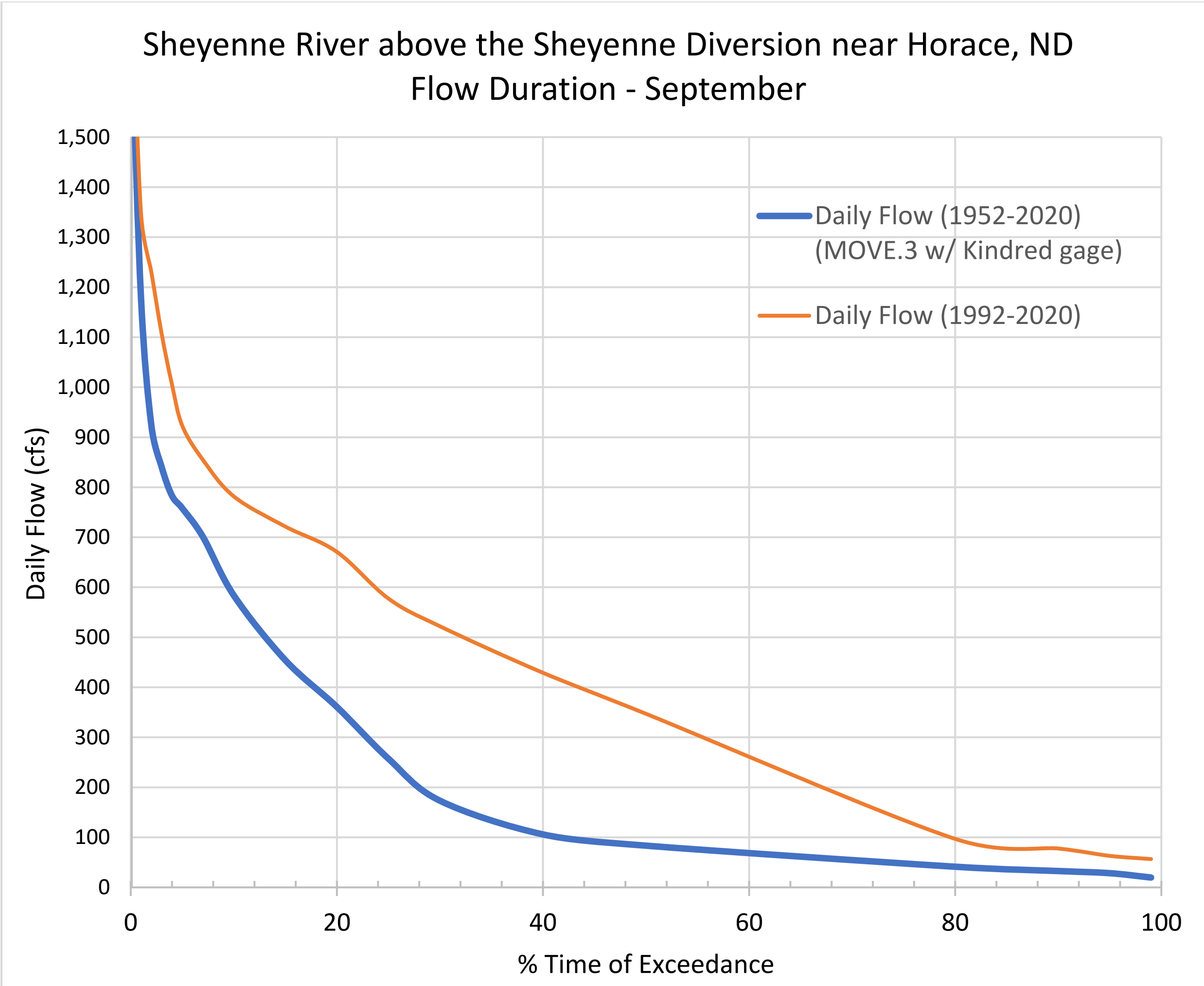


Figure 9. September flow duration curve, Sheyenne River above the Sheyenne Diversion near Horace, ND

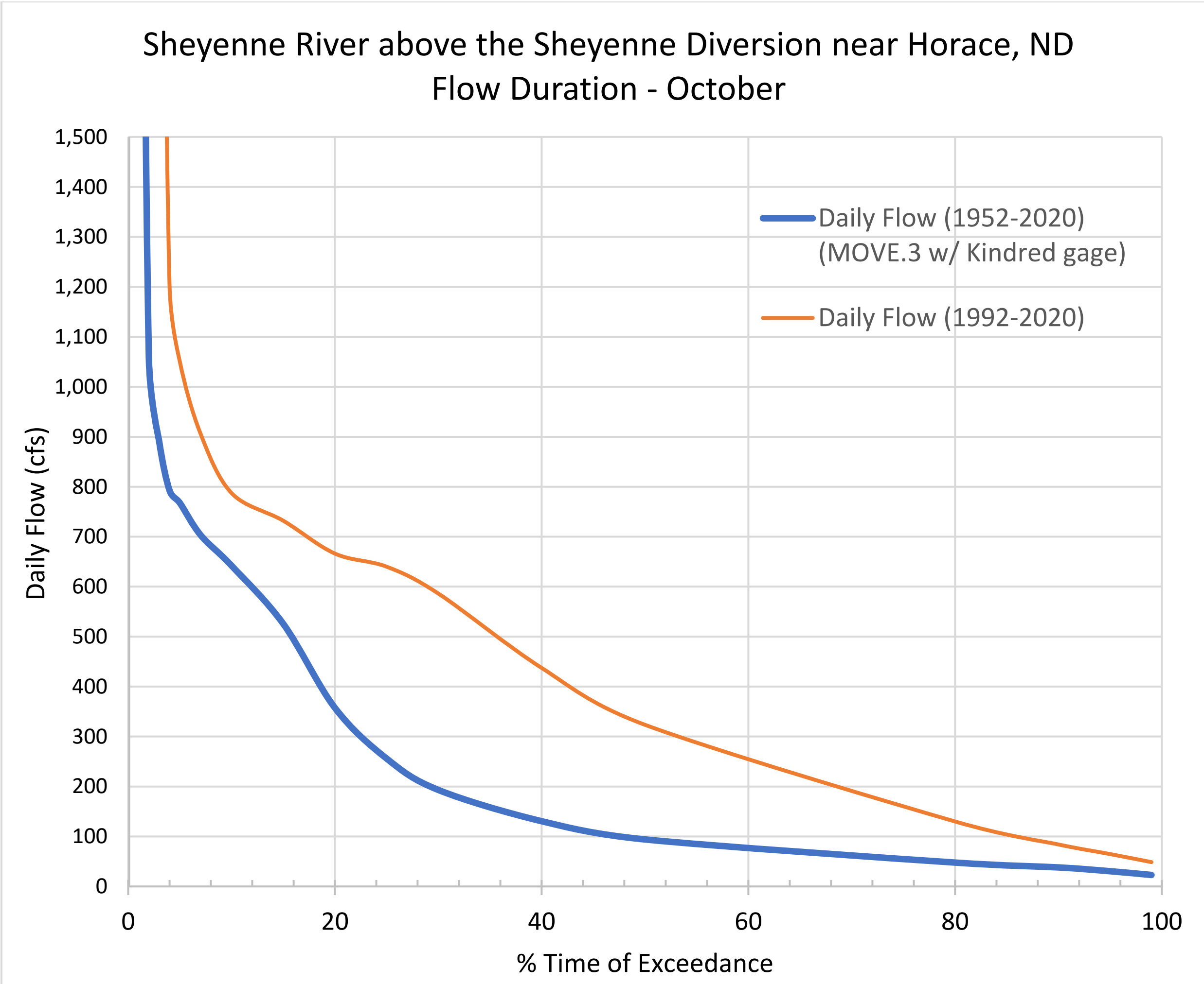


Figure 10. October flow duration curve, Sheyenne River above the Sheyenne Diversion near Horace, ND

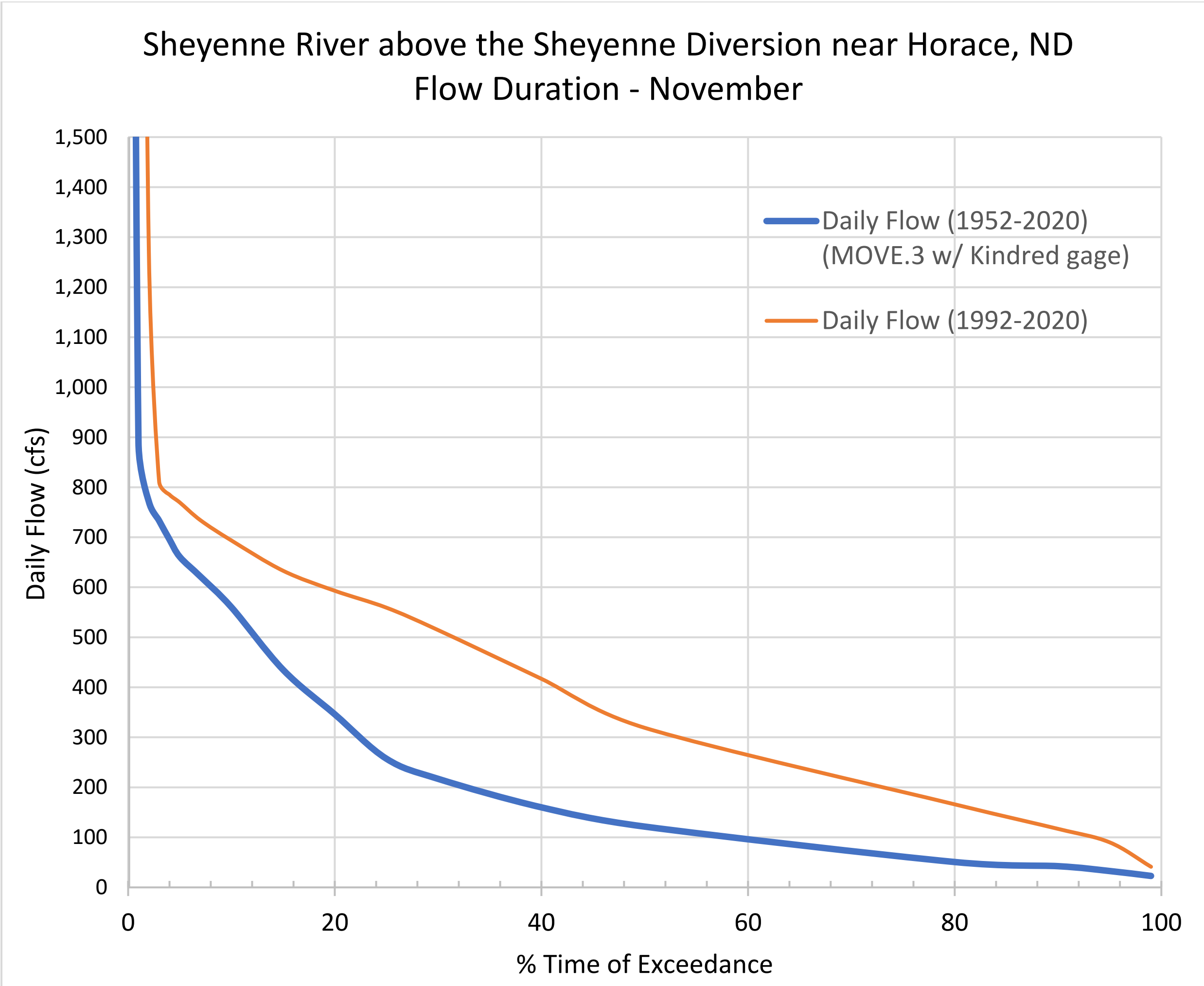


Figure 11. November flow duration curve, Sheyenne River above the Sheyenne Diversion near Horace, ND

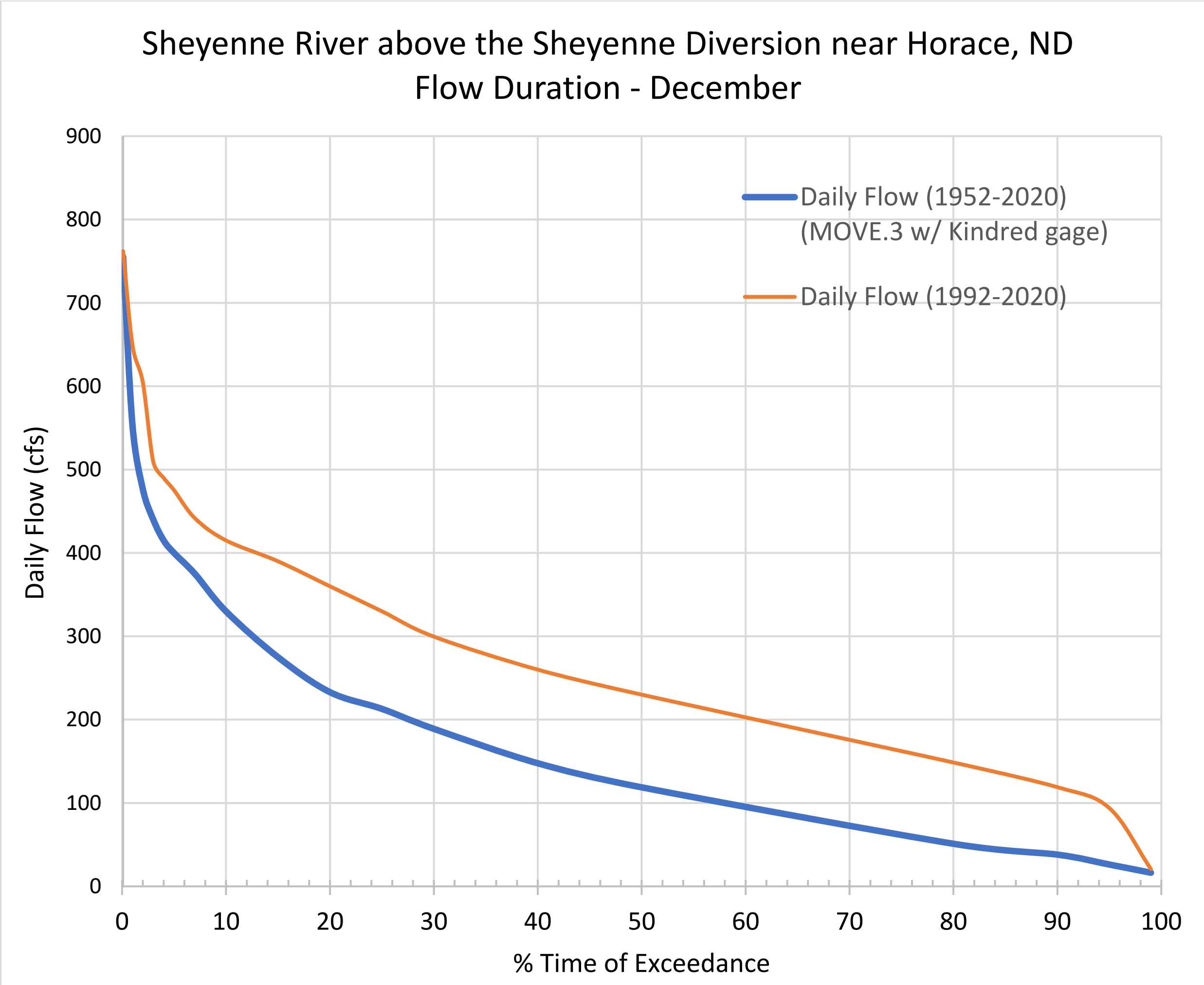


Figure 12. December flow duration curve, Sheyenne River above the Sheyenne Diversion near Horace, ND

Devils Lake Pumping

Purpose

The Sheyenne River mitigation project is one of the primary mitigation measures used to offset environmental impacts resulting from the construction of the Fargo-Moorhead Metropolitan Area Flood Risk Management Project. Understanding Sheyenne River flows is important for understanding how frequently different components of the Sheyenne River mitigation project convey water. It is hypothesized that Devils Lake pumping has increased Sheyenne River flows. Therefore, an investigation was conducted to better understand Devils Lake pumping and determine if the pumping increased flows along the Sheyenne River in the vicinity of the Sheyenne River mitigation project. Findings from the investigation are summarized in this document in response to specific questions. Findings from the investigation should not be used to associate Devils Lake pumping more broadly with any other changes in the Sheyenne River basin without further assessment.

Questions

1. When did pumping from Devils Lake begin?
2. How are the pump stations operated?
3. Is pumping from Devils Lake currently happening?
4. How much water is pumped from Devils Lake?
5. When is pumping from Devils Lake likely to end?
6. Does pumping from Devils Lake significantly impact flows on the Sheyenne River above the Sheyenne Diversion near Horace, ND?

Answers

1. There are two pump stations pumping water from Devils Lake to the Sheyenne River, the West End Outlet and the East End Outlet. The West End Outlet began operating in 2005, and the East End Outlet began operating in 2012. Initially, the maximum discharge capacity of the West End Outlet was 100 cfs, and the pump station was operated intermittently. However, in 2010, the discharge capacity was increased to 250 cfs. The East End Outlet has a discharge capacity of 350 cfs. A map displaying the location of each outlet and other important locations along the Sheyenne River is shown in Figure 1.

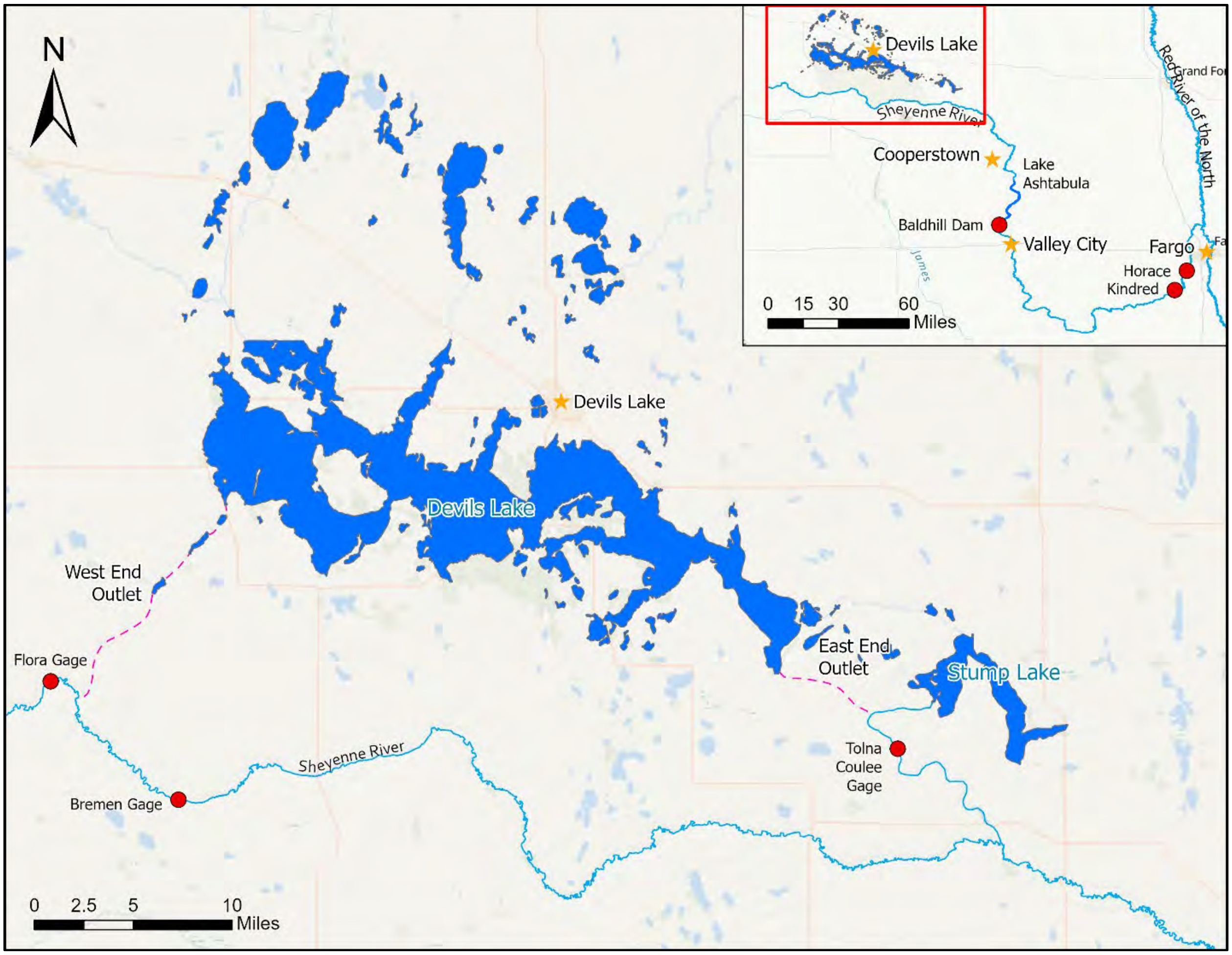


Figure 1. Map of Devils Lake outlets and Sheyenne River

2. Both pump stations are operated to limit flood damages and maintain water quality standards. According to the *Devils Lake Outlet Operational Guide* (North Dakota State Water Commission, 2020), the pumps do not operate when downstream flood gages are above flood stage. USGS gages in the Devils Lake and Sheyenne River basins are monitored and outlet discharge is adjusted to prevent flooding to the greatest extent possible. Based on past operation it has been determined that flooding begins to occur along the Sheyenne River near Cooperstown at flow above approximately 800 cfs. Twenty sites ranging from above the West End Outlet insertion point to the Red River at Pembina are regularly sampled and outlet discharge is adjusted to prevent exceedances of the water quality standards.

   Decisions regarding how the pumps are operated are made by the Governor of North Dakota and the North Dakota State Water Commission (SWC). To inform the operational decisions, the Devils Lake Outlet Management Advisory Committee was formed. Each spring, the 17-member committee meets to review the lake rise probability forecast and develop a recommendation that dictates how the pump stations will be managed for the rest of the year. Day-to-day operations are managed by the NDSWC.

The two pumps are operated simultaneously to balance downstream water quality and quantity. The pumps only operate after spring runoff has passed so as not to contribute to spring flooding. The outlets are typically operated continuously throughout the warm weather months unless large rainfall events occur, or they need to be shut down for maintenance. In the fall, the pumps are winterized after ambient air temperatures fall below 32 degrees F for an extended period. The West End Outlet was designed to operate for a minimum Devils Lake Level of 1445 feet and the East End Outlet was designed for a minimum lake elevation of 1446 feet. Since 2016, the target lake elevation for Devils Lake has been 1448 feet.

3. Pumping from Devils Lake is ongoing. Discharge records indicate the pumps are typically operated April through November, and pumping has occurred every year the structures have been in operation. Actual operation start and end dates are dictated based on spring runoff conditions and fall freeze-up. Pumping has only occurred consistently since 2010, and the current, maximum discharge capacity (600 cfs) was not achieved until the East End Outlet began operating in 2012. Releases from the outlets peaked in 2015 and have been decreasing since that point. The duration of pumping in 2019 was shorter than in preceding years because of high water on the Sheyenne River in late spring and early summer. Figure 2 is a plot from the *Devils Lake Outlet Operational Guide* (North Dakota State Water Commission, 2020) that shows annual pump discharge through 2019.

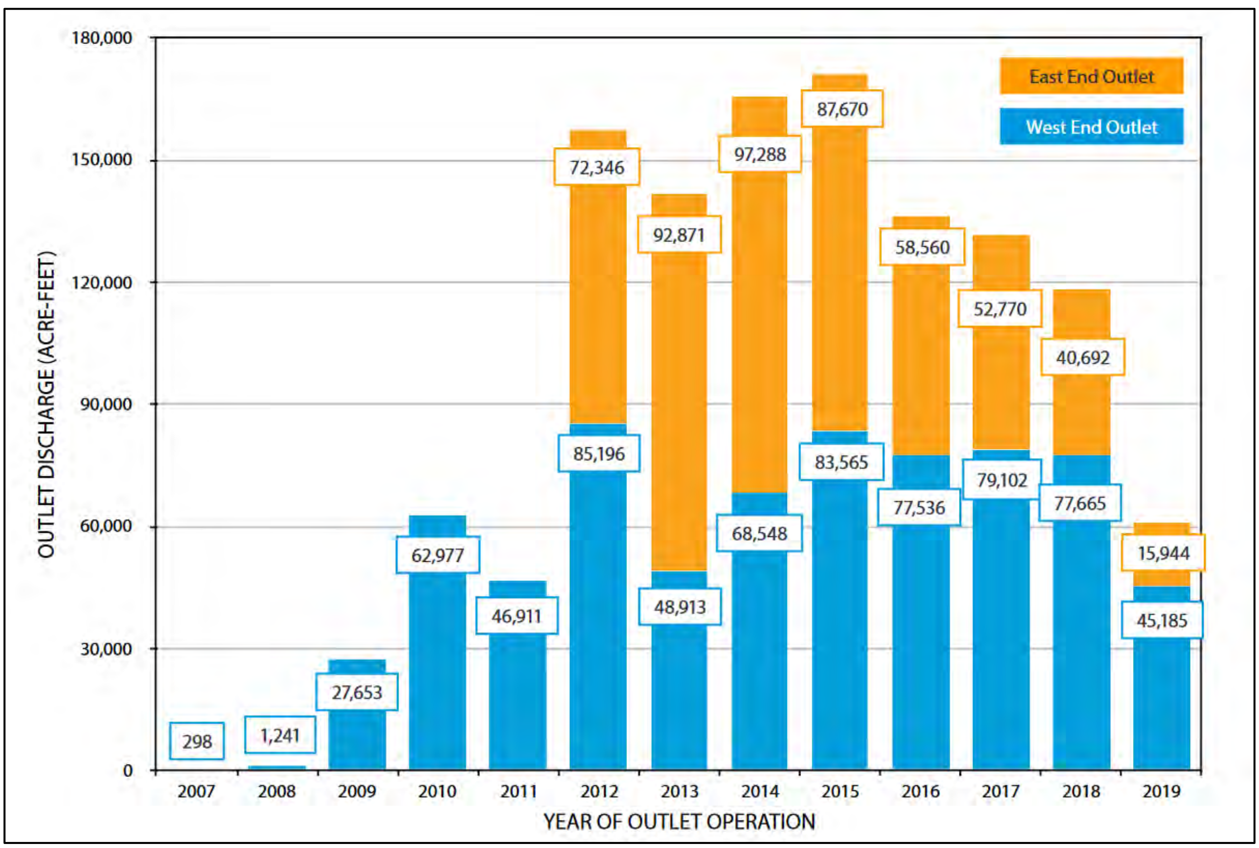


Figure 2. Annual Outlet Discharge from 2007-2019 (source: https://www.swc.nd.gov/pdfs/outlets_operations_plan.pdf)

4. Currently, the combined, maximum capacity of the West End and East End outlets is 600 cfs. Since 2012, the combined pumping rate has typically ranged from 200 cfs to 600 cfs. The discharge from both structures can be estimated using the *Estimating Outlet Discharges* fact sheet (North Dakota State Water Commission, 2017). To estimate the discharge at the West End Outlet, the discharge at the Sheyenne River above Devils Lake State Outlet near Flora, ND gage (USGS 05055300) is subtracted from the Sheyenne River below Devils Lake State Outlet near Bremen, ND gage (USGS 05055400). Negative flows, which occasionally result from this computation due to daily average flows at Flora exceeding daily average flows at Bremen, were removed in order to conduct the analysis described below. The discharge at the Tolna Coulee near Tolna, ND gage (USGS 05056678) is approximately equal to the outflows from the East End Outlet. The combined discharge from both pumping stations was estimated by advancing the West End Outlet discharges by 2 days to account for travel time to the Sheyenne River-Tolna Coulee confluence and combing the resulting flows with the East End Outlet discharges. These computation steps are shown in Figure 3. The computed discharge for each outlet, as well as the resulting, combined pumping discharge, is shown in Figure 4 for the period 2012-2020. Refer to Figure 1 for the location of each gage. Note the combined discharge occasionally exceeds the maximum pumping capacity of 600 cfs. This is due to the intervening drainage area between the gaged locations used to estimate pumped discharge, as well as small variations in routing and travel time between each gaged location.

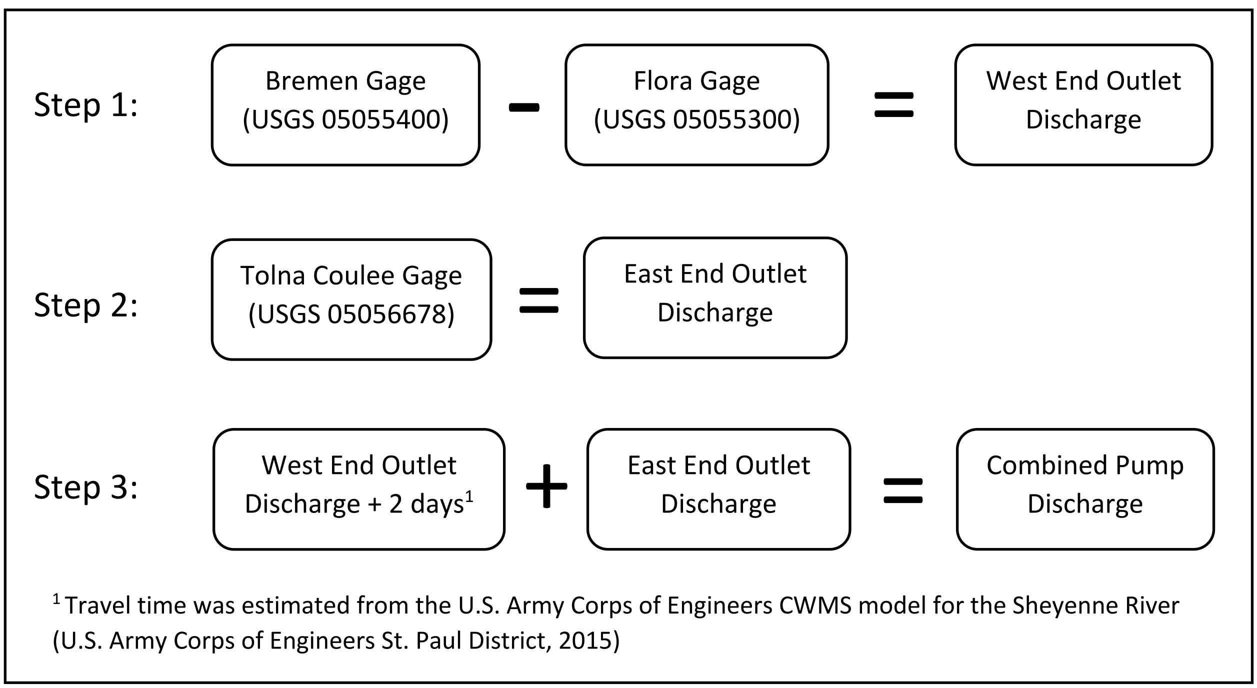
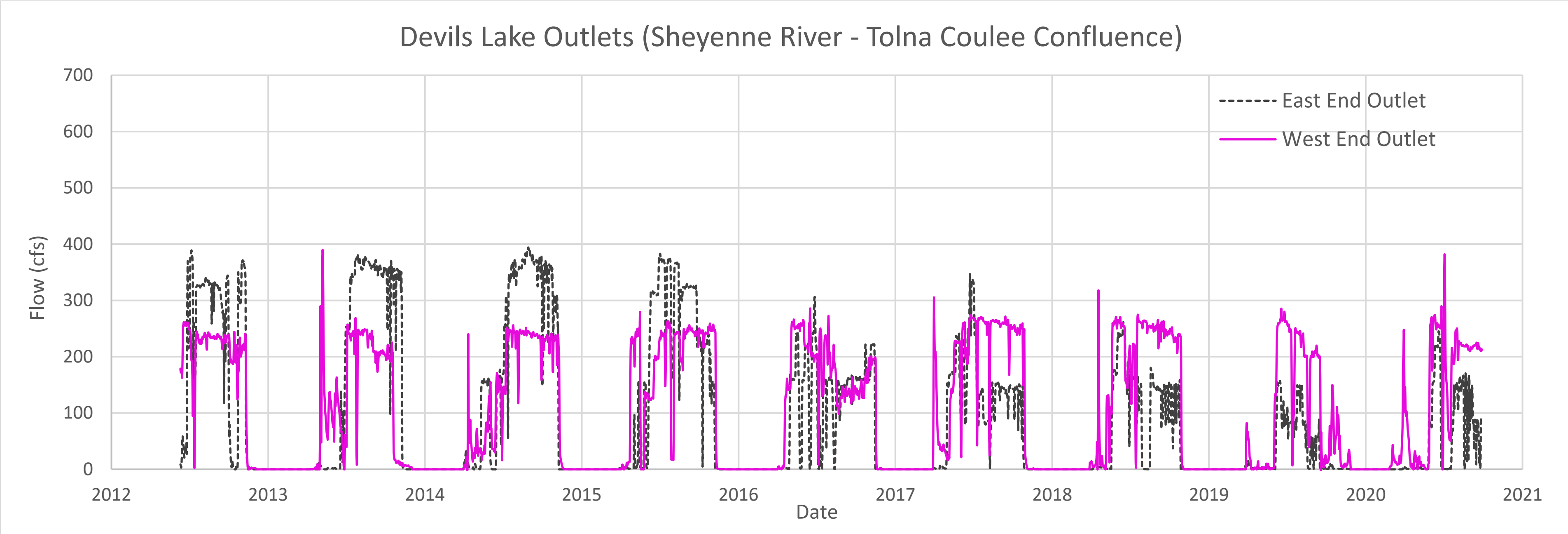


Figure 3. Computation steps to estimate combined pumping discharge from Devils Lake



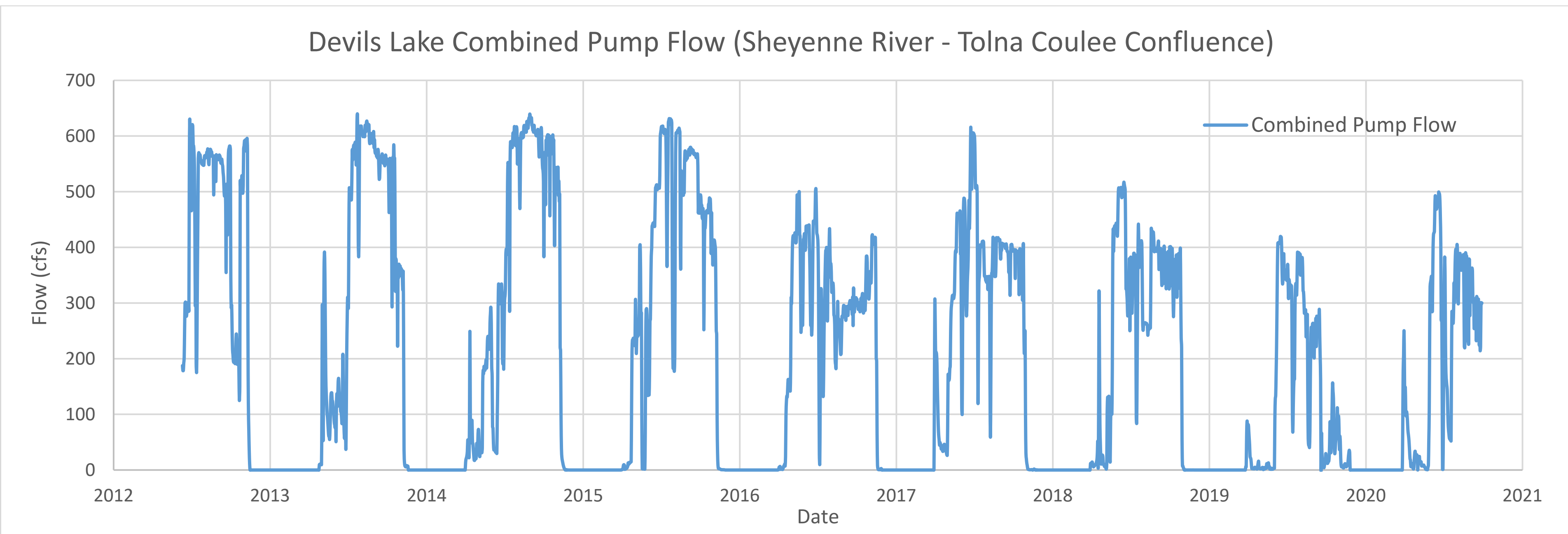


Figure 4. Discharge from the West End and East End outlets at Devils Lake, 2012-2020

5. It is not clear how long the pumping stations will operate in the future. Devils Lake reached its peak elevation of 1,454.3 ft (NGVD 29) in 2011 and has been falling since. If the lake level continues to decline, the outlets will eventually be forced to cease operation. According to the *Devils Lake Outlet Operational Guide* (North Dakota State Water Commission, 2020), there has been ongoing discussion regarding at what lake elevation pumping should cease. Higher lake elevations offer recreational benefits so some argue that pumping should be discontinued before the lake elevation falls too much further from where it is at presently. While others feel that the lake should be drawn down further to recover currently inundated agricultural land and to offer flood protection. During a full season of operation, the outlets are capable of reducing the Devils Lake water surface elevation by up to one foot. Within the past decade there have been several instances where spring runoff alone has caused the lake to rise over two feet.

   Both pump stations are designed to continue operating as necessary until the lake elevation falls below the pump station inverts (North Dakota State Water Commission, 2020). If the lake elevation continues to fall at the rate it has been falling since its peak in 2011, the pump stations will be rendered inoperable within the next 2-5 years (Figure 5). However, there is no guarantee the lake elevation will continue its downward trajectory.

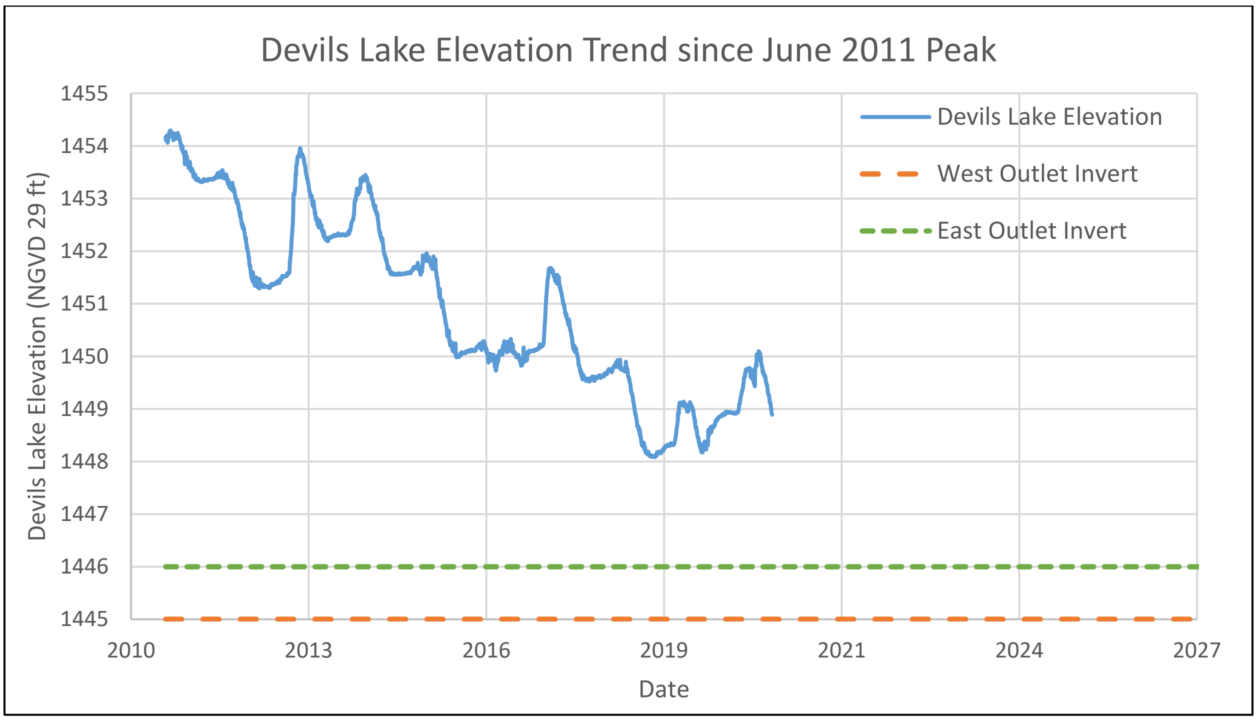


Figure 5. Devils Lake water surface elevation since peak in June 2011

6. To evaluate how discharge from the Devils Lake outlets affects flow on the Sheyenne River above the Sheyenne Diversion near Horace, ND, the approximated, daily combined pump discharge record from Devils Lake was translated downstream to Horace, ND and compared to the total daily flow record observed at Horace between 2012 and 2020 (as approximated based on the gaged record at Kindred, ND).

To assess how much attenuation and lag occurs to the pumped outflow between the pumps and Horace a routing model was used. This was accomplished by routing a 600 cfs pulse of flow (equivalent to the maximum combined pump capacity) from the West End and East End outlets downstream to Kindred, ND using the U.S. Army Corps of Engineers 2020 Corps Water Management System (CWMS) model for the Sheyenne River (U.S. Army Corps of Engineers St. Paul District, 2015). The Sheyenne River CWMS model contains Baldhill Dam which forms the impoundment of Lake Ashtabula. Observed flows at Kindred and Horace were compared to assess the lag time between the two locations.

The CWMS model is a comprehensive forecasting model that simulates a precipitation-runoff response in conjunction with reservoir operation by linking three separate models together. First, precipitation runoff throughout the Sheyenne River basin along with streamflow routing above Lake Ashtabula is modeled using the hydrologic model, HEC-HMS (version 4.2.1). Then, the pool elevation of Lake Ashtabula and releases from Baldhill Dam are modeled in the HEC-ResSim (version 3.4) reservoir model according to the physical characteristics of the dam and its water control manual. Finally, releases from Baldhill Dam are routed downstream to Kindred, ND using an HEC-RAS hydraulic model (version 5.0.7). The CWMS interface and a schematic of each associated model is shown in Figure 6.

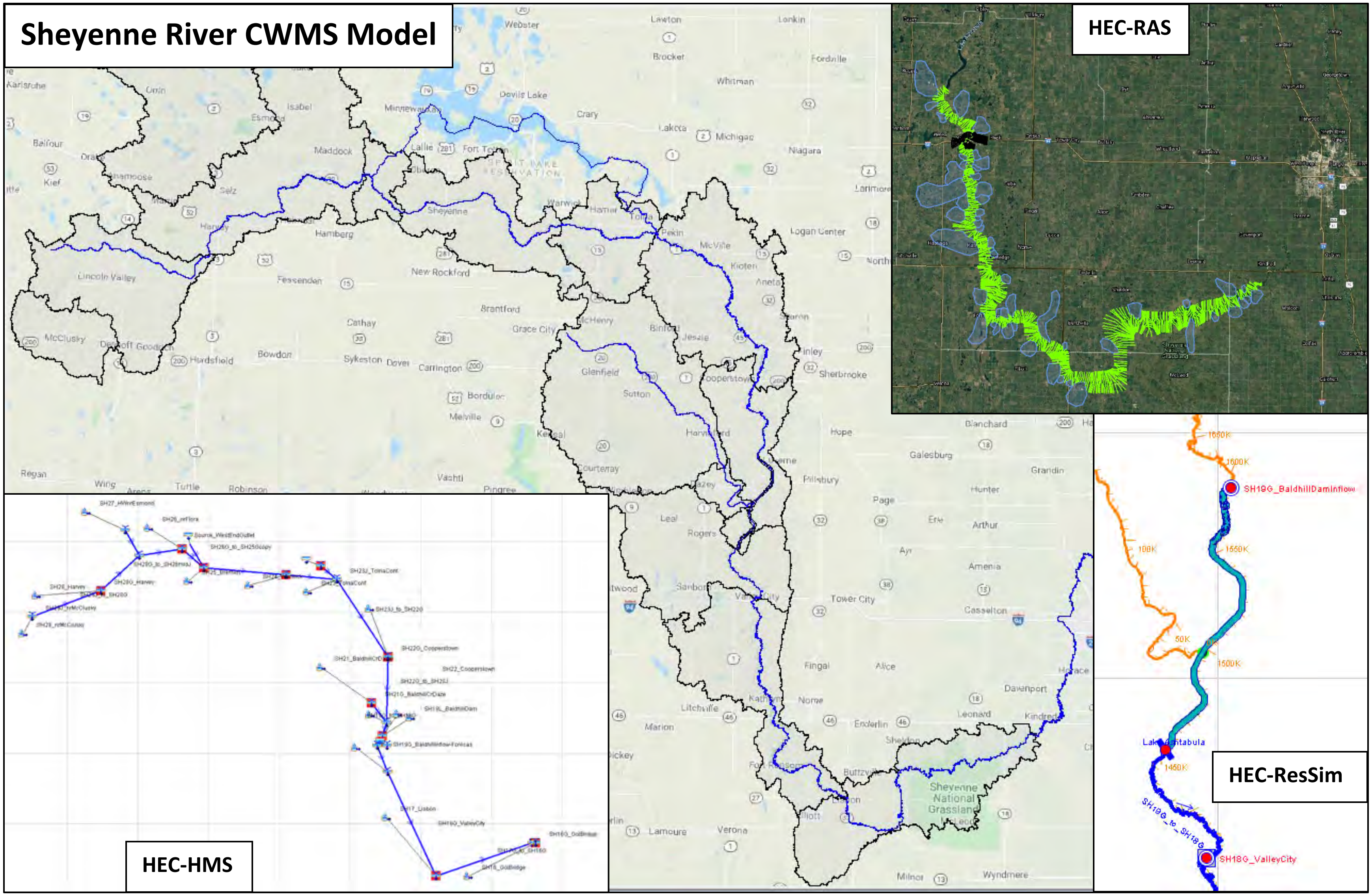


Figure 6. CWMS model interface and associated rainfall-runoff (HEC-HMS), reservoir operation (HEC-ResSim) and hydraulic models (HEC-RAS)

According to the Baldhill Dam Water Control Manual (U.S. Army Corps of Engineers St. Paul District, 2013), Lake Ashtabula is drawn down over the winter months (beginning on the first of October) to provide flood storage for spring snowmelt runoff. The normal drawdown schedule for Lake Ashtabula is displayed in Table 1. The pool must be drawn down to elevation 1262.5 feet by March 1^{st}. If conditions in the basin indicate there is more than 1.0 inch of snow-water-equivalent (SWE) additional drawdown may be required during the month of March. During the summer months, Baldhill Dam is operated to maintain a constant pool elevation of 1266 feet +/- 0.2 feet (NGVD 29).

Table 1. Normal Drawdown Schedule (Table 7-9 From the Water Control Manual)

Normal Pool Drawdown Schedule		
Month	**Storage Volume (acre-feet)**	**Pool Elevation (feet NGVD 29)**
1 October	70,600	1266.0
1 November	66,680	1265.3
1 December	62,800	1264.6
1 January	59,000	1263.9
1 February	55,500	1263.2
1 March	52,250	1262.5

Although the water control manual specifies that drawdown prior to spring runoff should be maintained until 31 March, the water control manual does not indicate when operators should allow the pool to climb back to the normal conservation elevation of 1266 +/- 0.2 feet (NGVD29). Based on an assessment of historic water surface elevation records it was determined that on average Lake Ashtabula reaches its summer conservation pool by mid-April (Valley City Feasibility Study 2012). Since normal pool is maintained at Lake Ashtabula between April and October, it is reasonable to assume that inflow is equivalent to outflow during these months unless flood operations have been initiated. As noted previously (see 3), the Devils Lake pumps are typically operated from April (post spring snowmelt) through November unless flooding occurs.

To route the 600 cfs pulse from the pumps downstream using the CWMS model, all discharge from Devils Lake via the pumps was assumed to pass through Lake Ashtabula (600 cfs inflow to the reservoir = 600 cfs outflow from the reservoir). This is consistent with how both the pumps and Baldhill Dam have been operated historically during non-flood conditions in the summer months (mid-April through September). According to the simulation results, the combined pumped discharge from Devils Lake (as measured at the Sheyenne River-Tolna Coulee confluence) reaches Kindred, ND in approximately 14 days, and attenuation reduces the magnitude of flow by approximately 25%. A plot of the simulation results is shown in Figure 7. Note the outflow from Lake Ashtabula is slightly lower than the inflow to the reservoir due to evaporation on the pool.

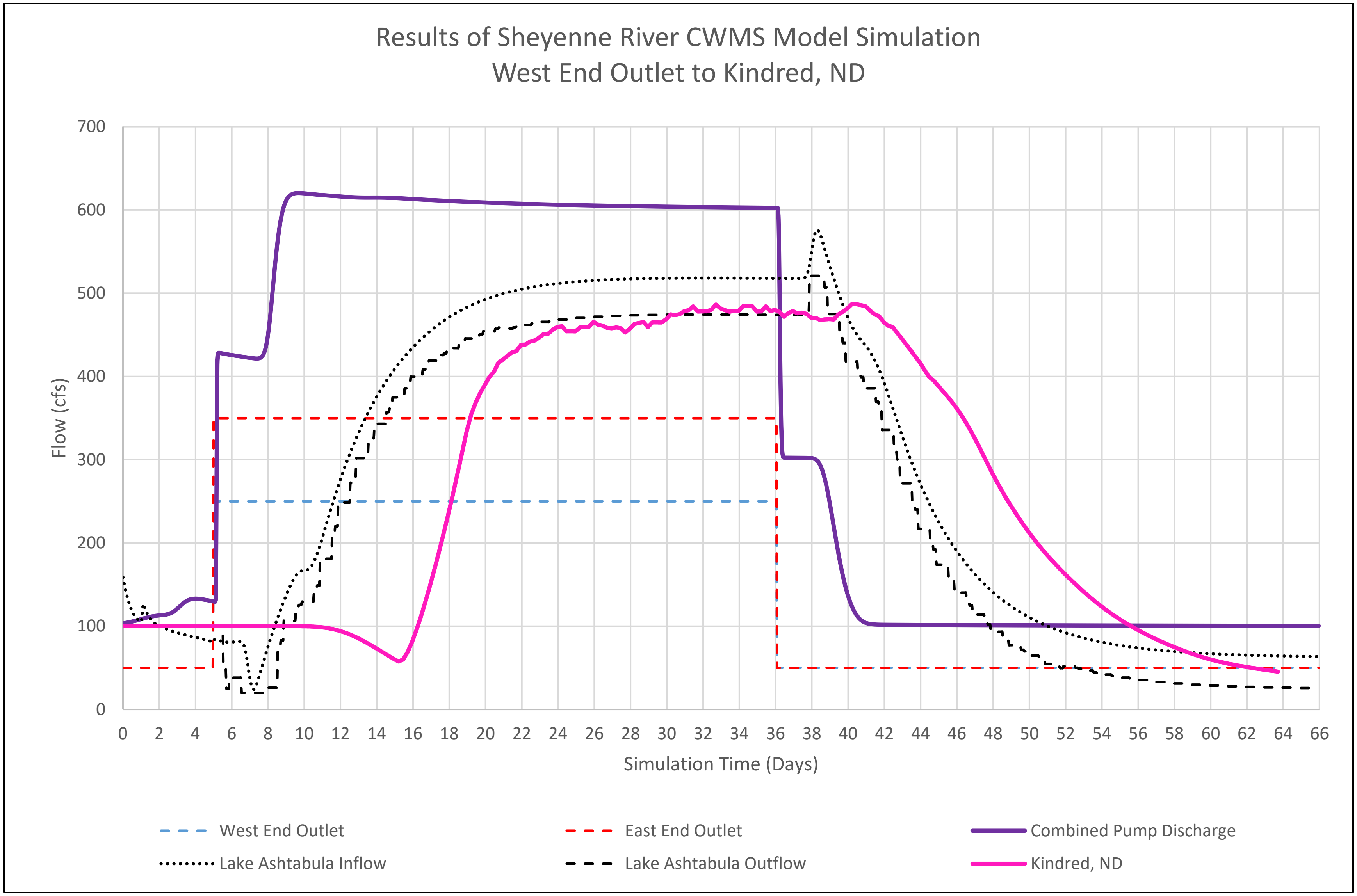
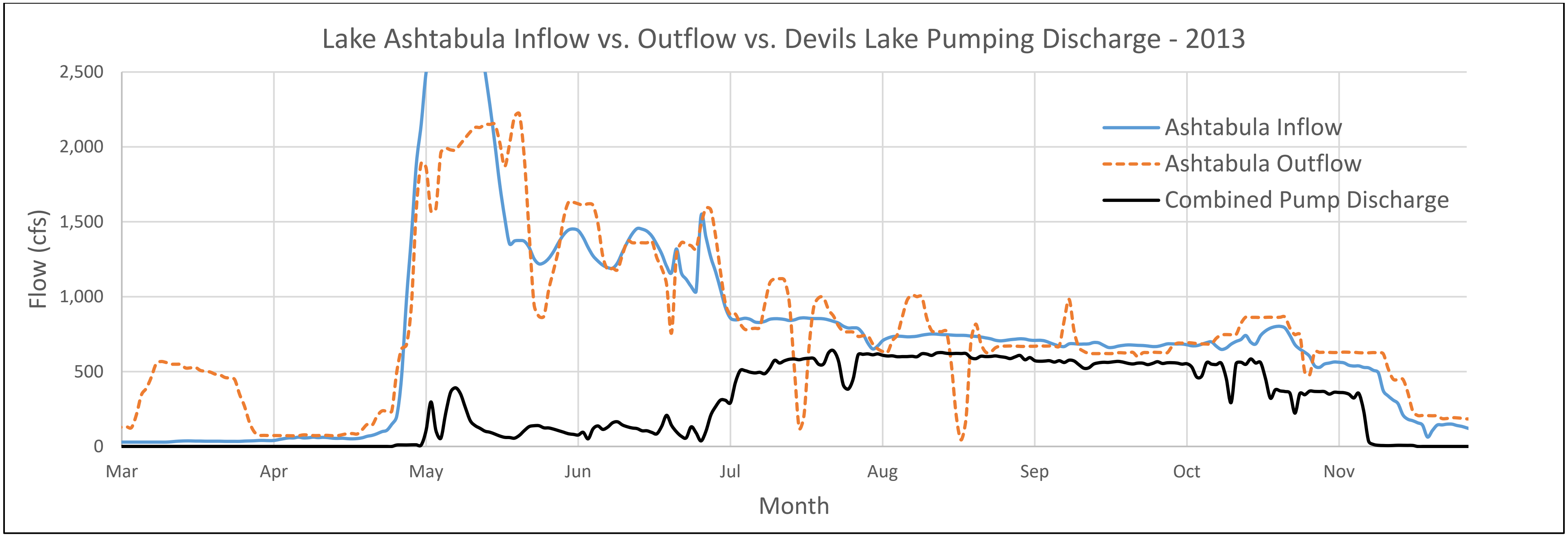


Figure 7. Results of CWMS routing model simulation

A comparison of discharge records at Kindred, ND and Horace, ND indicated the travel time from Kindred to Horace is approximately one day, and there is limited attenuation. Therefore, the combined pumping discharge from Devils Lake translated downstream to Horace, ND was approximated by advancing the flows approximated at Kindred by one additional day (total travel time 15 days).

To evaluate the impacts of the pumped flows between 2012 and 2020 the approximated, daily flow record representative of total pumped outflow from Devils Lake was lagged by 15 days and reduced by 25 percent to produce a representation of the pumped flows translated downstream to Horace. Since this approach does not account for any intervening local flow between Devils Lake and Kindred and assumes a constant pool elevation at Lake Ashtabula, the approximation of travel time and attenuation of pumped flows from Devils Lake is only applicable during scenarios in which pumped flows make up a significant percentage of inflow to Lake Ashtabula, the reservoir is releasing its inflow, and there is limited local flow inputs between the dam and Horace.

During the years 2012-2020, Lake Ashtabula maintained a consistent pool elevation of approximately 1266 feet (NGVD29) during the months of May through September. During years in which the reservoir was used for flood storage during a late spring, summer or fall flood event, such as 2013 (spring) and 2019 (fall), the Devils Lake pumps were either inactive or making limited releases. This is consistent with the operating objectives described in the *Devils Lake Outlet Operational Guide* (North Dakota State Water Commission, 2020), which states the pump discharge is adjusted to prevent flooding to the greatest extent possible. To illustrate how the pumps are operated in conjunction with flood events, as well as the operation of Baldhill Dam during the warm weather months, hydrographs for the years 2013 and 2017 are shown in Figure 8. These plots display Lake Ashtabula's inflow and outflow, as well as the combined pumping discharge from Devils Lake. As can be seen, the pumps make limited releases when inflow to the reservoir is high during the spring flood event and then ramp up releases when local inflows to the reservoir decrease. When the pumps are operating at capacity, their discharge makes up the majority of inflow into the reservoir, and the reservoir is approximately releasing the inflow it receives. Note the combined pump discharge shown in Figure 8 is computed at the Sheyenne River-Tolna Coulee confluence, and there are several days of travel time from that location to the reservoir.



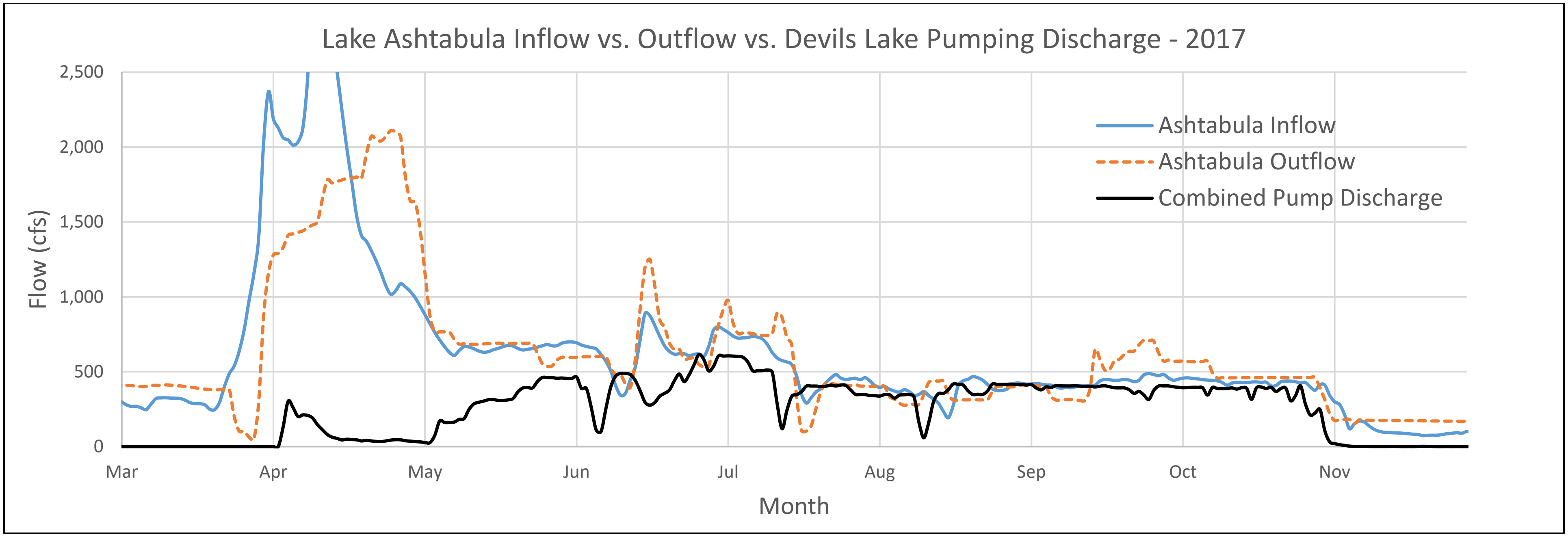


Figure 8. Combined pumping discharge compared to inflow and outflow of Lake Ashtabula

During October and November, the pool is drawn down by approximately 1.4 feet. As Lake Ashtabula is drawn down, releases slightly higher than inflow are made. Consequently, the reservoir at a minimum releases any water pumped from Devils Lake. Although breakout flows have been known to occur between Baldhill Dam and Horace, these breakout flows only occur when the discharge is above approximately 3,500 cfs at Kindred. Pumping from Devils Lake has not occurred when this threshold has been exceeded.

For these reasons, it is reasonable to assume that the vast majority of the inflow to Lake Ashtabula during non-flood conditions between April (post melt) and November (until freeze up) comes from Devils Lake and that outflow can reasonably be assumed to be equivalent to inflow. Therefore, for the purposes of this analysis, the simplified approach described above gives a reasonable approximation of the effects of pumping from Devils Lake during the period 2012-2017. The estimated, combined pumping discharge from Devils Lake translated to Horace, ND is shown in Figure 9.

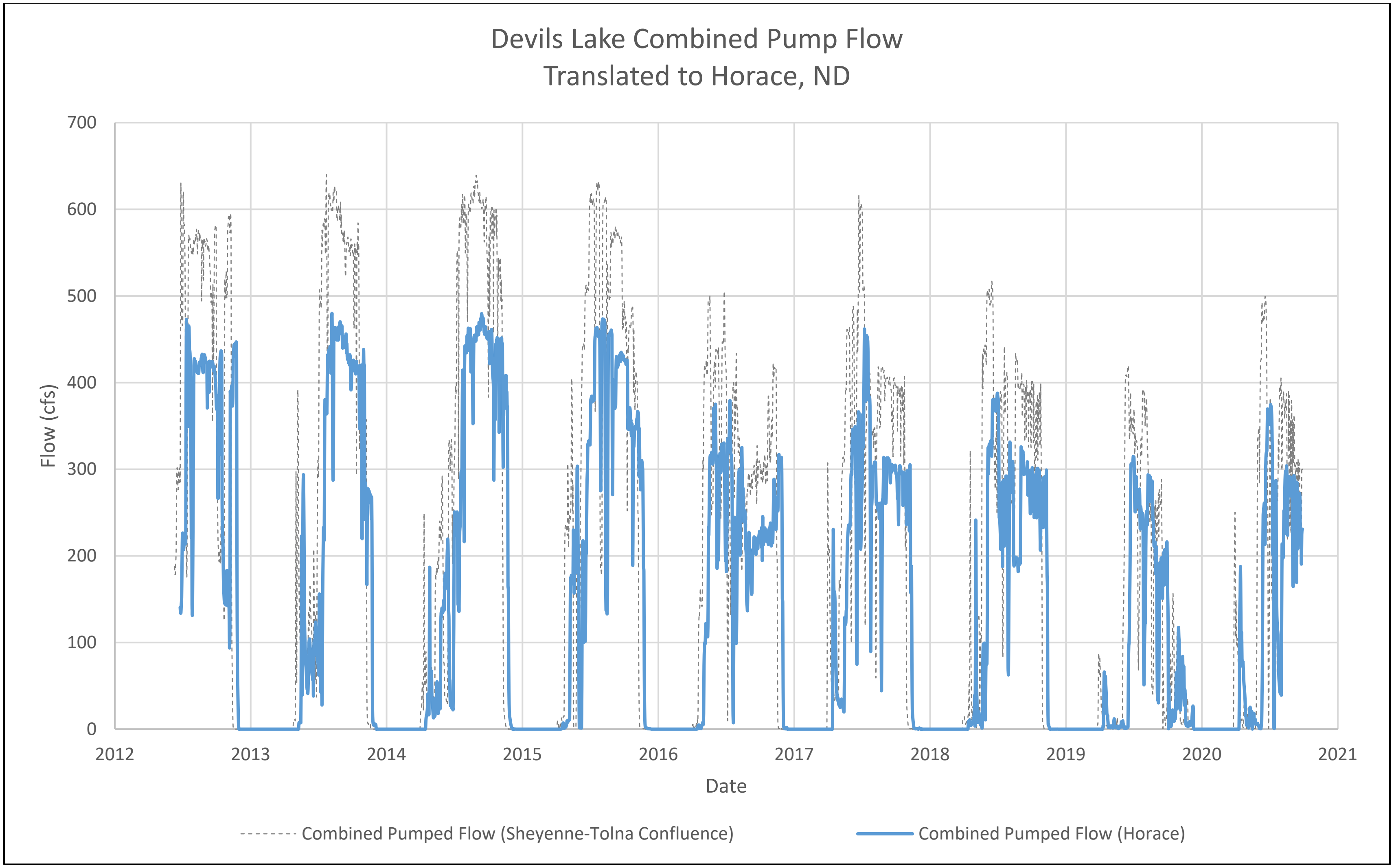


Figure 9. Devils Lake pumping discharge routed to Horace, ND

After estimating the contribution from pumped flows at Horace, ND, the average monthly volume of the translated pumped flows at Horace was compared to the average monthly volume of the observed flows at Horace (pumped flow contribution versus total flow). As shown in Figure 10, the pumped flows from Devils Lake made up at least 30% of the total flow volume at Horace during the months of July through November. During the months of August and September, the pumped flows accounted for approximately 50% of the flow volume at Horace. Note during October, November, and December, Lake Ashtabula is drawn down in accordance with its operating plan, so it is required to release flows in excess of inflow. During the month of December, the pumps have not historically operated, although some flow at Horace is attributed to pumping from Devils Lake due to the travel time from Devils Lake to Horace.

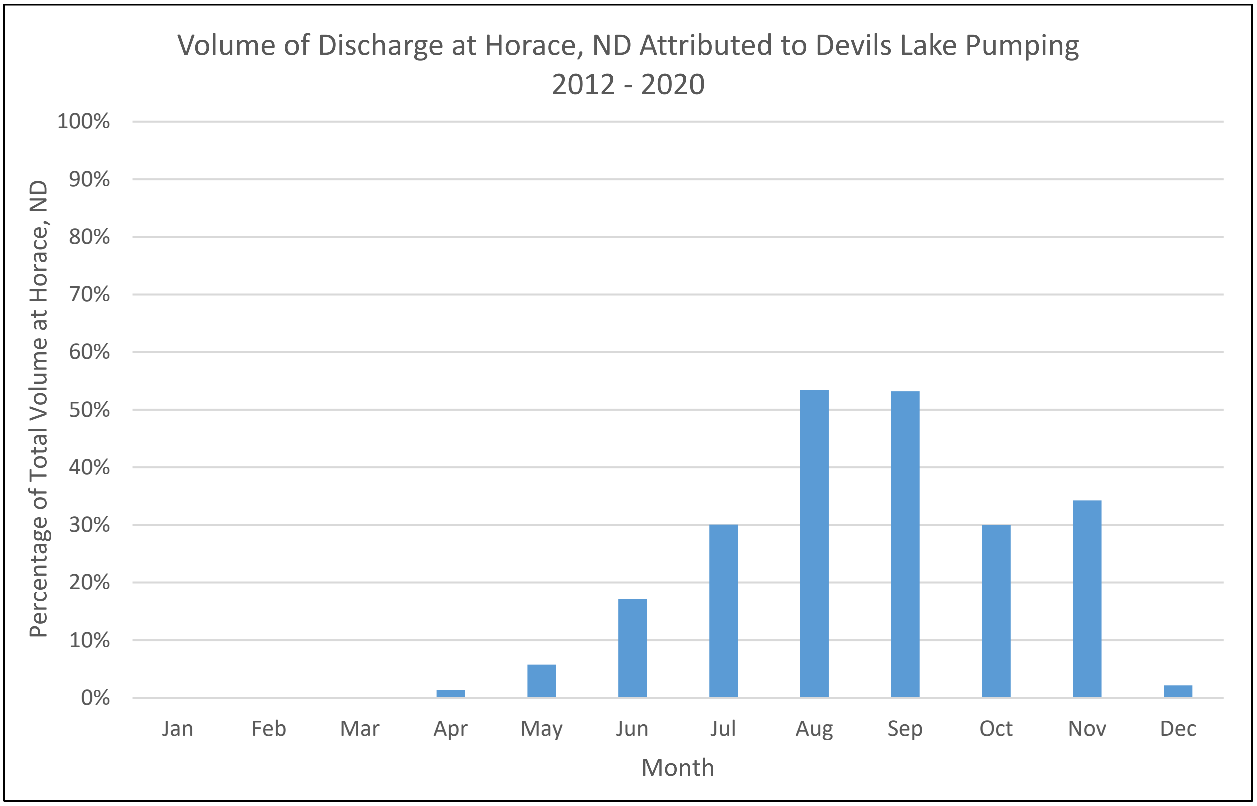


Figure 10. Monthly volume at Horace, ND attributed to pumping from Devils Lake, 2012-2020

The observed discharge record at Horace was modified to represent what the flows at that location would have been if the Devils Lake pumps were not in operation during the period 2012-2020. To do this, the translated, pumped flows displayed in Figure 9 (blue line) were subtracted from the flows recorded on the Sheyenne River above the Sheyenne Diversion near Horace, ND. Negative values were removed. The resulting hydrograph is shown in Figure 11.

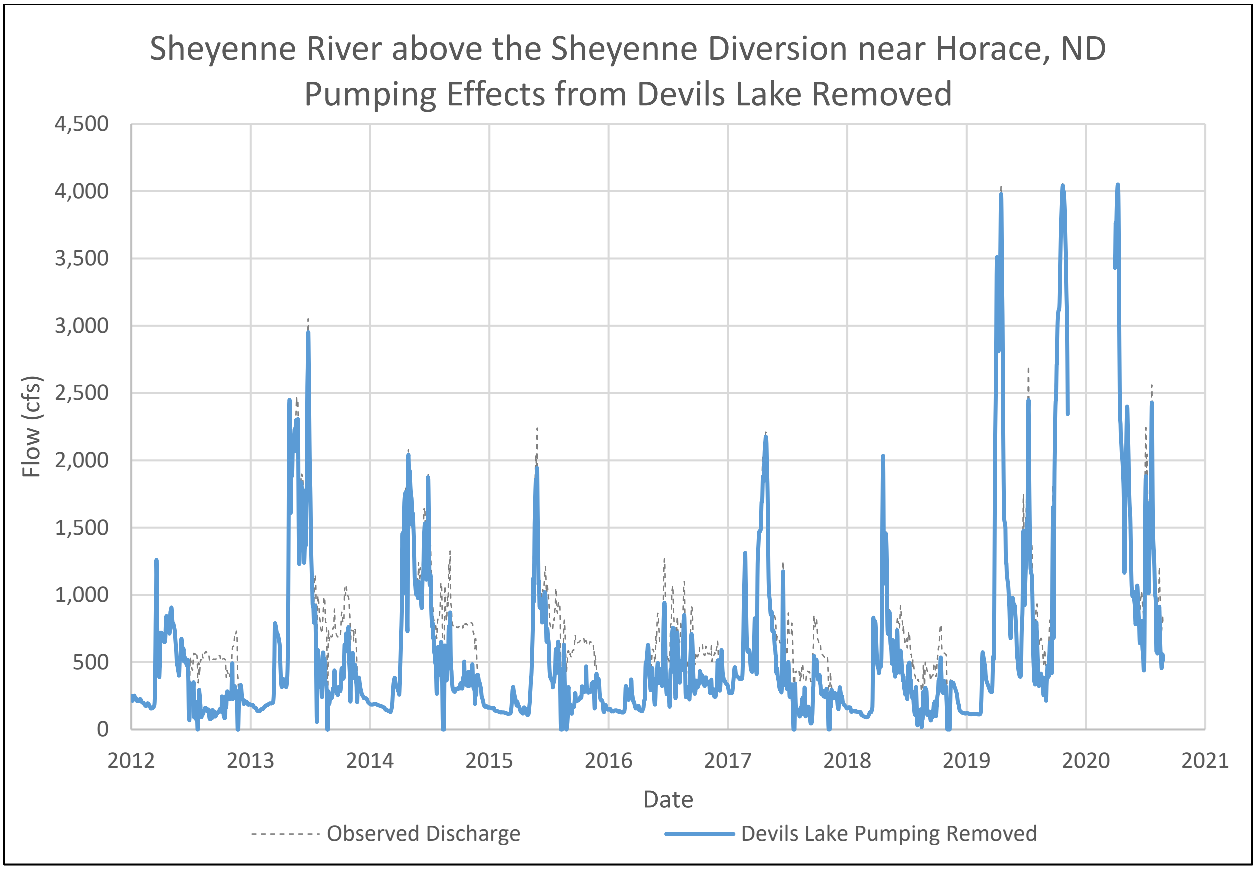


Figure 11. Sheyenne River above the Sheyenne Diversion near Horace, ND - observed vs. estimated without Devils Lake pumping

Annual flow duration curves at Horace for the period 2012-2020 were computed using both the observed flow record (with pumped flows) and the estimated flow record without the pumping effects from Devils Lake. Duration curves are shown in Figure 12. The pumps have had a significant impact on the low flow regime. The percentage time at which flows are maintained between 200 cfs to 1,000 cfs has increased. Note since pumping from Devils Lake does not impact the exceedance probability of large flood events, the y-axes of all flow duration curves shown in this document are limited to 1,500 cfs.

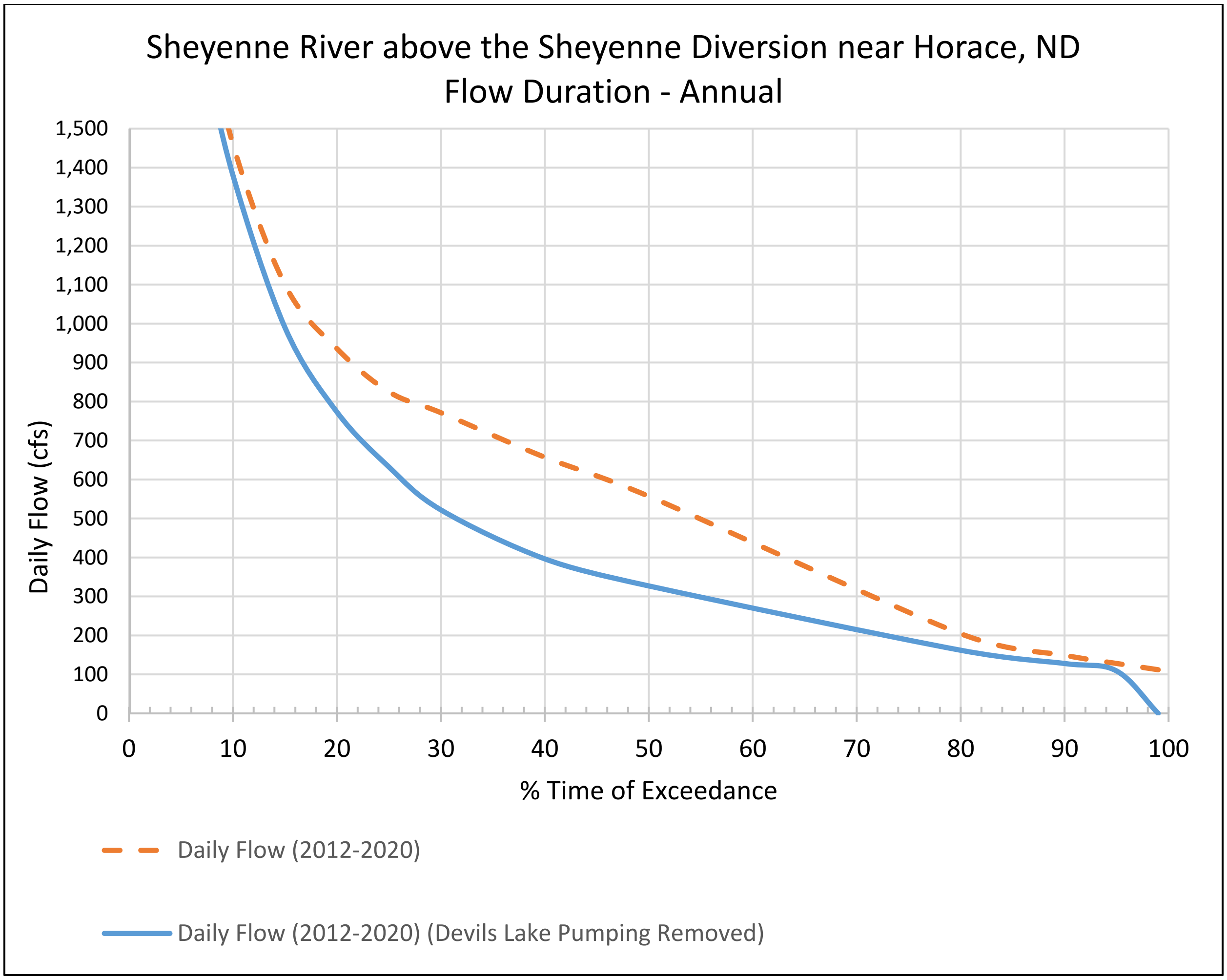


Figure 12. Flow duration curve comparison after removing Devils Lake pumping flows - annual

Monthly flow duration curves were also computed for the period 2012-2020, both with and without the effects of pumping from Devils Lake. These curves are shown in Figure 13 through Figure 21. As suggested by the monthly volume distribution shown in Figure 10, pumping from Devils Lake significantly increases the frequency at which flows exceed between 200 cfs and 1,000 cfs during the months of June through November. Pumping does not significantly affect the flow duration curves for the months of December through May.

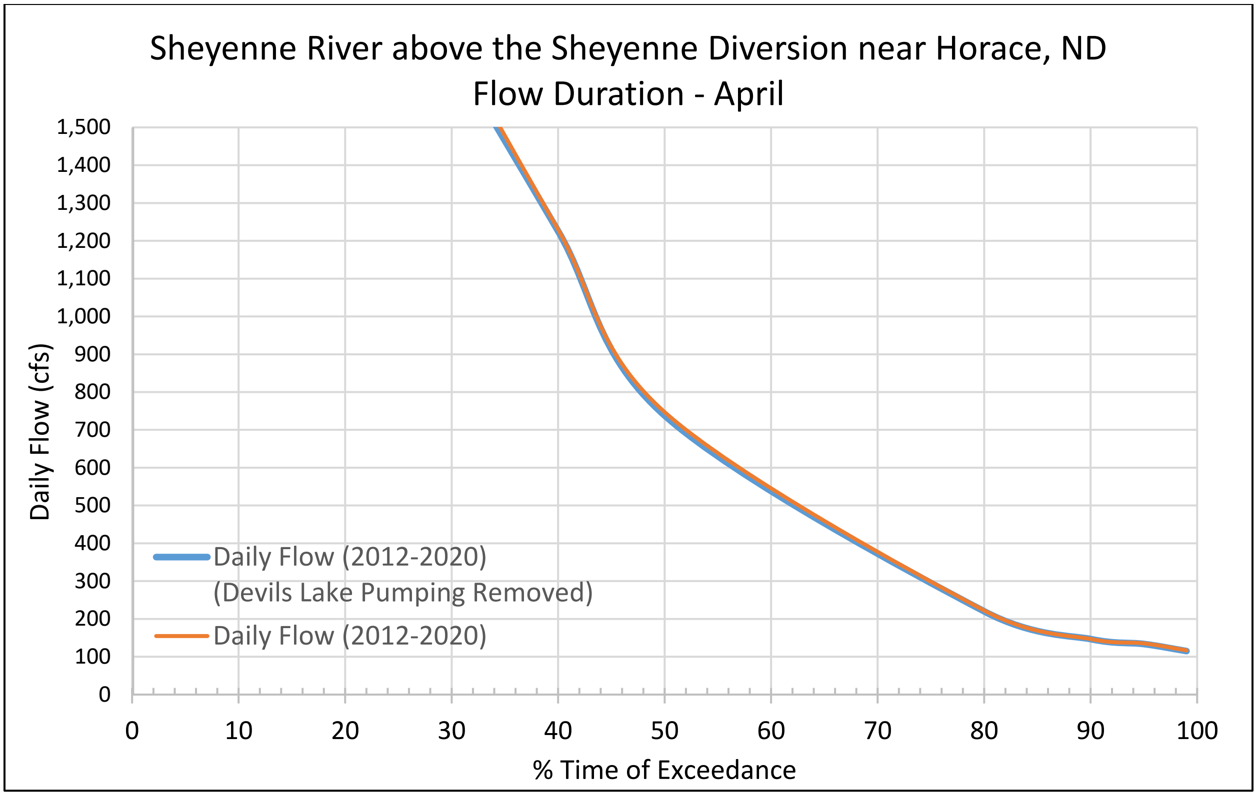


Figure 13. Flow duration curve comparison after removing Devils Lake pumping flows – April

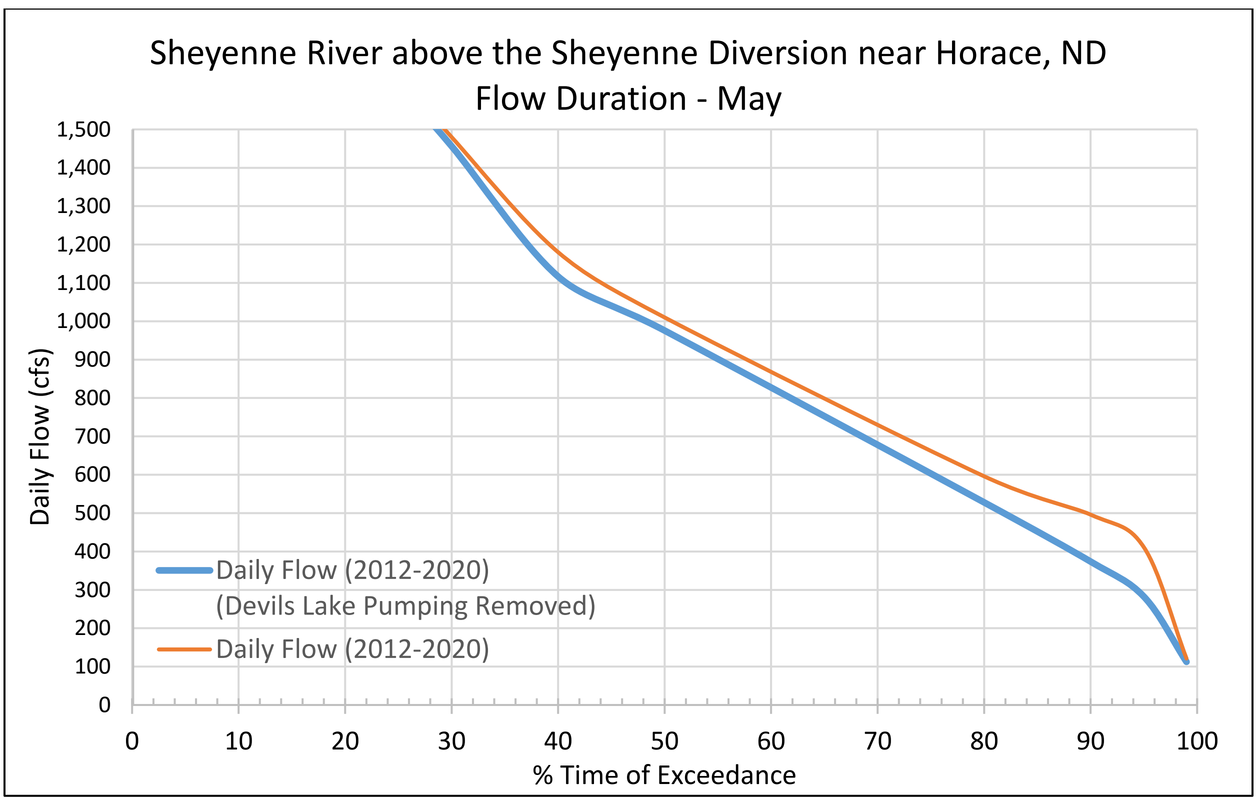


Figure 14. Flow duration curve comparison after removing Devils Lake pumping flows – May

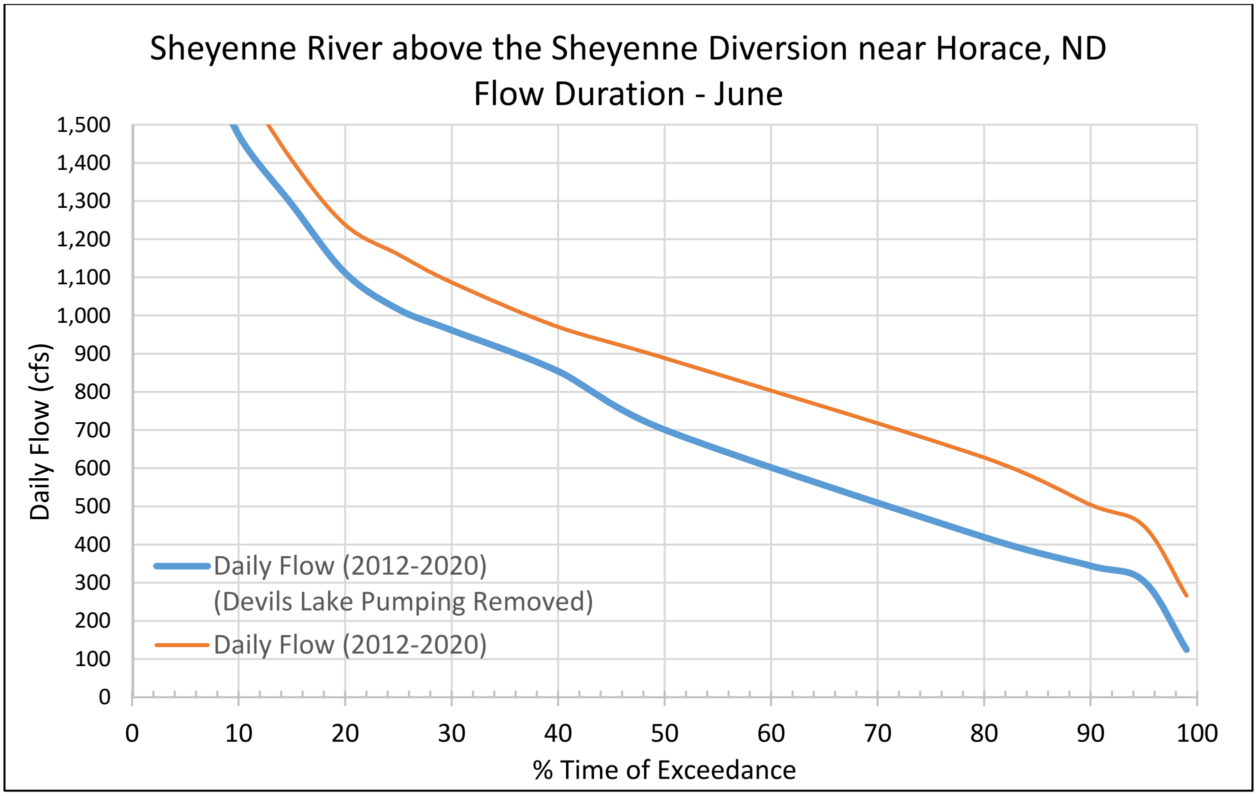


Figure 15. Flow duration curve comparison after removing Devils Lake pumping flows – June

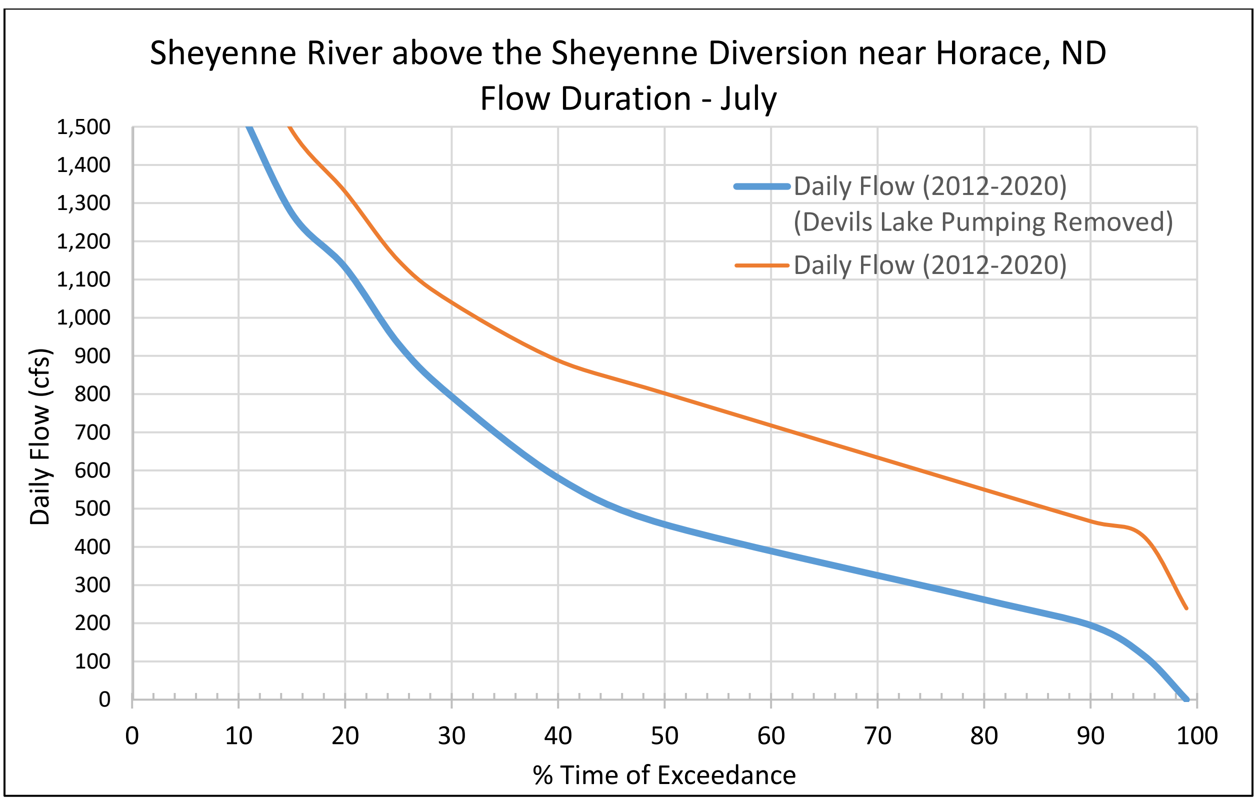


Figure 16. Flow duration curve comparison after removing Devils Lake pumping flows – July

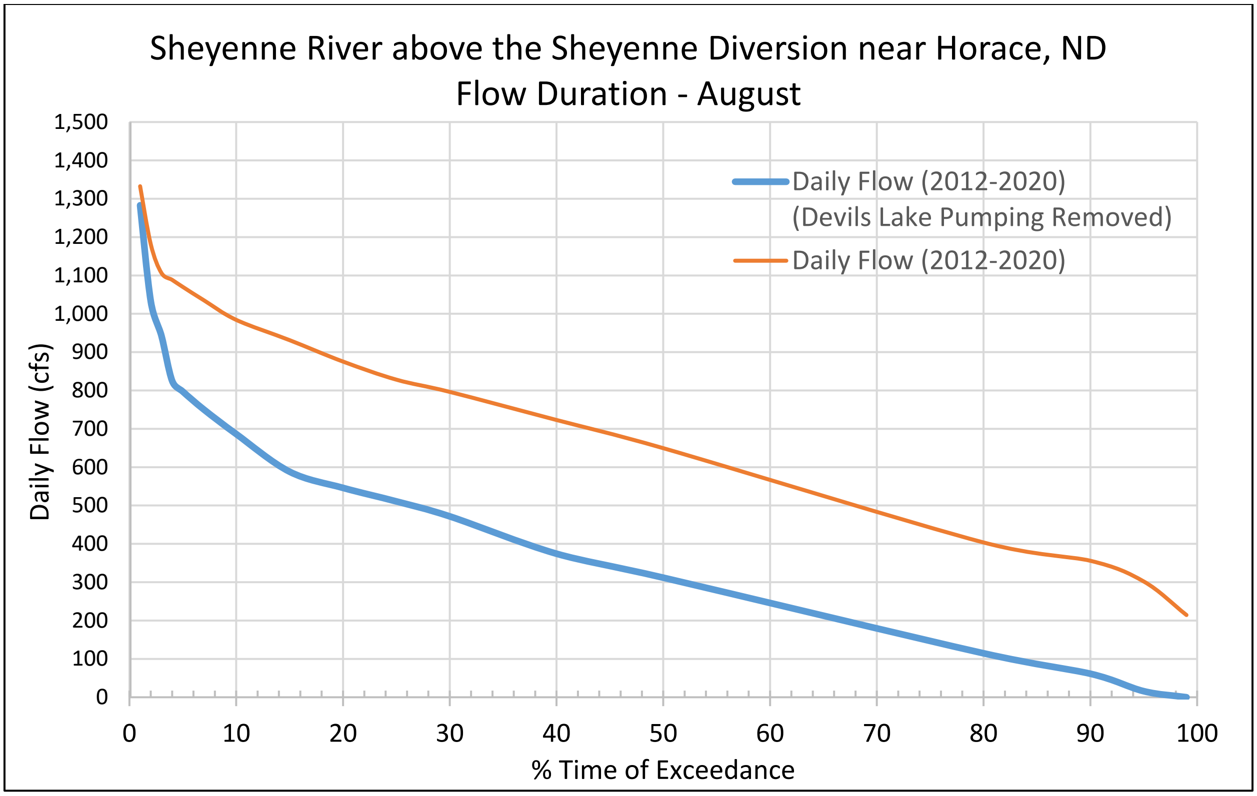


Figure 17. Flow duration curve comparison after removing Devils Lake pumping flows – August

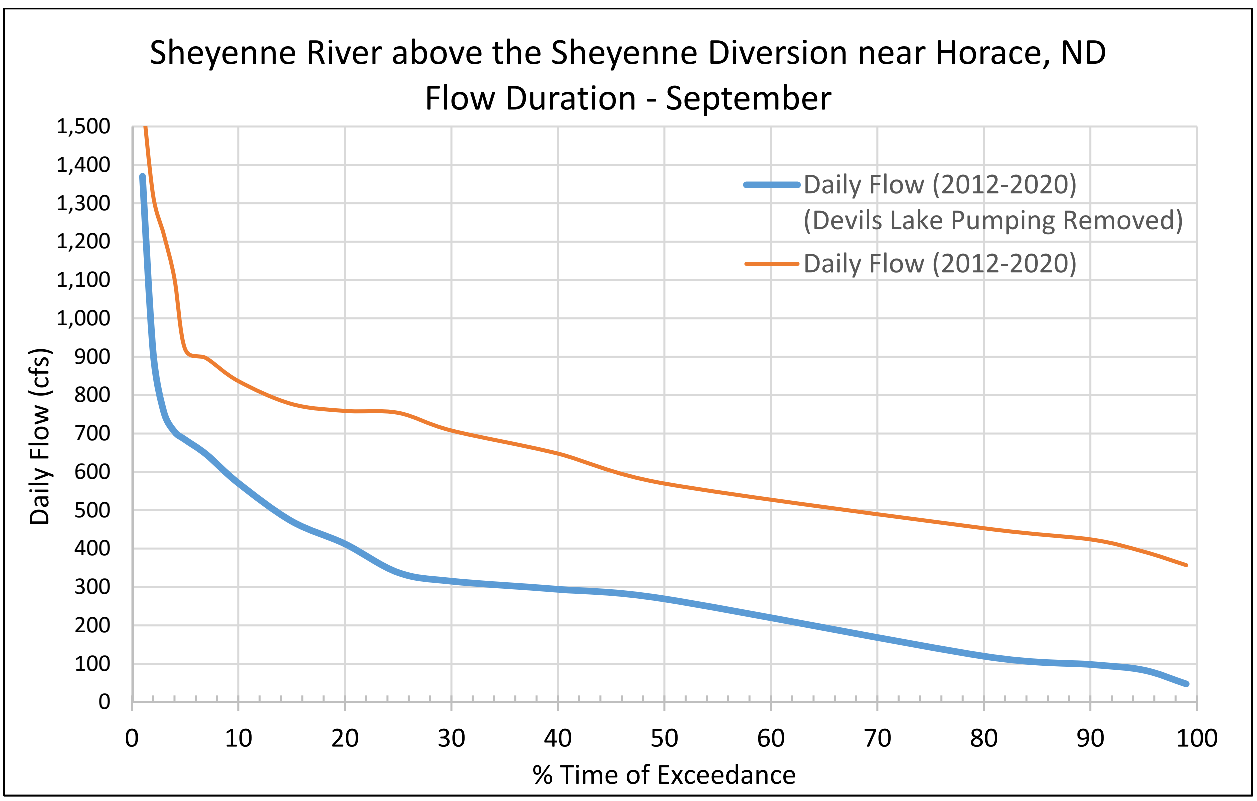


Figure 18. Flow duration curve comparison after removing Devils Lake pumping flows – September

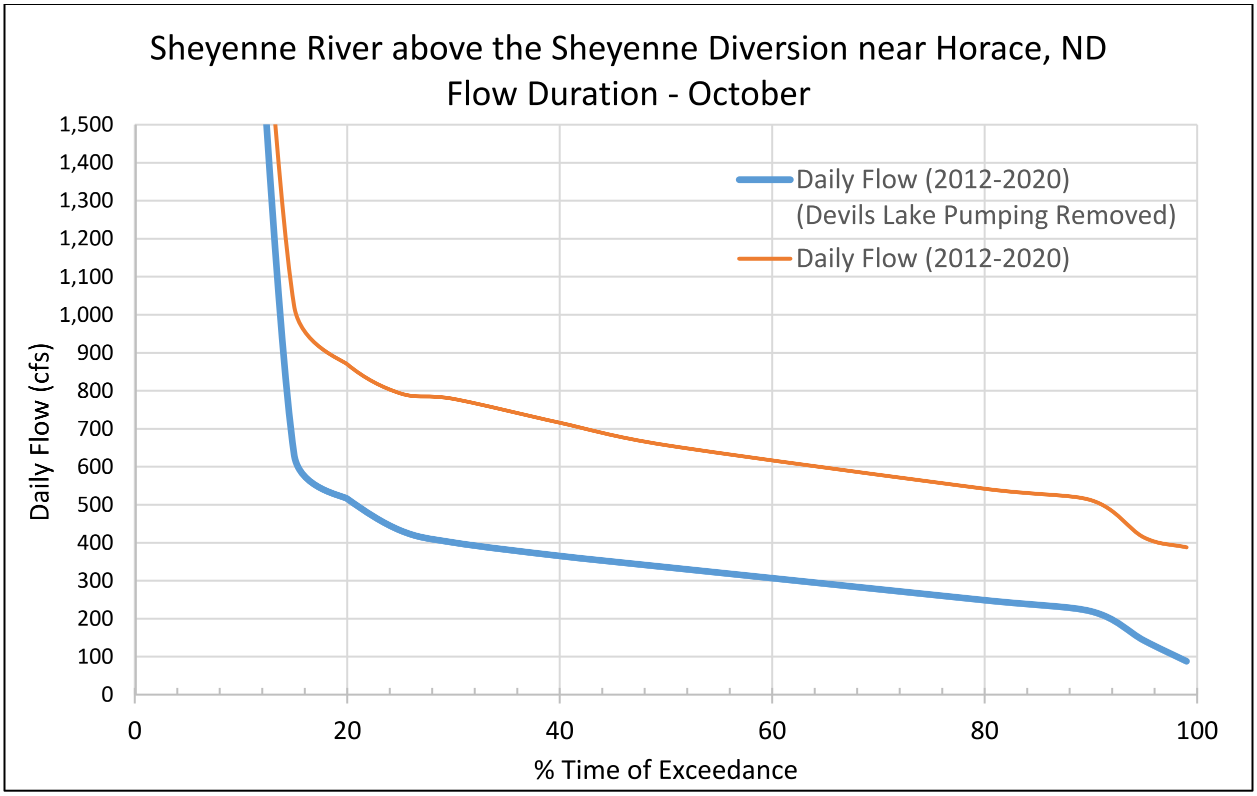


Figure 19. Flow duration curve comparison after removing Devils Lake pumping flows – October

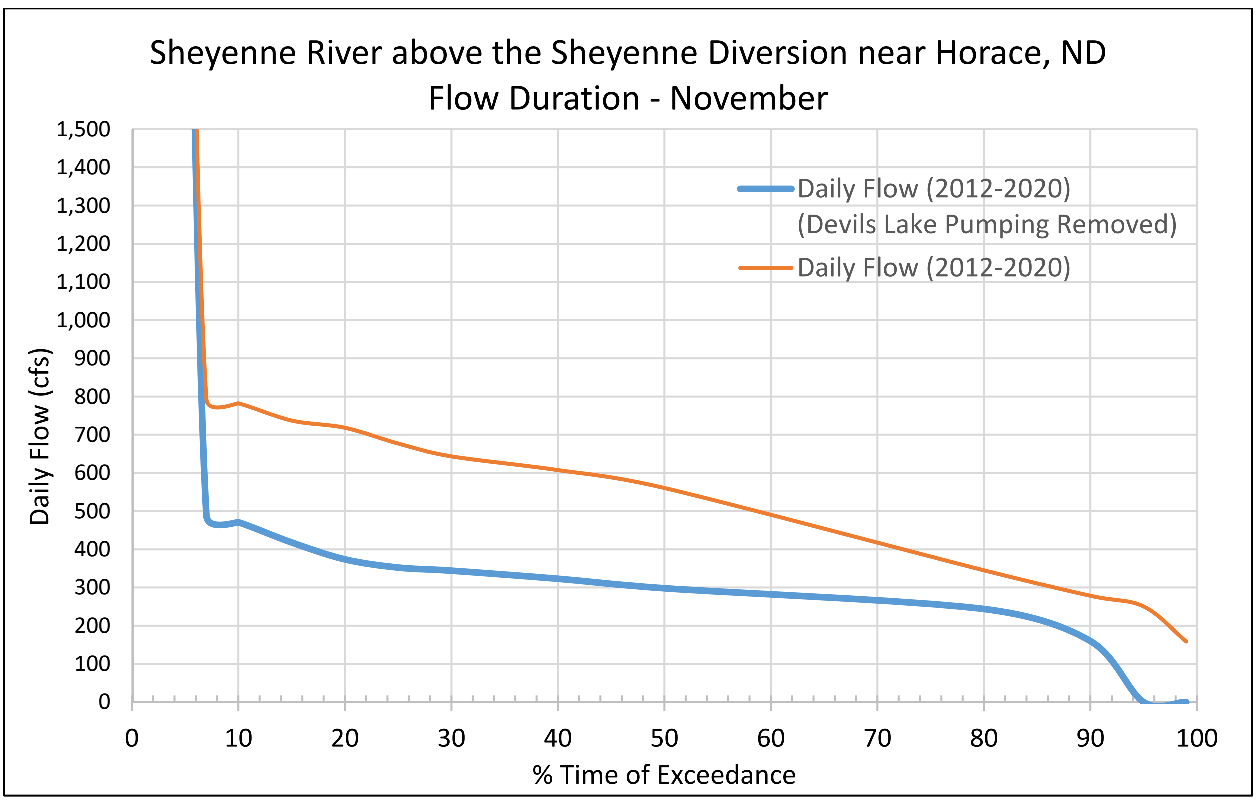


Figure 20. Flow duration curve comparison after removing Devils Lake pumping flows – November

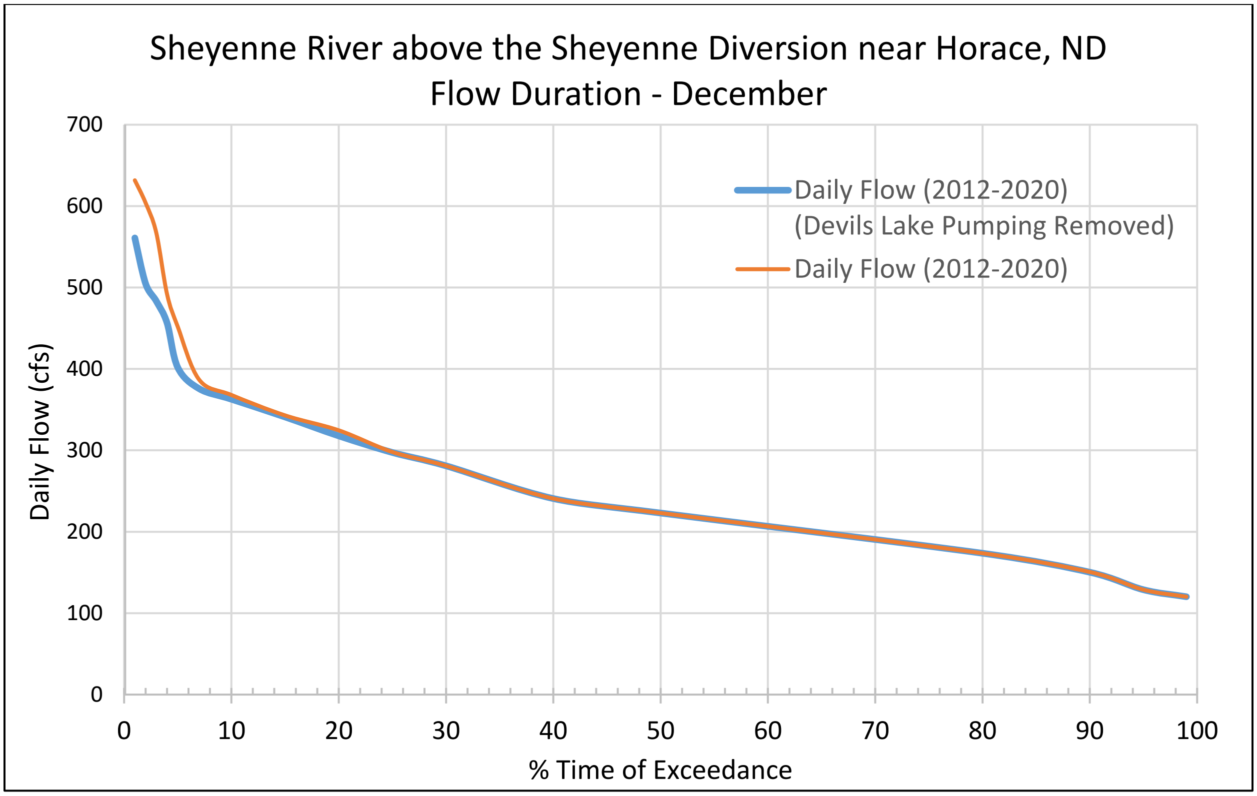


Figure 21. Flow duration curve comparison after removing Devils Lake pumping flows – December

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5. U.S. Army Corps of Engineers St. Paul District (2013). *Water Control Manual Baldhill Dam and Lake Ashtabula*. St. Paul, MN.
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Geomorphic Monitoring Plan for the Fargo-Moorhead Metropolitan Area Flood Risk Management Project

29 July 2021

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 are anticipated to be available in fall 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 the local 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 245 monitoring cross sections that has 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.

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 upstream and downstream of the FMM Project's Diversion Channel outlet. Contains ten cross sections. The GMT shall consider adding cross sections and splitting this GMS into two separate GMSs for future geomorphic assessments.
- **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** - Located at the dam. Contains six cross sections. The GMT shall consider removing this GMS for future geomorphic assessments given that the Red River will be re-routed through the Red River Structure.
- **RE08A** –Located one mile upstream of the FMM Project dam. Contains six cross sections.
- **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.

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.

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 WEST (2012) assessment. 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.

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.

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.

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.

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.

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.

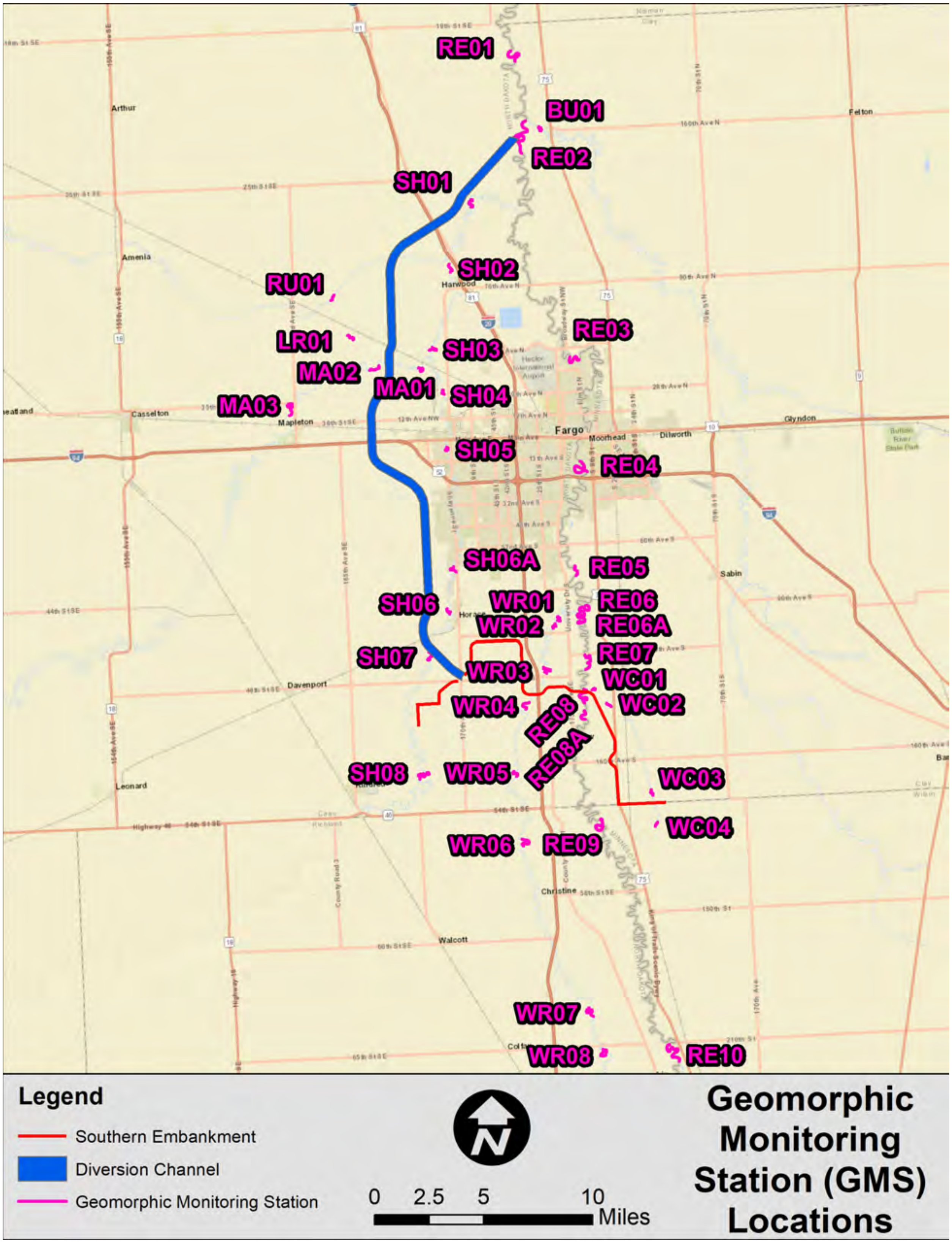


Figure 4-1: FMM Project Geomorphic Monitoring Station Locations

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

#	GMS	Cross Sections
1	RE01	7
2	RE02	10
3	RE03	6
4	RE04	6
5	RE05	6
6	RE06	6
7	RE06A	6
8	RE07	6
9	RE08	6
10	RE08A	6
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	*245*

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
RE01	Referred to as Red River – 1 – 410.65	Part of assessment	Part of assessment
RE02	Referred to as Red River – 2 – 419.14	Part of assessment	Part of assessment
RE03	Referred to as Red River – 3 – 440.57	Part of assessment	Part of assessment
RE04	Referred to as Red River – 4 – 452.52	Part of assessment	Part of assessment
RE05	Referred to as Red River – 5 – 463.56	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
RE06A	Referred to as Red River – 6 – 470.23		Part of assessment
RE07	Not part of assessment	Part of assessment	Part of assessment
RE08	Not part of assessment	Part of assessment	Part of assessment
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
RE10	Referred to as Red River – 8 – 521.18	Part of assessment	Part of assessment
WR01	Referred to as Wild Rice River – 1 – 3.01	Part of assessment	Part of assessment
WR02	Referred to as Wild Rice River – 2 – 4.23	Part of assessment	Part of assessment
WR03	Not part of assessment	Part of assessment	Part of assessment
WR04	Not 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
WR06	Referred to as Wild Rice River – 4 – 22.94	Part of assessment	Part of assessment
WR07	Referred to as Wild Rice River – 5 – 38.49	Part of assessment	Part of assessment
WR08	Referred to as Wild Rice River – 6 – 42.36	Part of assessment	Part of assessment
SH01	Referred to as Sheyenne River – 1 – 4.20	Part of assessment	Part of assessment
SH02	Referred to as Sheyenne River – 2 – 11.56	Part of assessment	Part of assessment
SH03	Referred to as Sheyenne River – 3 – 18.15	Part of assessment	Part of assessment
SH04	Referred to as Sheyenne River – 4 – 22.27	Part of assessment	Part of assessment
SH05	Referred to as Sheyenne River – 5 – 26.47	Part of assessment	Part of assessment
SH06	Not 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

GMS	2012 WEST Assessment	2019 WEST Assessment	2021 WEST Assessment
SH07	Referred to as Sheyenne River – 7 – 43.27	Part of assessment	Part of assessment
SH08	Referred to as Sheyenne River – 8 – 55.75	Part of assessment	Part of assessment
MA01	Referred to as Maple River – 1 – 0.78	Part of assessment	Part of assessment
MA02	Not part of assessment	Part of assessment	Part of assessment
MA03	Referred to as Maple River – 2 – 11.39	Part of assessment	Part of assessment
LR01	Referred to as Lower Rush River – 2 – 6.03	Part of assessment	Part of assessment
RU01	Referred to as Rush River – 2 – 6.15	Part of assessment	Part of assessment
WC01	Referred to as Wolverton Creek – 1 – 0.64	Not part of assessment	Part of assessment
WC02	Referred to as Wolverton Creek – 2 – 2.02	Not part of assessment	Part of assessment
WC03	Not part of assessment	Not part of assessment	Part of assessment
WC04	Not part of assessment	Not part of assessment	Part of assessment
BU01	Referred to as Buffalo River – 1 – 1.19	Not part of assessment	Part of assessment

4.2 Geomorphic Monitoring Stations Recommended for Post-FMM Project

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.

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), bankfull elevation, 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. Make a qualitative description of riparian vegetation types and how that would impact bank stability.
3. Estimate percentage of banks slumping within each GMS based on field observations.
4. Document any erosion or deposition features and significant sources of sediment.
5. 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.
6. 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).
7. 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. 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 is 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 shall also occur in any GMS in which sediment type or size changes are observed and where overbank deposition is observed.

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.

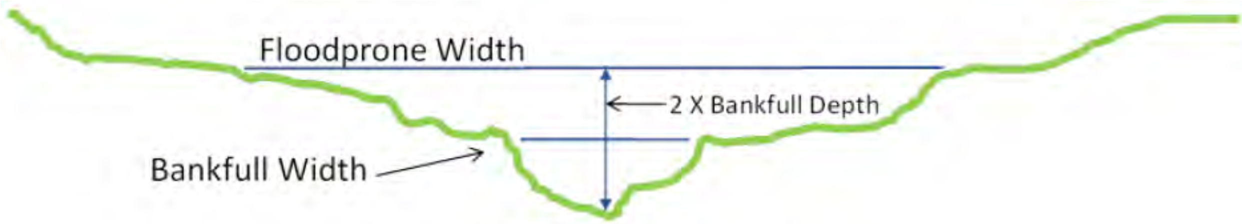
6.1 Triggers

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.

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

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 and 2019, with the methodology that was followed in calculating these Entrenchment Ratios defined in Section 7.1. The observed range of Entrenchment Ratios within both datasets for each stream is 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.

Table 6-1: Observed Entrenchment Ratios by Stream

Stream	Entrenchment Ratio
Buffalo River	2.8 – 3.0
Lower Rush River	6.4 – 8.1
Maple River	5.3 – 11.1
Red River	3.8 – 10.3
Rush River	17.0 – 26.9
Sheyenne River	7.5 – 14.0
Wolverton Creek	2.0 – 5.0
Wild Rice River	2.6 – 8.0

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 displayed in Table 6-2.

Table 6-2: Entrenchment Ratio Action Triggers by Stream

Stream	Action Trigger
Buffalo River	<2.3
Lower Rush River	<2.3
Maple River	<2.3
Red River	<2.3
Rush River	<2.3
Sheyenne River	<2.3
Wolverton Creek	<1.8
Wild Rice River	<2.3

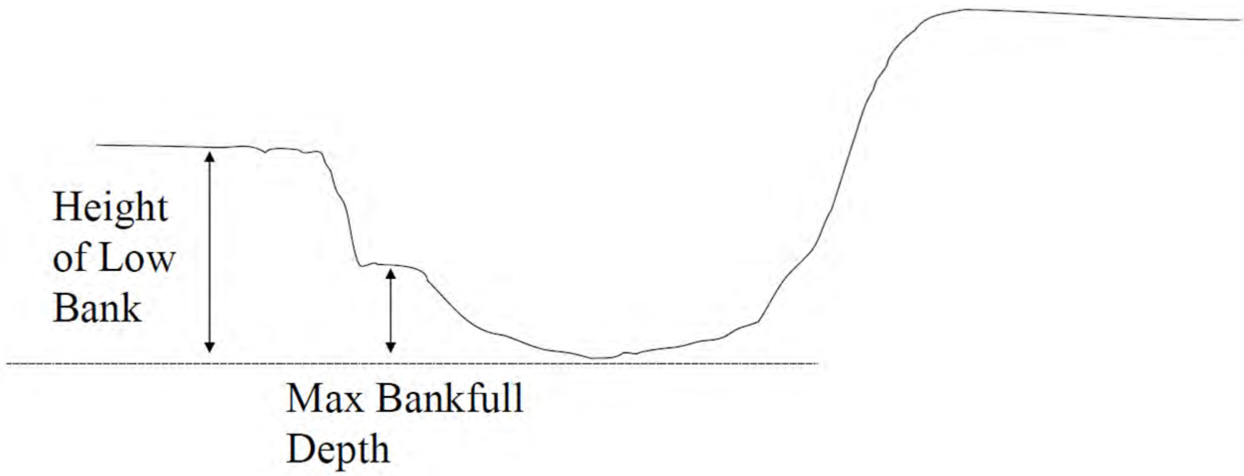
It is noted that these Entrenchment Ratio action triggers will be re-evaluated by the AMT and GMT if any additional pre-FMM Project geomorphic assessments are completed (which would only happen if a flood occurs in the pre-FMM Project timeframe). The methodology that shall be used to calculate Entrenchment 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.

6.1.2 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

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 an 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 and 2019, with the methodology that was followed in calculating these Bank Height Ratios defined in Section 7.1. The observed range of Bank Height Ratios within both datasets for each stream is summarized in Table 6-3. 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 6-3: Observed Bank Height Ratios by Stream

Stream	Bank Height Ratio
Buffalo River	1.3 – 1.3
Lower Rush River	1.1 – 1.4
Maple River	1.0 – 1.2
Red River	1.0 – 1.3
Rush River	1.2 – 1.5
Sheyenne River	1.0 – 1.4
Wolverton Creek	0.8 – 2.1
Wild Rice River	0.9 – 1.3

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 stream, then added 0.1 to that value for each stream.

The final trigger establishment was to set the trigger for each stream 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 displayed in Table 6-4.

Table 6-4: Bank Height Ratio Action Triggers by Stream

Stream	Action Trigger
Buffalo River	>1.4
Lower Rush River	>1.5
Maple River	>1.3
Red River	>1.4
Rush River	>1.6
Sheyenne River	>1.5
Wolverton Creek	>2.2
Wild Rice River	>1.4

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 would 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.

6.1.3 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 any of the triggers identified in Section 6.1 are exceeded or if it is the GMT's judgment that other significant change is occurring throughout the system and is 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

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.

6.2.2 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)

6.2.2.1 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.

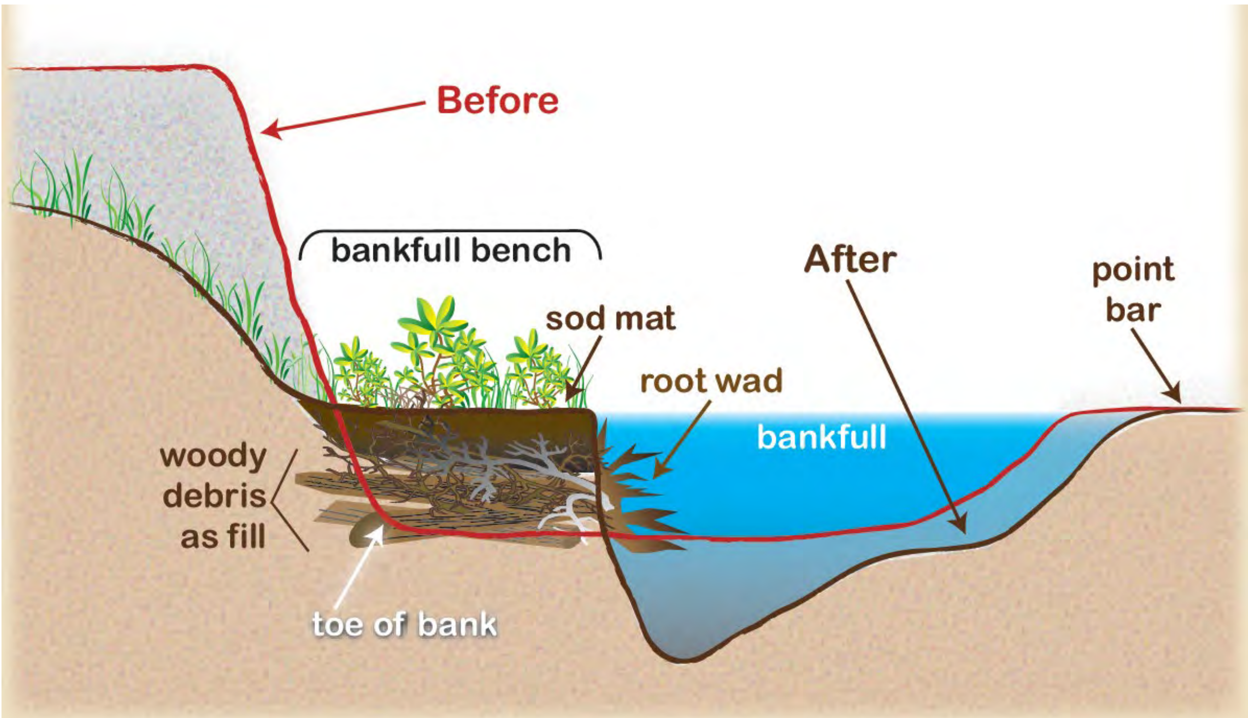


Figure 6-4: Toe Wood-Sod Mat Conceptual Example (source: Minnesota DNR)

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.

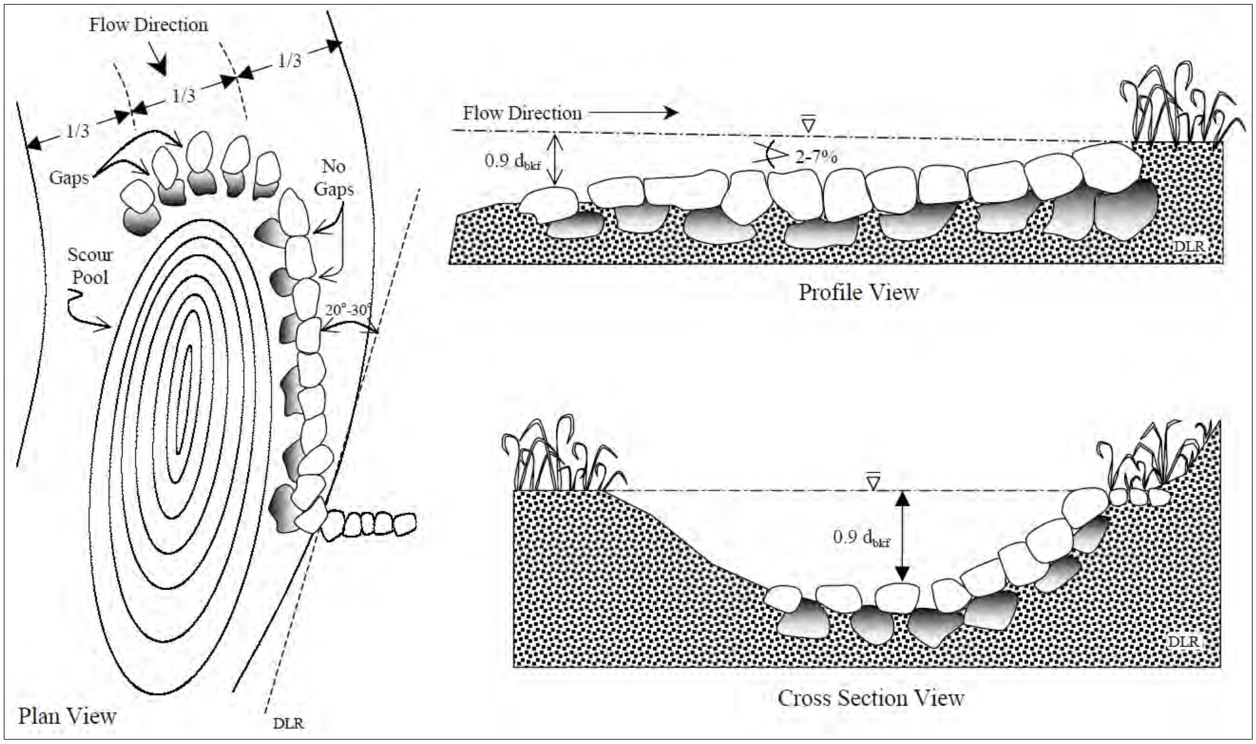


Figure 6-6: Generic J-Hook Vane Plan, Profile, and Cross-Sectional View Detail

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)

6.2.2.2 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.

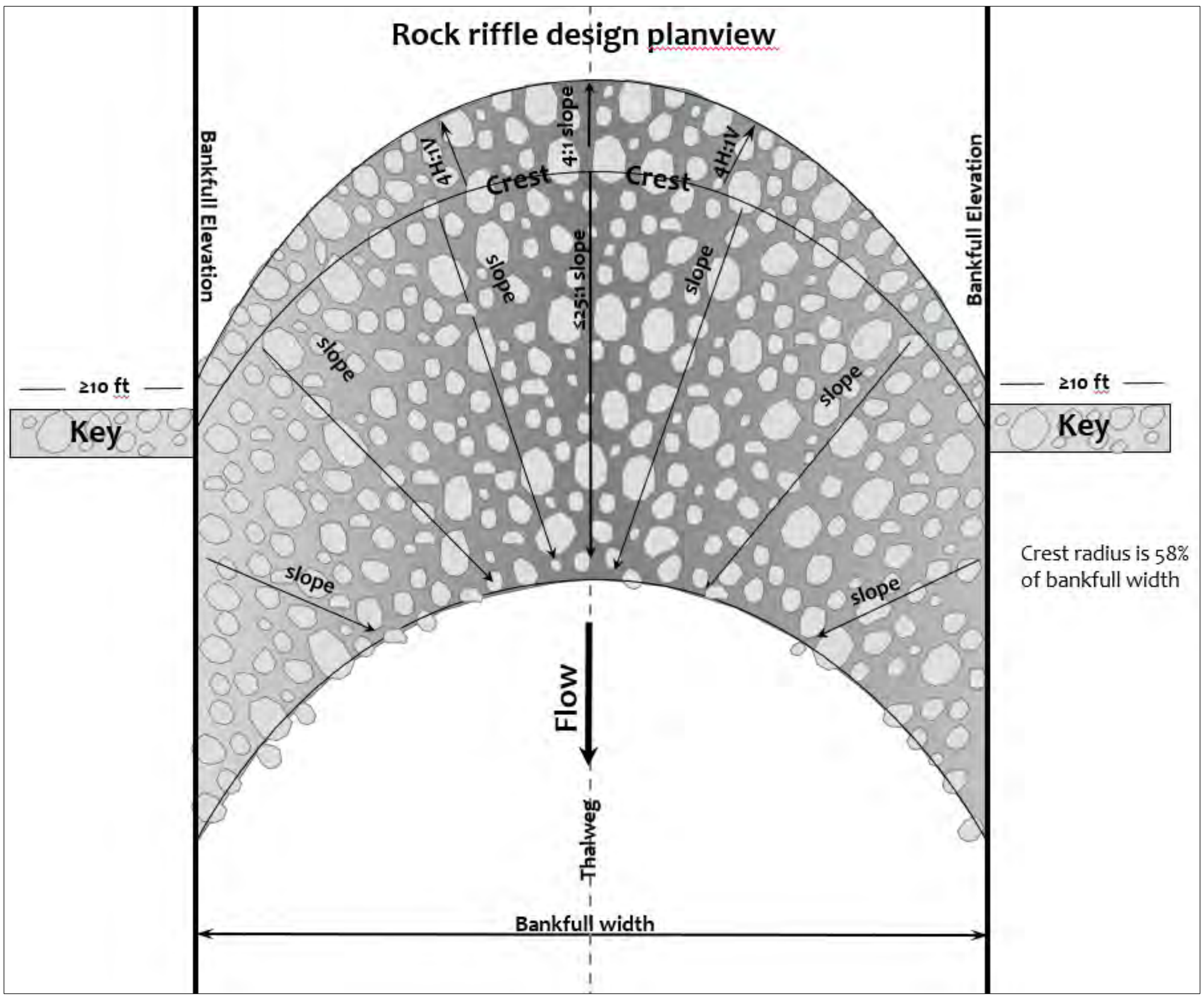


Figure 6-9: Generic Riffle Plan View Detail (Minnesota DNR)

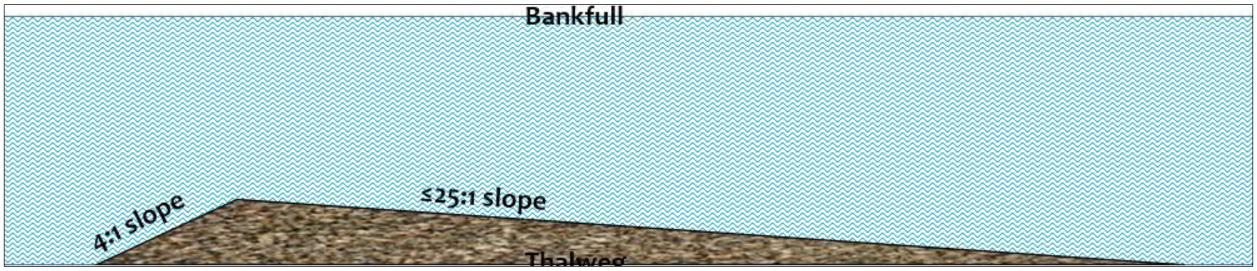


Figure 6-10: Generic Riffle Longitudinal Profile View Detail (Minnesota DNR)

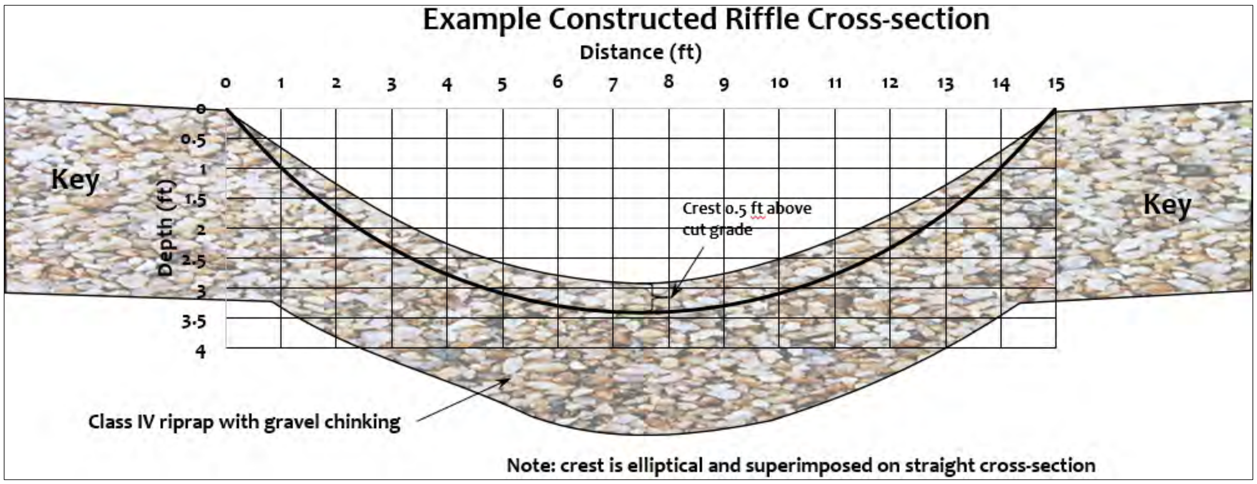


Figure 6-11: Generic Riffle Cross-Sectional View Detail (Minnesota DNR)

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.

6.2.2.3 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 6.2.2.1.

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.

6.2.2.4 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. Regrading 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.

6.2.2.5 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 Evaluating Geomorphic Triggers

This section prescribes the methods that shall be used for calculating/determining the Entrenchment Ratio, Bank Height Ratio, and bank line locations for the purpose of determining whether a trigger has been exceeded.

7.1.1 Bankfull Flow Rate Prescription

An accurate establishment of bankfull flows is integral to the calculations of both Entrenchment Ratio and Bank Height Ratio. WEST (2019) determined the bankfull flows for each geomorphic monitoring station by establishing bankfull elevations based on field observations then using a calibrated hydraulic model (HEC-RAS) to determine the flow needed to generate a water surface profile that equaled the field-observed bankfull elevations. The bankfull flows established as part of the WEST (2019) assessment for the Lower Rush River, Maple River, Red River, Rush River, Sheyenne River, and Wild Rice River were used to calculate Entrenchment Ratios and Bank Height Ratios using the survey data from the WEST 2012, 2019, and 2021 assessments. The bankfull flows established as part of the WEST (2021) assessment for the Buffalo River and Wolverton Creek were used to calculate Entrenchment Ratios and Bank Height Ratios using the survey data from the WEST 2012 and 2021 assessments (the 2019 assessment did not cover these streams). Table 7-1 summarizes the bankfull flows that shall be used for each geomorphic monitoring station. It is noted that the flow for SH05 was set to the same values for SH06 and SH04; however, this GMS is not actually connected to the rest of the Sheyenne River as it is protected by the Sheyenne River Flood Control Project. The Sheyenne River mitigation project that will be completed once the FMM Project becomes operational will allow flow to flow through SH05 again naturally. The calculations for the Entrenchment Ratio and Bank Height Ratio variables were completed using hydraulic model settings for the pre-FMM Project conditions with the Sheyenne River Flood Control Project that produced bankfull water surface elevations of approximately 896.7 feet in SH05 in the WEST (2019) hydraulic model. It is recommended that the GMT re-evaluate this flow and determine an appropriate bankfull flow for post-FMM Project calculations in SH05.

Table 7-1: Bankfull Flows for Use in Entrenchment Ratio and Bank Height Ratio Calculations

GMS	Bankfull Flow (cfs)	GMS	Bankfull Flow (cfs)	GMS	Bankfull Flow (cfs)
BU01	800	RE08	2,500	SH08	1,600
LR01	135	RE08A	2,500	WC01	150
MA01	1,050	RE09	2,500	WC02	145
MA02	1,050	RE10	2,300	WC03	30
MA03	1,050	RU01	200	WC04	25
RE01	5,000	SH01	2,800	WR01	1,000
RE02	5,000	SH02	2,700	WR02	1,000
RE03	3,800	SH03	2,600	WR03	850
RE04	3,800	SH04	1,500	WR04	825
RE05	3,800	SH05	750^	WR05	800
RE06	3,800	SH06A	1,500	WR06	775
RE06A	2,800	SH06	1,500	WR07	750
RE07	2,800	SH07	1,600	WR08	750

^See text above regarding Sheyenne River Flood Control Project influence in SH05

To validate the selection of the bankfull flows shown in Table 7-1, the average bankfull cross-sectional area for each geomorphic monitoring station using survey data from the WEST 2021 report was compared with the Minnesota DNR western region curve for this characteristic. Figure 7-1 shows that the bankfull cross-sectional areas generally align within the range of expected values; therefore, the use of these bankfull flows (which generated the associated bankfull cross-sectional areas using the 2021 WEST report survey data) are considered appropriate.

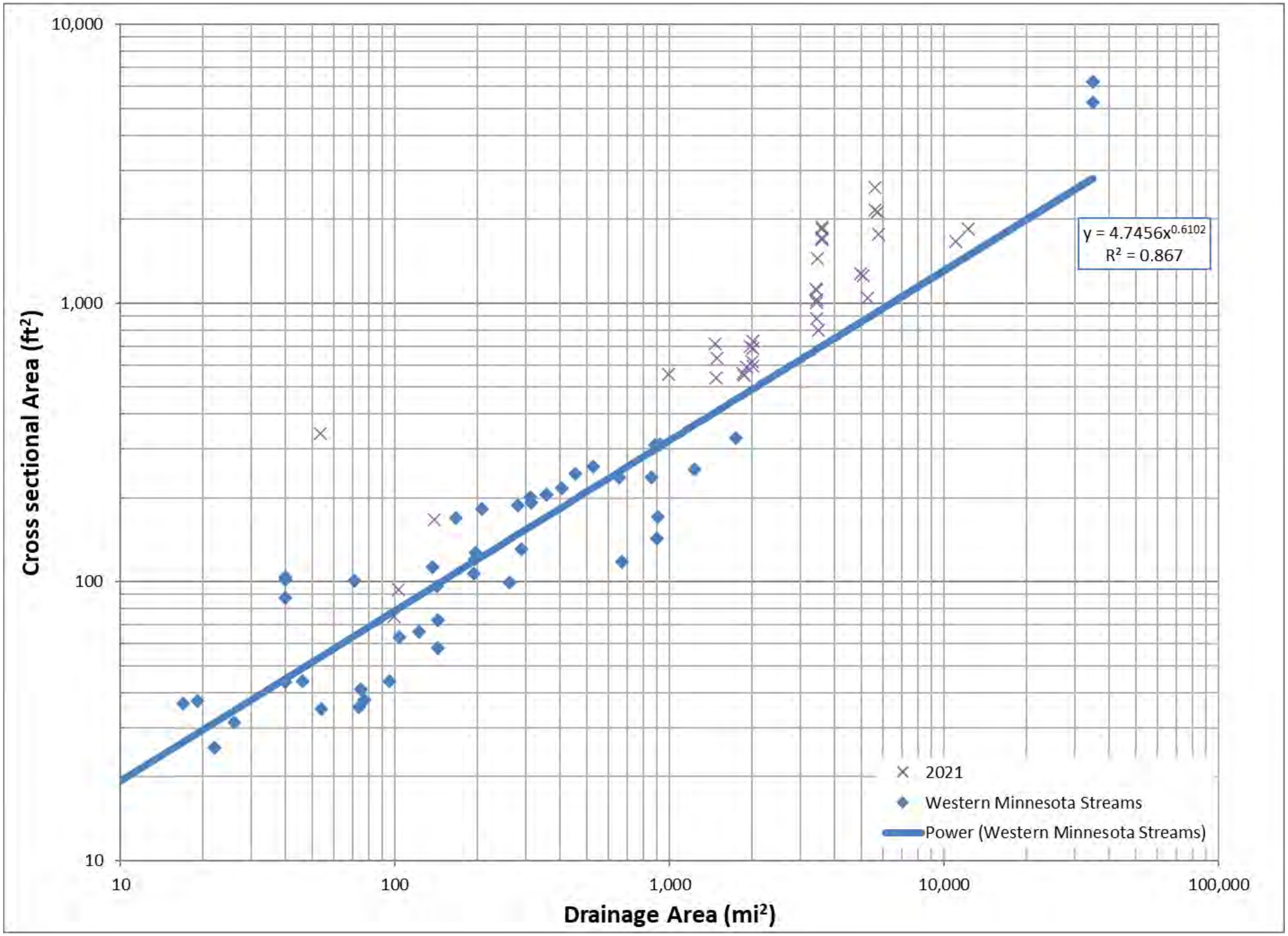


Figure 7-1: Comparison of Bankfull Cross-Sectional Area Calculations for the FMM Project and the MN DNR Western Area Dataset

7.1.2 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.

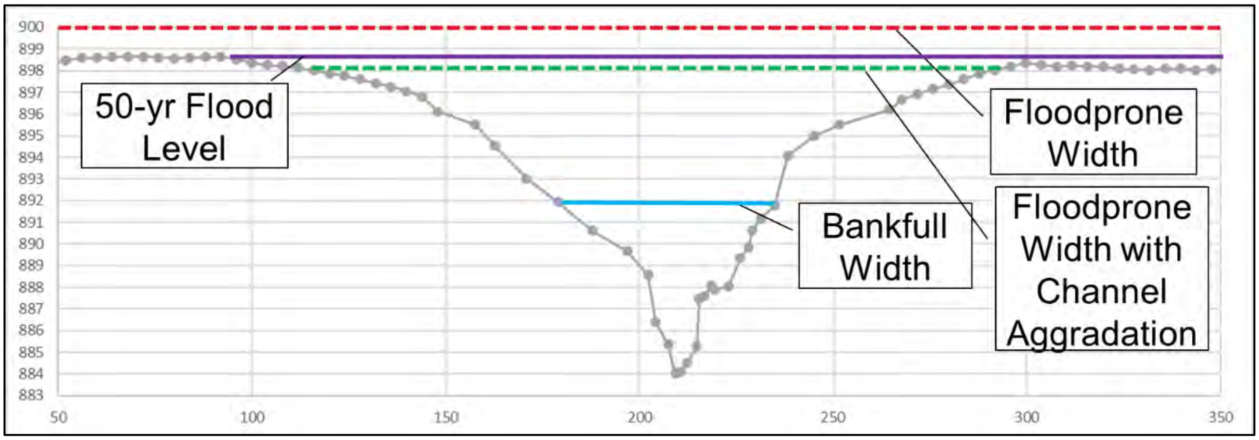


Figure 7-2: Comparison of Floodprone Widths with Small Changes in Floodprone Elevations

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.

Finally, as discussed in Section 2, an accurate establishment of bankfull flows is integral to the Entrenchment Ratio calculation. Therefore, all Entrenchment Ratio calculations completed for the purposes of evaluating trigger exceedance shall use the bankfull flow rates shown in Table 7-1 and a hydraulic model (such as HEC-RAS) to determine the bankfull elevation at which the bankfull width is to be calculated. A hydraulic model shall be used due to the presence of features downstream of each geomorphic monitoring station that influence water surface elevations at bankfull flows. Special attention in the hydraulic model shall be given to boundary conditions to ensure water level changes are associated with changes in cross-sectional geometry and not with hydraulic modeling techniques. The electronic appendix of each WEST (2012, 2019, and 2021) assessment includes the HEC-RAS models used in the bankfull flow and elevation calculations.

Table 7-2: Floodprone Widths for Riffle Monitoring Cross Sections

Cross Section	Floodprone Width (ft)	Cross Section	Floodprone Width (ft)
BU01X01	253	SH01X07	439
BU01X04	233	SH02X01	1,000
BU01X06	196	SH02X03	1,000
LR01X01	1,000	SH02X04	1,000
LR01X03	1,000	SH02X06	1,000
LR01X06	222	SH03X01	412
MA01X01	1,000	SH03X02	1,000
MA01X03	473	SH03X05	1,000
MA01X05	645	SH04X01	1,000
MA01X06	417	SH04X03	1,000
MA02X01	1,000	SH04X05	1,000
MA02X03	1,000	SH05X01	1,000
MA02X06	1,000	SH05X03	1,000
MA03X01	1,000	SH05X06	1,000
MA03X04	1,000	SH06AX02	1,000
MA03X06	1,000	SH06AX04	1,000
RE01X01	768	SH06AX05	1,000
RE01X03	559	SH06X02	1,000
RE01X05	850	SH06X03	1,000
RE01X07	530	SH06X05	1,000
RE02X01	540	SH07X01	1,000
RE02X03	547	SH07X02	1,000
RE02X05	596	SH07X03	1,000
RE02X06	726	SH07X04	1,000
RE02X08	720	SH07X05	1,000
RE02X10	485	SH07X08	1,000
RE03X01	1,037	SH08X01	1,000
RE03X03	980	SH08X06	1,000
RE03X05	1,395	WC01X03	61
RE03X06	1,325	WC01X05	91
RE04X01	765	WC01X06	51
RE04X03	1,500	WC02X02	84
RE04X05	1,500	WC02X04	120
RE05X02	1,500	WC02X06	122
RE05X04	1,406	WC03X01	142
RE05X06	942	WC03X04	142
RE06AX01	1,500	WC03X06	157
RE06AX04	1,500	WC04X02	180
RE06AX06	1,500	WC04X04	144
RE06X01	1,500	WC04X06	157

Cross Section	Floodprone Width (ft)	Cross Section	Floodprone Width (ft)
RE06X02	1,500	WR01X01	444
RE06X03	1,500	WR01X03	383
RE06X05	1,500	WR01X06	328
RE07X01	1,087	WR02X02	1,000
RE07X03	1,500	WR02X04	338
RE07X06	1,171	WR02X06	287
RE08AX02	645	WR03X01	295
RE08AX04	478	WR03X04	289
RE08AX06	1,500	WR03X06	611
RE08X01	893	WR04X02	331
RE08X03	800	WR04X03	359
RE08X04	1,109	WR04X04	270
RE08X06	1,104	WR04X06	288
RE09X02	1,500	WR05X01	240
RE09X03	495	WR05X03	215
RE09X05	1,075	WR05X06	218
RE09X06	1,500	WR06X01	239
RE10X01	1,167	WR06X02	282
RE10X03	1,282	WR06X04	215
RE10X05	1,500	WR06X06	353
RE10X06	1,210	WR07X01	696
RU01X01	1,000	WR07X03	842
RU01X02	1,000	WR07X05	468
RU01X04	1,000	WR07X06	510
RU01X07	249	WR08X01	447
SH01X01	859	WR08X05	503
SH01X03	920	WR08X07	361
SH01X05	798		

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, Table 7-4, and Table 7-5, respectively. 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 7-3: Entrenchment Ratios using 2012 Survey Data and the Calculation Methodology Outlined in this Section

GMS	Entrenchment Ratio	GMS	Entrenchment Ratio	GMS	Entrenchment Ratio
BU-01	3.0	RE-08	-	SH-08	11.9
LR-01	8.1	RE-08A	-	WC-01	2.4
MA-01	8.2	RE-09	8.4	WC-02	3.9
MA-02	-	RE-10	7.7	WC-03	-
MA-03	11.1	RU-01	26.9	WC-04	-
RE-01	4.1	SH-01	7.5	WR-01	4.5
RE-02	4.2	SH-02	8.3	WR-02	6.1
RE-03	7.0	SH-03	7.9	WR-03	-
RE-04	7.6	SH-04	11.7	WR-04	-
RE-05	7.4	SH-05	13.8	WR-05	2.8
RE-06	-	SH-06A	14.0	WR-06	3.6
RE-06A	10.3	SH-06	-	WR-07	7.3
RE-07	-	SH-07	11.4	WR-08	5.3

Table 7-4: Entrenchment Ratios using 2019 Survey Data and the Calculation Methodology Outlined in this Section

GMS	Entrenchment Ratio	GMS	Entrenchment Ratio	GMS	Entrenchment Ratio
BU-01	-	RE-08	5.8	SH-08	11.5
LR-01	6.7	RE-08A	-	WC-01	-
MA-01	5.3	RE-09	8.5	WC-02	-
MA-02	9.9	RE-10	7.6	WC-03	-
MA-03	9.2	RU-01	17.0	WC-04	-
RE-01	3.9	SH-01	7.9	WR-01	3.8
RE-02	3.8	SH-02	8.7	WR-02	5.8
RE-03	6.7	SH-03	8.2	WR-03	4.6
RE-04	6.8	SH-04	11.5	WR-04	3.1
RE-05	6.9	SH-05	12.7	WR-05	2.7
RE-06	7.9	SH-06A	12.3	WR-06	3.2
RE-06A	9.6	SH-06	12.0	WR-07	6.1
RE-07	8.0	SH-07	10.4	WR-08	4.9

Table 7-5: Entrenchment Ratios using 2021 Survey Data and the Calculation Methodology Outlined in this Section

GMS	Entrenchment Ratio	GMS	Entrenchment Ratio	GMS	Entrenchment Ratio
BU-01	2.8	RE-08	6.6	SH-08	11.8
LR-01	6.4	RE-08A	6.4	WC-01	2.0
MA-01	8.3	RE-09	8.6	WC-02	5.0
MA-02	10.4	RE-10	8.1	WC-03	3.9
MA-03	10.0	RU-01	18.1	WC-04	4.9
RE-01	3.9	SH-01	7.9	WR-01	4.0
RE-02	3.9	SH-02	8.5	WR-02	6.0
RE-03	7.4	SH-03	7.5	WR-03	5.4
RE-04	6.3	SH-04	10.7	WR-04	3.3
RE-05	6.3	SH-05	12.2	WR-05	2.6
RE-06	9.2	SH-06A	10.2	WR-06	3.0
RE-06A	10.3	SH-06	10.8	WR-07	8.0
RE-07	8.9	SH-07	9.9	WR-08	5.2

7.1.3 Bank Height Ratio Calculation Prescription

The Bank Height Ratio 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.

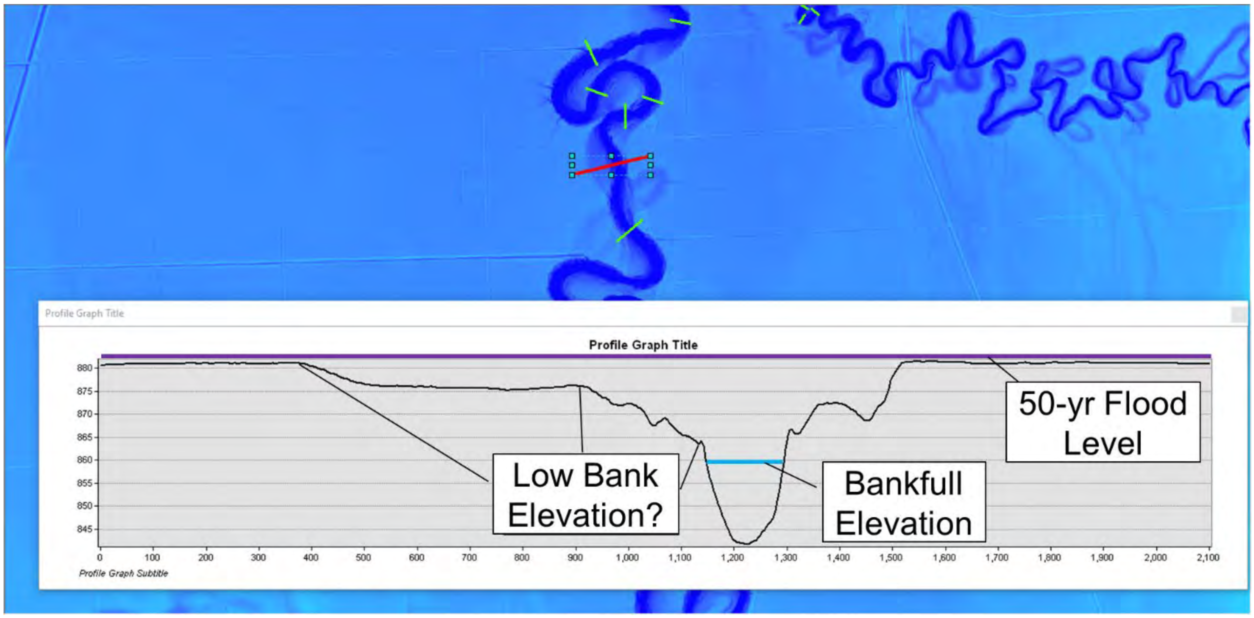


Figure 7-3: Comparison of Low Bank Height Possibilities

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 7-6.

Finally, as discussed in Section 2, an accurate establishment of bankfull flows is integral to the Bank Height Ratio calculation. Therefore, all Bank Height Ratio calculations completed for the purposes of evaluating trigger exceedance shall use the bankfull flow rates shown in Table 7-1 and a hydraulic model (such as HEC-RAS) to determine the bankfull elevation from which the maximum bankfull depth is to be calculated. A hydraulic model shall be used due to the presence of features downstream of each geomorphic monitoring station that influence water surface elevations at bankfull flows. Special attention in the hydraulic model shall be given to boundary conditions to ensure water level changes are associated with changes in cross-sectional geometry and not with hydraulic modeling techniques. The electronic appendix of each WEST (2012, 2019, and 2021) assessment includes the HEC-RAS models used in the bankfull flow and elevation calculations.

Table 7-6: Low Bank Elevations for Riffle Monitoring Cross Sections

Cross Section	Low Bank Elevation (ft NAVD88)	Cross Section	Low Bank Elevation (ft NAVD88)
BU01X01	859.8	SH01X07	875.3
BU01X04	862.9	SH02X01	884.2
BU01X06	862.1	SH02X03	883.9
LR01X01	896.1	SH02X04	884.7
LR01X03	896.6	SH02X06	884.5
LR01X06	895.7	SH03X01	886.8
MA01X01	888.7	SH03X02	886.8
MA01X03	887.4	SH03X05	886.4
MA01X05	887.4	SH04X01	894.0
MA01X06	889.7	SH04X03	893.9
MA02X01	890.8	SH04X05	893.3
MA02X03	890.7	SH05X01	897.5
MA02X06	892.2	SH05X03	902.3
MA03X01	899.8	SH05X06	902.6
MA03X04	897.8	SH06AX02	908.3
MA03X06	898.7	SH06AX04	911.6
RE01X01	857.6	SH06AX05	908.0
RE01X03	857.7	SH06X02	911.3
RE01X05	856.4	SH06X03	911.6
RE01X07	856.6	SH06X05	910.6
RE02X01	862.9	SH07X01	918.3
RE02X03	861.8	SH07X02	915.1
RE02X05	862.2	SH07X03	917.2
RE02X06	863.8	SH07X04	918.8
RE02X08	864.0	SH07X05	918.5
RE02X10	862.0	SH07X08	919.3
RE03X01	875.7	SH08X01	932.9
RE03X03	872.9	SH08X06	932.6
RE03X05	873.7	WC01X03	892.0
RE03X06	873.8	WC01X05	894.2
RE04X01	881.5	WC01X06	896.0
RE04X03	881.5	WC02X02	899.4
RE04X05	881.8	WC02X04	900.3
RE05X02	887.7	WC02X06	901.1
RE05X04	888.2	WC03X01	912.3
RE05X06	887.5	WC03X04	912.7
RE06AX01	888.1	WC03X06	912.7
RE06AX04	891.0	WC04X02	915.0
RE06AX06	890.4	WC04X04	915.2
RE06X01	888.8	WC04X06	914.9

Cross Section	Low Bank Elevation (ft NAVD88)	Cross Section	Low Bank Elevation (ft NAVD88)
RE06X02	889.7	WR01X01	890.5
RE06X03	888.9	WR01X03	889.9
RE06X05	888.2	WR01X06	891.8
RE07X01	891.4	WR02X02	891.7
RE07X03	890.9	WR02X04	891.0
RE07X06	890.4	WR02X06	891.6
RE08AX02	894.6	WR03X01	895.7
RE08AX04	890.7	WR03X04	896.6
RE08AX06	893.4	WR03X06	895.2
RE08X01	891.5	WR04X02	896.9
RE08X03	890.5	WR04X03	899.1
RE08X04	891.8	WR04X04	898.5
RE08X06	894.1	WR04X06	900.0
RE09X02	900.9	WR05X01	901.8
RE09X03	900.9	WR05X03	902.0
RE09X05	901.9	WR05X06	902.2
RE09X06	901.0	WR06X01	906.1
RE10X01	917.1	WR06X02	904.2
RE10X03	917.1	WR06X04	905.2
RE10X05	917.0	WR06X06	905.2
RE10X06	918.3	WR07X01	912.3
RU01X01	893.4	WR07X03	914.0
RU01X02	892.2	WR07X05	914.5
RU01X04	894.0	WR07X06	915.7
RU01X07	893.6	WR08X01	918.7
SH01X01	872.1	WR08X05	914.3
SH01X03	871.0	WR08X07	917.1
SH01X05	873.3		

Once the Bank Height Ratios for each monitoring cross section are calculated using the methodology listed 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 listed 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 7-7, Table 7-8, and Table 7-9, respectively. The Bank Height Ratio values in these tables were then used to establish the maximum and minimum pre-FMM Project Bank Height 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 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 7-7: Bank Height Ratios using 2012 Survey Data and the Calculation Methodology Outlined in this Section

GMS	Bank Height Ratio	GMS	Bank Height Ratio	GMS	Bank Height Ratio
BU-01	1.3	RE-08	-	SH-08	1.4
LR-01	1.4	RE-08A	-	WC-01	2.1
MA-01	1.2	RE-09	1.2	WC-02	1.1
MA-02	-	RE-10	1.2	WC-03	-
MA-03	1.2	RU-01	1.5	WC-04	-
RE-01	1.2	SH-01	1.2	WR-01	1.3
RE-02	1.2	SH-02	1.4	WR-02	1.1
RE-03	1.0	SH-03	1.1	WR-03	-
RE-04	1.0	SH-04	1.3	WR-04	-
RE-05	1.1	SH-05	1.3	WR-05	1.1
RE-06	-	SH-06A	1.4	WR-06	1.2
RE-06A	1.0	SH-06	1.2	WR-07	1.0
RE-07	-	SH-07	1.3	WR-08	1.1

Table 7-8: Bank Height Ratios using 2019 Survey Data and the Calculation Methodology Outlined in this Section

GMS	Bank Height Ratio	GMS	Bank Height Ratio	GMS	Bank Height Ratio
BU-01	-	RE-08	1.0	SH-08	1.4
LR-01	1.2	RE-08A	-	WC-01	-
MA-01	1.1	RE-09	1.2	WC-02	-
MA-02	1.0	RE-10	1.1	WC-03	-
MA-03	1.1	RU-01	1.2	WC-04	-
RE-01	1.2	SH-01	1.3	WR-01	1.1
RE-02	1.2	SH-02	1.4	WR-02	1.1
RE-03	1.0	SH-03	1.3	WR-03	1.0
RE-04	1.0	SH-04	1.4	WR-04	1.0
RE-05	1.0	SH-05	1.3	WR-05	1.1
RE-06	1.0	SH-06A	-	WR-06	1.1
RE-06A	1.0	SH-06	1.2	WR-07	0.9
RE-07	1.0	SH-07	1.3	WR-08	1.0

Table 7-9: Bank Height Ratios using 2021 Survey Data and the Calculation Methodology Outlined in this Section

GMS	Bank Height Ratio	GMS	Bank Height Ratio	GMS	Bank Height Ratio
BU-01	1.3	RE-08	1.0	SH-08	1.4
LR-01	1.1	RE-08A	1.1	WC-01	1.7
MA-01	1.1	RE-09	1.3	WC-02	1.2
MA-02	1.0	RE-10	1.3	WC-03	0.8
MA-03	1.1	RU-01	1.2	WC-04	0.9
RE-01	1.2	SH-01	1.3	WR-01	1.1
RE-02	1.3	SH-02	1.4	WR-02	1.1
RE-03	1.1	SH-03	1.2	WR-03	1.2
RE-04	1.0	SH-04	1.3	WR-04	1.1
RE-05	1.0	SH-05	1.3	WR-05	1.1
RE-06	1.0	SH-06A	1.1	WR-06	1.2
RE-06A	1.0	SH-06	1.0	WR-07	1.2
RE-07	1.0	SH-07	1.2	WR-08	1.2

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 shall be analyzed by the GMT during working meetings initiated within 90 calendar days of the final 2021 WEST report (anticipated in fall 2021), noting any changes deemed significant by the GMT. The working meetings for interpreting the analyzed data with regards to geomorphic stability 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 final 2021 WEST 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
- 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 will ultimately be responsible for determining appropriate responses and actions based on the GMT recommendations.

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, 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.

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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Appendix A: Scope of Work for the 2020 Geomorphic Assessment

SCOPE OF WORK (SOW)
Geomorphologic Monitoring of Rivers Potentially Affected
By the Fargo-Moorhead Metro Flood Risk Management Project

1 DESCRIPTION OF SERVICES

The Contractor shall provide all management, equipment, fuel, and labor necessary to complete this Task Order. All work performed by the Contractor shall be performed in accordance with all applicable laws, regulations, instructions, and commercial practices.

1.1 Purpose

The purpose of this study is to monitor aspects of the hydrology and geomorphology for each of the river reaches to provide the necessary empirical data for assessment of the potential affects from the flood risk management project. These include the Red River, Wild Rice River, Sheyenne River, Maple River, Rush River, Lower Rush River, Wolverton Creek, and Buffalo River.

1.2 Background and Objectives

The Fargo-Moorhead Metro Flood Risk Management Project (the Project) was authorized by Section 7002 of the Water Resources Reform and Development Act of 2014 (WRRDA). The Project is led by the St. Paul District, U.S. Army Corps of Engineers (USACE), in partnership with the non-federal sponsors consisting of the Metro Flood Diversion Authority, the City of Fargo, North Dakota and the City of Moorhead, Minnesota.

The Project is designed to directly alter the hydrology of the Red River and tributaries in the Project area by storing and diverting high flows. This change in hydrology has the potential to affect the geomorphology of the river channel and lateral connectivity between the river and its floodplain within the flood risk management area and for some distance upstream of the diversion. Water quality, as it relates to geomorphology, will be included in this assessment. Similarly, geomorphic processes could potentially affect the function and effectiveness of the proposed Project.

Monitoring how the hydrology, geomorphology, and water quality for each of the river reaches change through time provides the necessary empirical data for assessment of the Project's impacts. One objective of the monitoring plan is to understand what the natural and adaptive ranges of geomorphic change is for each river reach and to recognize and measure changes over time. Pre-construction and pre-Project operation surveys and other supporting data will be collected to allow for the establishment of these baseline ranges. This will include multiple sampling events prior to and following construction. It also will include sampling within the diversion channel and impact areas, as well as adjacent control sites. The first two iterations of geomorphic monitoring were completed by WEST Consultants, Inc. (WEST 2012 and 2019). This current SOW builds on the WEST monitoring data sets and will be described in more detail later.

Another objective of the monitoring plan will be relating measured geomorphic changes outside the natural and adaptive ranges to causes that may or may not include and are not limited to the Project. Identifying contributing factors other than those due to the Project, for measured changes outside of those expected for a system in dynamic equilibrium, will likely require obtaining data in addition to that which was included in the WEST reports. Examples might include land use and drainage change information, precipitation records, and others as determined to be of probable significance at specific locations. The Contractor's analysis report will identify such areas of change for future analysis by the Geomorphic Monitoring Team (GMT).

2 SERVICE SUMMARY

The Contractor will perform hydrologic analyses and comparison to past analyses and field work to complete station sampling for geomorphology assessments. Data analysis and report preparation also shall be performed. Quality Control measures will be utilized during execution of the Task Order. The USACE will inspect and evaluate the Contractor's performance to ensure services are received in accordance with this Task Order and the base contract. A written Quality Control Plan shall be submitted to the Contracting Officer for review, feedback, and approval.

This SOW details the work to be performed under this Task Order to complete the geomorphology monitoring study. The study will document and measure physical properties to help evaluate the potential interactions between geomorphic processes and flood risk management efforts.

The study area will include the following rivers in the Project area:

- Red River of the North from Abercrombie, ND to Perley, MN
- Wild Rice River from Abercrombie, ND to the Red River of the North
- Sheyenne River from Kindred, ND to the Red River of the North
- Rush River from Prosper, ND to the Sheyenne River
- Lower Rush River from Prosper, ND to the Sheyenne River
- Maple River from Mapleton, ND to the Sheyenne River
- Buffalo River from 1 mile upstream of Georgetown, MN to the Red River of the North
- Wolverton Creek for 9 miles upstream of the Red River of the North

2.1 Location of the Study Area

The study location is shown in Figure 1. The study area is the Fargo-Moorhead Metropolitan (FMM) area and communities in the vicinity, shown in the inset map on Figure 1. Fargo-Moorhead is located on the Red River of the North, but the Wild Rice, Sheyenne, Maple, Rush and Lower Rush Rivers in North Dakota and the Buffalo River and Wolverton Creek in Minnesota also cross the study area. Fargo and Moorhead are on the west and east banks, respectively, of the Red River of the North which flows north approximately 453 river miles to the mouth of the river at

Lake Winnipeg in Manitoba, Canada. The drainage area of the Red River of the North above the U.S. Geological Survey gaging station at Fargo is approximately 6,800 square miles.

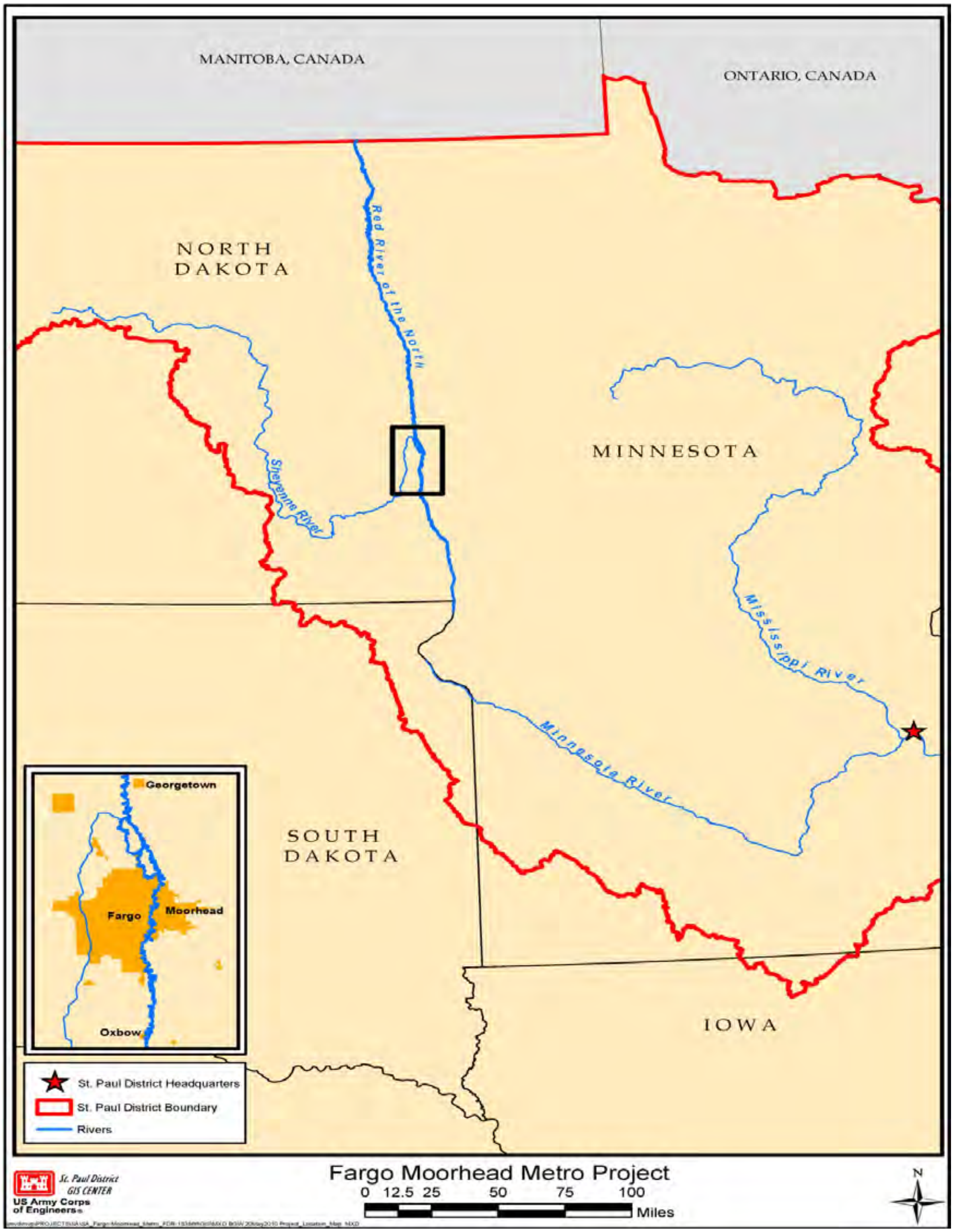


Figure 1 – Project Location Map

2.2 Project Overview

The Project consists of an approximately 30 mile-long diversion channel, an upstream staging area, individual structures on the Wild Rice River, the Red River, and at the diversion channel inlet, and a 21-mile long embankment dam, as shown in Figure 2. The diversion channel and dam alignment shapefiles are provided in Attachment A. Exact alignments of Project features are subject to change before finalization of the Project.

The Red River and the Wild Rice River structures will regulate the amount of flow passing out of the staging area into the flood risk management area during larger flood events. Flow into the diversion channel from the staging area will be controlled by the Diversion Inlet Structure. The diversion channel outlet will be a rock spillway with a low flow channel to accommodate fish passage.

The main line of flood risk management includes the three structures and the southern embankment. The structures and southern embankment will impound water and will therefore be designed to meet USACE dam safety criteria. Collectively, the structures and the southern embankment will be referred to as the dam.

At the Sheyenne and Maple Rivers, aqueduct structures will allow base flows to follow the natural river channels to maintain habitat in the natural channels. The Lower Rush River and Rush River inlet structures into the diversion will be rock ramps with the Rush River ramp being passable to fish.

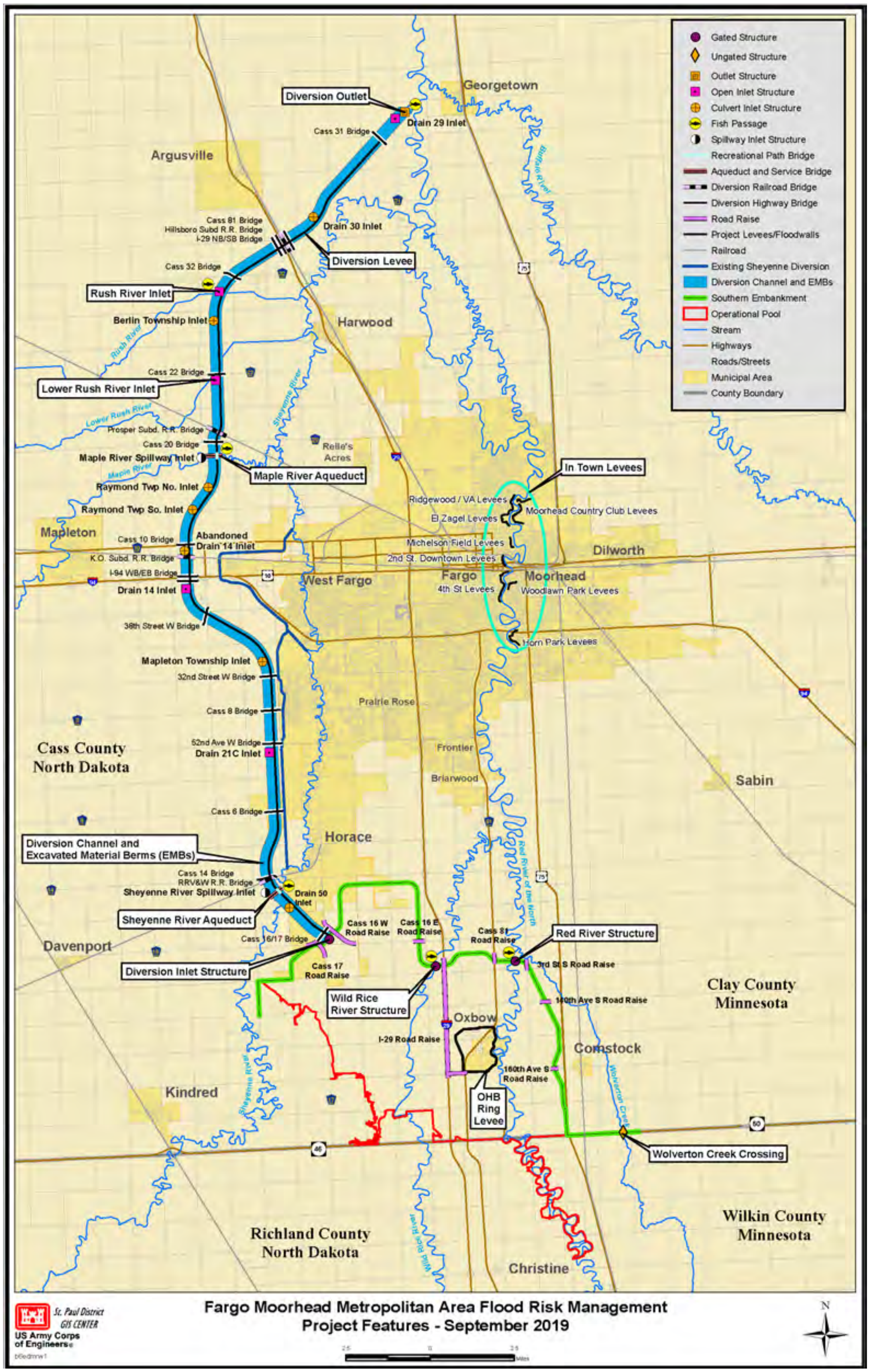


Figure 2 – Diversion Channel and Dam Alignments and Other Project Features

2.3 Project Horizontal and Vertical Datum

The Project horizontal datum is North Dakota State Plane South (US feet) and the Project vertical datum is North American Vertical Datum of 1988 (US feet). All data collected and provided as part of this SOW shall be referenced to these Project datums.

2.4 General Monitoring Plan Sampling Design

Using the Before-After Control-Impact (BACI) (Smith, 2002) accounting method for monitoring Project features has been suggested. The BACI sampling framework compares the *before* (pre-construction condition using baseline data) condition to the *after* (post-Project operation) 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 the control or reference site. This is a site that is not expected to be impacted by Project operations but is within close proximity of the Project area and is representative of the reach/sites in which changes may be observed due to Project activities. To establish baseline conditions, sampling is carried out on a number of occasions before Project operation and a number of occasions following. The sampling design discussed by the GMT has incorporated BACI methods of sampling areas both inside and outside the impacted areas and sampling several times before Project operation as well as after. This approach will help to establish a statistical basis as a means for assessing if an impact occurs. Additional input may be provided by the GMT with respect to sampling protocols during the Pre-Field Work Teleconference and during the Field Reconnaissance Tasks.

**Terminology Note: For the purposes of this SOW, "pre-construction" is defined as the time period prior to construction and during construction activities. "Post-construction" is defined as the time period following construction completion of all the Project features. This includes any planned mitigation projects that have been proposed, permitted, and/or funded. "Post-project operation" is defined as after the new dam and diversion system is operated in response to high water events.*

2.5 Geomorphic Monitoring Stations

The GMT identified cross section and data collection locations (Figure 3) for this monitoring plan. It is the best judgment of the GMT, based on their knowledge of available information, that the current list of data collection sites includes those areas most likely to show impacts from the Project as well as reference reaches that are not expected to be impacted by the 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.

A total of 42 Geomorphic Monitoring Stations (GMSs) are being monitored both pre- and post-construction with a combined 263 cross sections. The location of each GMS is shown in Figure 3 and a summary of the number of cross sections in each GMS is provided in Table 1. GMS extents, cross section locations, GMS access points, and river centerlines are provided as GIS shapefiles in

Attachment A. The paragraphs after Figure 3 and Table 1 provide descriptive details for each GMS. Each GMS is comprised of permanent cross section locations for replicate data collection. Data was collected in most of the GMSs in either the WEST (2012) and/or WEST (2019) study. The GMSs in the Diversion will be surveyed after it is constructed; therefore, data in these GMSs will not be collected as part of this Scope of Work.

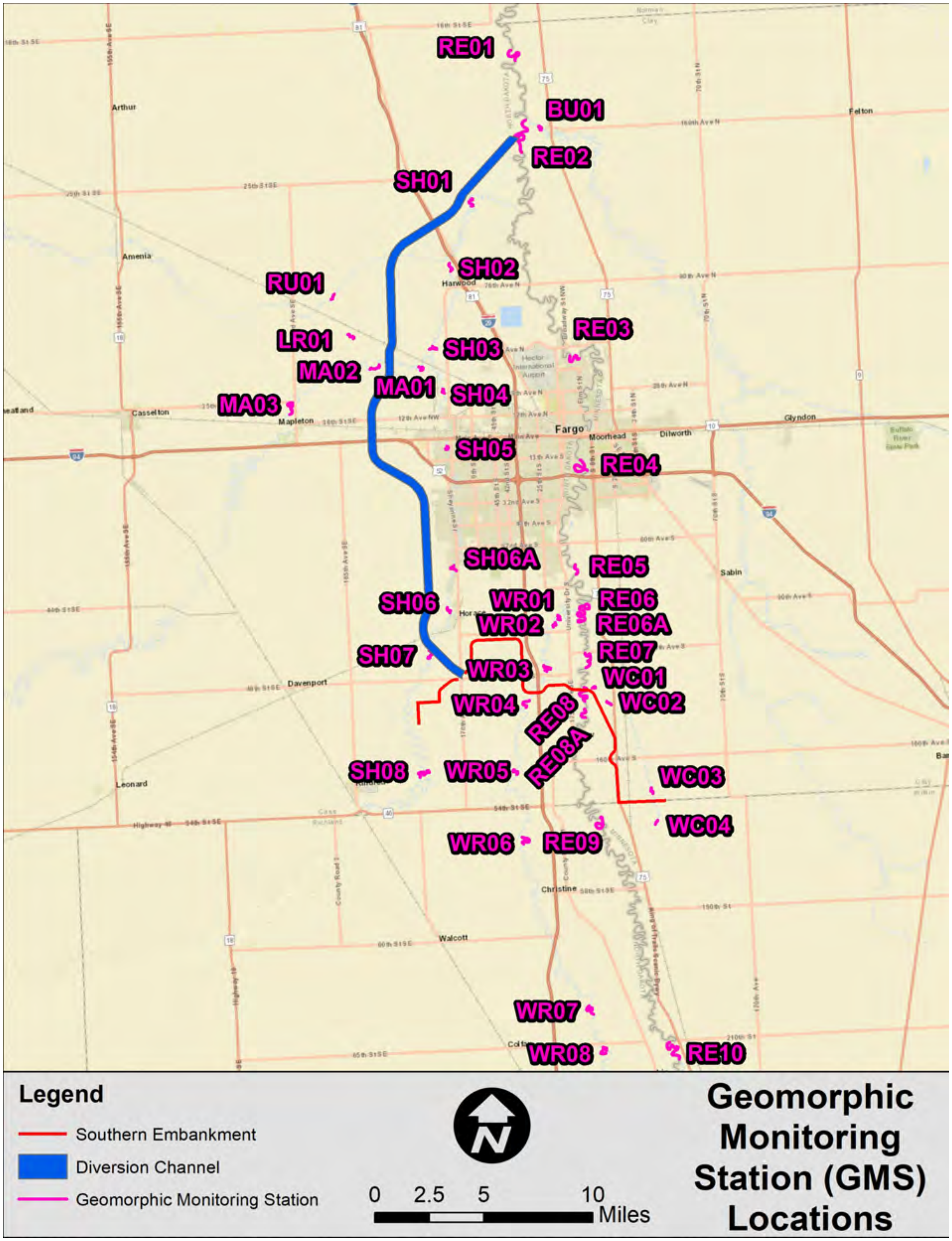


Figure 3 –Geomorphic Monitoring Station Locations

Table 1 – Geomorphic Monitoring Stations

#	GMS Name	Cross Sections	
		Total Pre-Construction	Total Post-Construction
1	RE-01	7	7
2	RE-02	10	10
3	RE-03	6	6
4	RE-04	6	6
5	RE-05	6	6
6	RE-06	6	6
7	RE-06A	6	6
8	RE-07	6	6
9	RE-08	6	6
10	RE-08A	6	6
11	RE-09	6	6
12	RE-10	6	6
13	WR-01	6	6
14	WR-02	6	6
15	WR-03	6	6
16	WR-04	6	6
17	WR-05	6	6
18	WR-06	6	6
19	WR-07	6	6
20	WR-08	7	7
21	SH-01	7	7
22	SH-02	6	6
23	SH-03	6	6
24	SH-04	6	6
25	SH-05	6	6
26	SH-06	6	6
27	SH-06A	6	6
28	SH-07	8	8
29	SH-08	6	6
30	MA-01	7	7
31	MA-02	6	6
32	MA-03	6	6
33	LR-01	6	6
34	RU-01	7	7
35	WC-01	6	6
36	WC-02	6	6
37	WC-03	6	6
38	WC-04	6	6
39	BU-01	6	6

#	GMS Name	Cross Sections	
		Total Pre-Construction	Total Post-Construction
40	DI-01	0	6
41	DI-02	0	6
42	DI-03	0	6
	TOTALS	*245*	*263*

The following paragraphs identify GMS and cross section locations along each river in the study area. GMS and cross section locations are included as GIS shapefiles in Attachment A.

Maple River

- **MA-01** - Most downstream Maple River GMS located between the confluence with Sheyenne and the diversion aqueduct. Contains a total of seven existing cross sections.
- **MA-02** - Located just upstream of diversion and aqueduct. Contains six existing cross sections.
- **MA-03** - Near Mapleton, this is the furthest upstream GMS on the Maple River. Contains six existing cross sections.

Lower Rush River

- **LR-01** - Located upstream of diversion. Contains six existing cross sections. LR-01 is the only GMS on the Lower Rush River.

Rush River

- **RU-01** - Located upstream of diversion. Contains seven existing cross sections. RU-01 is the only GMS on the Rush River.

Sheyenne River

- **SH-01** - Located upstream from the confluence with the Red River, this is the farthest downstream study GMS on this river. Contains seven existing cross sections.
- **SH-02** - Located between the Rush River's and Lower Rush River's confluences with the Sheyenne River. Contains six existing cross sections.
- **SH-03** - Located just downstream of the Maple River confluence. Contains six existing cross sections.
- **SH-04** - Located downstream of Sheyenne Diversion. Contains six existing cross sections.
- **SH-05** - Located in West Fargo upstream of the Main Avenue crossing. Contains six existing cross sections.
- **SH-06A** – Located near the 64th Avenue South crossing. Contains six existing cross sections. Note that this GMS was not included in the WEST (2019) geomorphic assessment but it was included in the WEST (2012) assessment. Survey data was collected in this GMS by WEST

in 2012 and by USACE in 2019. The USACE-collected survey data is included as Attachment B. Monuments will be placed by the USACE in this GMS as part of Task 4.2.3.

- **SH-06** - Located close to the USGS sediment monitoring site just downstream of Wall Street in Horace. Contains six existing cross sections.
- **SH-07** - Located just upstream of diversion and aqueduct. Contains eight existing cross sections.
- **SH-08** - Furthest upstream Sheyenne River GMS. Contains six existing cross sections.

Wild Rice River

- **WR-01** – Most downstream Wild Rice River GMS upstream of its confluence with the Red River. Contains six existing cross sections.
- **WR-02** - This study GMS is located downstream of 100th Ave S. Contains six existing cross sections.
- **WR-03** - Located downstream of the Wild Rice River dam. Contains six existing cross sections.
- **WR-04** - Located within the staging area. Contains six existing cross sections.
- **WR-05** - This study GMS is located in the upper retention footprint. Contains six existing cross sections.
- **WR-06** - Upstream of staging area footprint. Contains six existing cross sections.
- **WR-07** - Located upstream of County Road 28. Contains six existing cross sections.
- **WR-08** - Located upstream of County Road 4. Contains seven existing cross sections.

Red River:

- **RE-01** - Farthest downstream GMS. Contains seven existing cross sections. Important monitoring GMS just downstream of all diversion and retention features.
- **RE-02** - Covers the area immediately upstream and downstream of the downstream diversion confluence. Contains ten existing cross sections.
- **RE-03** - This study GMS is located adjacent to Trollwood Park, just downstream of Edgewood Golf Course, and upstream of Broadway N. Contains six existing cross sections.
- **RE-04** - Located just downstream of Interstate 94, bounded on the west by Lindenwood Park in Fargo and Gooseberry Mound Park in Moorhead. Contains six existing cross sections.
- **RE-05 -** Located near Briarwood, ND. Contains six existing cross sections.
- **RE-06** - This study GMS is located just downstream of the Wild Rice River confluence. RE-06 was previously defined to contain both the cross sections for this updated RE-06 and the updated RE-06A defined below in the WEST (2019) study. Contains six existing cross sections.

- **RE-06A** - This study GMS is located just upstream of the Wild Rice River confluence. The cross sections for this GMS were contained within RE-06 in the WEST (2019) study. Contains six existing cross sections.
- **RE-07 –** Located downstream of the dam and just upstream of 110th Ave S in Fargo. Contains six existing cross sections.
- **RE-08** - Located at the dam. Contains six existing cross sections.
- **RE-08A –** New GMS added to be located upstream one mile upstream of the dam. Contains six new cross sections.
- **RE-09** - GMS is located in upper staging area. Contains six existing cross sections.
- **RE-10** - This is the original furthest upstream study GMS and is located just downstream of Abercrombie, ND. Contains six existing cross sections.

Wolverton Creek

- **WC-01 –** Downstream-most GMS located between 130th Ave S and 3rd St S. GMS was not surveyed as part of the WEST (2019) effort but was surveyed as part of the WEST (2012) effort. Contains six existing cross sections.
- **WC-02** - Located downstream of Highway 75 and upstream of 130th Ave S. GMS was not surveyed as part of the WEST (2019) effort but was surveyed as part of the WEST (2012) effort. Two new riffle cross sections added to four existing cross sections to make a full complement of three riffle and three pool cross sections.
- **WC-03 –** New GMS located just downstream of the dam. Contains six new cross sections.
- **WC-04 –** New GMS located just upstream of the dam. Contains six new cross sections.

Buffalo River

- **BU-01** - Only GMS located on the Buffalo River located just on the western edge of Georgetown, downstream of Mason Street. GMS was not surveyed as part of the WEST (2019) effort but was surveyed as part of the WEST (2012) effort. One new riffle cross section added to five existing cross sections.

3 DESCRIPTION OF WORK

The Contractor shall perform all work required to conduct the specific Tasks in Section 4. All work shall conform to existing Federal, state and local regulations. The USACE will provide the Contractor with parcel maps and copies of letters sent to the public to help facilitate access to private property. The Contractor shall supply all services, labor, materials, supplies, and equipment necessary to conduct the work required under this SOW. The Contractor shall be responsible for obtaining all necessary permits and compliance with all Federal, state, and local regulations.

This SOW is similar to the scopes of work completed previously by WEST Consultants, Inc. for the USACE, as documented in the reports dated October 25, 2012 and September 10, 2019.

Similar sampling and analysis will be performed by the Contractor for this SOW and comparisons with the previous data will be documented by the Contractor as part of an ongoing trend analysis.

Phrases within the report that suggest that changes are or are not within the range of natural dynamic variability (e.g., significant, minor, etc.) shall not be used unless they are quantified and/or supported.

4 SPECIFIC TASKS

This SOW is separated into a Base Task and Options due to ongoing property access rights acquisition. Only tasks and subtasks requiring field reconnaissance data or survey data collected in support of this effort shall be considered part of the Options. All tasks and subtasks that do not require field reconnaissance data or survey data (for example, Task 4.6.1: Aerial Imagery Analysis) shall be conducted as part of the Base Task for all of the rivers and each of the 39 GMSs throughout the study area.

BASE TASK consists of the following 35 GMSs: MA-01, MA-02, MA-03, RU-01, LR-01, SH-02, SH-03, SH-04, SH-05, SH-06, SH-06A, SH-07, SH-08, WR-01, WR-02, WR-03, WR-04, WR-05, WR-08, WC-01, WC-02, WC-03, WC-04, RE-01, RE-02, RE-03, RE-04, RE-05, RE-06, RE-06A, RE-07, RE-08, RE-08A, RE-09, and RE-10.

OPTION 1 consists of the following 1 GMS: SH-01

OPTION 2 consists of the following 2 GMSs: WR-06 and WR-07

OPTION 3 consists of the following 1 GMS: BU-01

The Contractor is responsible for the following Tasks under this Task Order:

4.1 Document and Data Review

This Task Order is an extension of the analysis of geomorphic impacts and sensitivity previously documented in WEST (2012 and 2019). The existing data and studies will provide the basis for the historical channel conditions and ongoing monitoring comparison assessment. WEST (2012 and 2019) are recommended templates for reporting and analyzing the data. New data collected as part of this Task Order will be compared with the previous and historical data to track changes and trends.

As part of this Task, the Contractor shall:

1. Review previous "Geomorphology Monitoring of Rivers Potentially Affected By the Flood Risk Management Project located within the City of Fargo, Cass County, ND & City of Moorhead, Clay County, MN" reports (WEST, 2012 and 2019), included in Attachment C.

Report appendices can be provided to the Contractor by USACE upon request.

2. Review Section 4.4 of the "Supplemental Environmental Assessment, Appendix G: Adaptive Management and Mitigation Plan" (USACE, 2019), included in Attachment C.
3. Review "Project Operating Plan", included in Attachment C.
4. Review "Diversion Features", included in Attachment C.
5. Review "Sheyenne River Mitigation", included in Attachment C.
6. Review "Draft Red River of the North Basin Long-Term Flood Solutions and Flood Risk Reduction Study, Fargo, ND: Qualitative Assessment of Climate Change" (USACE, 2020), included in Attachment C.
7. Submit a statement to the Contracting Officer that these items have been fully reviewed and understood.

4.2 Field Investigations

The results of the geomorphic assessment surveys will be used to evaluate the potential interactions between near and in-channel land-surface processes and the proposed Project. The work will document the status of stream conditions and needs to be completed when stream flow is well within its banks. Topographic survey data will include cross section and longitudinal elevation data collected by the USACE survey team. The USACE will compile and process the collected topographic data in an electronic format and submit the file with a point file description table to the Contractor. The Contractor shall review and use the provided topographic survey data to calculate stream width, depth, velocity, and discharge of stream flow. Overbank, stream bank, and in-stream sediments samples shall be collected by the Contractor. In addition, the Contractor is responsible for surveying vegetation and collecting sediment samples and cores to establish deposit properties and depths.

A total of 245 cross sections and 39 GMSs are defined for the field investigations conducted under this SOW. It is noted that the Diversion channel will not be sampled under this SOW. Throughout the field investigation timeframe, USACE and other Federal, state, and local agency Project partners may be present to observe the investigation.

4.2.1 Pre-Field Work Teleconference

The Contractor shall hold a teleconference of up to four (4) hours total in duration with the USACE, as well as Federal and state natural resource agencies represented in the GMT, at least two weeks prior to the initiation of field work. Purpose is to review the SOW, sampling approach, field schedule, survey sites, and equipment to be used at each survey site, coordination with the USACE surveyor on type and resolution of topographic data to collect, coding of collected point survey data, data submittal and data review, Contractor field personnel, and agency participation.

4.2.2 GMS Reconnaissance

A reconnaissance shall be performed prior to sampling for the geomorphic, hydraulic, and vegetation assessments. The Contractor's Geomorphologists and Technician/Surveyor(s) shall participate in the reconnaissance, which will be coordinated by the Contracting Officer. Any suggested deviation in sampling protocols, based on field conditions observed during reconnaissance, must be coordinated with the Contracting Officer. The USACE will lead the effort of planning the reconnaissance with input from the Contractor and Project partner agencies.

1. The Contractor shall lead discussions in field techniques, observational methods, and sampling protocols that will be used in this effort and will ensure these will support long-term quality control and reproducibility.

2. The Contractor shall lead discussions resulting in a common field understanding and language for concepts such as bankfull elevations that will provide a basis for consistency and quality in data collection and interpretation.

3. The Contractor shall become familiar with each GMS area to the extent that will allow efficient sampling through this reconnaissance. The reconnaissance shall include a cursory view of survey sites; confirming the appropriateness of gear for temporarily locating monumented cross sections, performing surveys, and sampling sediments based on sample reach characteristics; and confirming reach access and any other logistical issues for sampling.

4.2.3 Long Term Monitoring Cross Sections

The long term nature of this study requires professional surveys and good monumentation that can be reset from the national network if and when disturbed or displaced. It is important to maintain accurate vertical and horizontal controls and many field access conditions can change over 5 and 10 year periods. Therefore, cross section end points were permanently physically "monumented" by the USACE survey team for a majority of the cross sections in concert with the WEST (2019) effort. The permanent monument location GIS shapefile is included in Attachment A. However, no monuments have been placed on private land in Minnesota or along Sheyenne River GMS site SH-06A. Therefore, at all existing cross sections in part or wholly in Minnesota and in SH-06A, the USACE will locate and monument these locations for use in the monitoring effort to allow for reproducibility in the monitoring cross section survey location. This work will be completed prior to field work completed by the Contractor. The following tasks shall be completed by the Contractor:

1. Establish long term monitoring cross section location for each new cross section defined in the following GMSs: RE-08A, WC-02, WC-03, WC-04, and BU-01. The cross section locations on the maps included as Attachment D that are referenced as new are the preliminary locations of the cross sections. The preliminary layout of the new (additional or changed) cross sections were placed in likely crossing and pool locations based on inflection points and outside bends visible in the aerial imagery. No LiDAR or field observations were used when defining the location of the new cross sections. Therefore, each new cross section's final position shall be determined in the field by the Contractor's geomorphologists and supporting investigators and shall consider crossing/riffle, pool, bankfull, terrace, flood prone area, valley geometry, erosion, and riparian features when defining the locations. Some adjustments to the preliminary new cross section locations are likely during this effort. The Contractor shall contact the Contracting Officer when sampling is planned to commence or when changes of more than 250 feet to the preliminary new cross section location is needed.

2. Contractor to field stake where cross sections need to be surveyed and monumented along each new cross section and provide descriptions for how far the cross section needs to extend past the permanent monument locations (e.g., 50 feet into the farm field in a straight line projected from the two monument locations). All field-staked locations shall have an approximate northing and easting locations (in the Project horizontal datum) collected by handheld GPS units. These field-staked locations shall be included in the Task 4.2 Field Investigations Data Submittal. If it becomes apparent that climate and/or flow conditions will make meeting this milestone unsafe or unproductive, the Contractor shall contact the Contracting Officer immediately to brief on the situation and define alternatives. The best practice for locating survey end and monument points permanently for each cross section is site dependent and shall be determined on a case by case basis. For example, when a depositional zone extends past the near overbank into an agricultural field, the Contractor shall locate the permanent monument on the cross section at a point before the field edge and use only temporary stakes and measuring tape or GPS to locate the cross section endpoint in the field.

The USACE survey team will permanently monument and survey the cross sections within 45 calendar days of the completion of Task 4.2.3 and Tasks 4.2.5.1 through 4.2.5.3.

Terminology Note: *The Red River and its tributaries exhibit 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. 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.*

4.2.4 Cross Section Sampling

Two types of cross sections shall be collected at each cross section location within each GMS. The first type of cross section is the monitoring cross section. These cross sections extend in a straight line from the monumented location on one overbank to the monumented cross section on the other overbank. The monitoring points shall be located such that the straight line between the two points is perpendicular to the valley line. The second type of cross section is one used for hydraulic modeling purposes. In many cases, this cross section may be the same as the monitoring cross section. However, as channels move and change location over the course of the monitoring period, the cross section may need to bend at points along the cross section to appropriately capture the direction of flow in the overbanks and within the channel. These cross sections must be aligned perpendicular to the bankfull channel to bankfull elevations then turned perpendicular to the valley above bankfull. The cross section end points are to be extended as necessary to cover features that may influence the hydraulics of the area. All sediment sampling, staking of top of bank, bankfull, and water surface elevations, and subsequent surveying shall be completed on a straight line of sight basis from left to right monument end locations. This will allow for replicate cross sections to be collected in the future. There is a minimum of six cross sections within each GMS, with a minimum of three at crossings (i.e., inflection point/riffle) and three at pool habitats. Some GMSs have more than the minimum 6 cross sections.

The Contractor is responsible for the following tasks:

1. Field-stake points corresponding to top-of-bank elevation (channel bank), bankfull elevation, 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. All field-staked locations shall have an approximate northing and easting locations (in the Project horizontal datum) collected by handheld GPS units. 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 (e.g., "extend cross section 50 feet beyond monument").

2. Make a qualitative description of riparian vegetation types and how that would impact bank stability.

3. Estimate percentage of banks slumping within each GMS based on field observations.

4. Document any erosion or deposition features and significant sources of sediment.

5. Look for, identify, and document contributing factors other than those due to the Project which may be affecting the channel morphology and stability since the last surveys (e.g.,

land use changes, obvious drainage changes, etc.).

6. 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).

7. Establish long-term photo stations for monitoring change at each existing and new cross sections and post-operative photo sampling each time the Project is operated. All photographs shall have approximate northing and easting locations (in the Project horizontal datum) collected either by handheld GPS units or shall be collected with a device capable of geotagging the photograph with its collected location. These are complimentary to the cross section measurements and provide additional contextual information on the location. Maintain an 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. 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.

8. Submit copies of field sheets used to document the observations and information collected in completing Tasks 4.2.4.1 through 4.2.4.7 as part of the Task 4.2 Field Investigations Data Submittal.

9. Submit electronic copy of photos collected in completing Task 4.2.4.7 organized by GMS as part of the Task 4.2 Field Investigations Data Submittal. The file name of each photo shall identify the GMS, the cross section, and the photo type (e.g., SH07X03 Left Bank).

The USACE surveyors will collect the horizontal and vertical location of all Contractor field-staked locations. The USACE surveyors will also capture cross sectional location and elevation information at grade breaks both above and below water on a straight line between the monuments (and outside the monuments, if requested to do so on field stakes by the Contractor). The USACE surveyors will also capture longitudinal profiles from the upstream-most cross section to the downstream-most cross section for each of the GMSs. These longitudinal profiles collect bed topography data in the down-channel direction and provide additional points to capture changes in the channel slope that might otherwise be missed between the monumented cross sections and is a cost-effective way of capturing that data.

4.2.5 Sediment Sampling and Analysis

In-stream, bed, bank, and overbank sampling shall be conducted by the Contractor. The Contractor shall obtain sediment samples from the three new GMSs: RE-08A, WC-03, and WC-04. Three sediment samples are anticipated within each of the new GMSs (left bank, channel, and right bank). Additionally, one overbank sedimentation sample is anticipated at every GMS (both existing and new).

1. Sediment samples representative of the size of bedload that is transported at bankfull stage shall be collected from the bed of each new GMS. This information can be used to calculate sediment competence and determine bed stability. Bed material shall be sampled at different depths (bed surface, subsurface, etc.) and locations in the plan form of the channel (thalweg, point bar, etc.) if necessary when there is an observable change in grain size distributions to provide the range of grain size gradations about those in-stream sources and deposits of material available for transport by the stream. Bed material sampling complements some of the other data like Suspended Sediment Concentrations (SSC) being collected by the USGS at locations within the Project area and cross section change. All bed sediment samples shall have an approximate northing and easting location (in the Project horizontal datum) collected by handheld GPS units.

2. Bank material samples shall be collected at one cross section within each new GMS. If vertical variation in the banks exists, this shall be noted in the field observations and samples shall be collected in each stratigraphy. All bank sediment samples shall have an approximate northing and easting locations (in the Project horizontal datum) collected by handheld GPS units.

3. Sediment samples shall be collected from deposits in overbank areas in every existing and new GMS. These samples will assist in understanding sediment deposition dynamics, as overbanks are a potential area of deposition for overbank flows carrying sediment. The Project may change the locations, extent, and depths of sediment deposited compared to existing conditions. Areas of potential increases and decreases in overbank deposition rates were identified in Section 7.1 of the WEST (2019) report. All overbank sediment samples shall have an approximate northing and easting locations (in the Project horizontal datum) collected by handheld GPS units.

4. Submit the sediment sampling report/charts/tables/figures 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) results along with a photograph and the northing and easting location for each sample collected in Tasks 4.2.5.1 through 4.2.5.3 above as part of the Task 4.2 Field Investigations Data Submittal.

4.2.6 Review of Collected Survey Data

Contractor to review survey data collected and provided by the USACE survey team within two weeks of receipt of data and indicate where additional survey points per cross section need to be collected or where the electronic data needs to be clarified, recoded, etc.

4.3 General Study Reach Update

The initial General Study Reach (GSR) extents were defined and numbered in WEST (2012). In that study, one GMS was generally defined per GSR. However, in the years since that study, the proposed dam alignment has changed, development has continued to occur, GMSs have been added, moved, or modified, and additional knowledge of the system has been gained through the two WEST reports (2012 and 2019). To address these changes, the Contractor shall reevaluate all of the GSRs and updated the GSR names and extents, as appropriate. GSRs shall be defined by considering, at a minimum, the following features: dam embankment alignment, diversion channel alignment, watercourse confluences, land uses, valley types, stream types, in-stream habitat types, controlling hydraulic features, and bed material types. Multiple GMSs are allowed to be in each GSR, if the GMSs are determined to be geomorphically similar.

The GSRs shall be named using the "GSR" abbreviation, followed by the same two letter code used to define each GMS location (e.g., RE for the Red River), followed by a letter, beginning with "A" for the downstream-most GSR of each river. For example, the downstream-most GSR on the Sheyenne River shall be referred to as "GSR-SH-A".

A figure of the GSR extents shall be included in the report and a shapefile of the GSR extents shall be provided by the Contractor in the electronic appendix to the report. A table showing the GSR in which each GMS is location shall also be included in the report.

4.4 Hydrology Assessment

As part of this Task, the Contractor shall:

1. 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 (2019) analysis forward. Additionally, the USGS gage 0505152130 – Red River of the North at Enloe, ND shall be added to the analysis and its full period of record analyzed. Finally, an evaluation of gage hydraulic controls, included in Attachment E, shall be conducted as part of the specific gage analysis to inform whether any stage changes are the result of hydraulic control changes. The provided hydraulic control information shall be included as an appendix to the report.

2. Re-determine channel-forming discharge based on the bankfull elevation defined in the Field Investigations Assessment (Section 4.2) and compare to the previous studies (WEST 2012 and 2019).

3. Assess the recurrence intervals for each of the channel-forming discharges determined in Task 4.4.2. To determine the recurrence intervals, use the recurrence interval data provided by the USACE for the WEST (2019) report.

4. Identify and evaluate significant hydrologic events observed since the WEST (2019) report that may have impacted the geomorphology of the system.

4.5 Rosgen Assessments

As part of this Task, the Contractor shall:

1. Complete all Rosgen (2006) Level II worksheets and summarize results of assessments in the report. Any maps on which results are extrapolated from an individual GMS to the broader study reach shall include language both on the map and in the report text noting that the information is extrapolated to the broader reach from the individual GMS.

2. Complete Rosgen Level III worksheets 3-1, 3-5, 3-6, and 3-10 and summarize results of assessments in the report. Any maps on which results are extrapolated from an individual GMS to the broader study reach shall include language both on the map and in the report text noting that the information is extrapolated to the broader reach from the individual GMS.

3. Compare (using figures) bankfull cross-sectional area to curves and data points developed by the MNDNR (2013) for the western area (see Attachment F).

4. Provide RIVERMorph input files for the field data that is applicable to the RIVERMorph format. 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. RIVERMorph is a commercial software and may need to be purchased by the Contractor.

4.6 Stability Analysis

Aerial imagery has been collected by the Project Non-Federal Sponsor for a number of years: 2008, 2011, 2014, and 2017 (provided in Attachment G). Imagery will also be collected in 2020. It is noted that aerial imagery covers inconsistent portions of the study area from year to year; therefore, any analysis of the imagery shall only cover those areas where imagery exists and surrogate imagery shall not be used. LiDAR data was collected at the same time the aerial images were collected. The 2017 LiDAR data has been processed into a 2.5-foot resolution Digital Elevation Model and is provided in Attachment H. As part of this Task, the Contractor shall:

1. Delineate bank lines for the study area, defined in this case as spanning from the upstream end of the upstream-most GMS on each river to that river's confluence with the Red River, or to the downstream end of RE-01 in the case of the Red River. Bank lines shall be delineated

throughout the project area for the 2008, 2011, 2014, and 2017 aerial imagery at a 1:1,000 scale. If bank lines are masked by vegetation, use 2017 LiDAR data to help inform the bank line location. None of the aerial imagery covers the entire study area, so only the portions of the study area that are covered by the imagery for the year being delineated shall be delineated. Surrogate imagery shall not be used in the delineation effort if none exists for the year being delineated.

2. Locate, measure, and document where lateral shifts in the bank line locations have occurred in the 2008, 2011, 2014, and 2017 aerial imagery. It is noted that the 2012 and 2019 WEST reports used different imagery data to identify the bank line locations. Therefore, comparisons to the WEST (2012 and 2019) bank line locations shall not be made as part of this SOW; only comparisons to the bank line locations determined as part of this SOW shall be evaluated.

3. Determine sinuosity, channel (meander) migration and erosion rates, and meander amplitude and frequency using the 2008, 2011, 2014, and 2017 aerial imagery. The Contractor shall 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.

4. Evaluate trends in sedimentary features (in-stream sediment bars), changes in large woody debris (LWD), and changes in riparian vegetation type using the 2008, 2011, 2014, and 2017 aerial imagery.

5. Evaluate the degree of incision. If channel is incised, then the influence of contained flow may increase channel erosion.

6. Identify failure mechanics under both existing and proposed conditions and identify areas that are particularly susceptible to failure.

7. Evaluate changes in surveyed cross section geometry for all historic data reported in WEST (2019) and survey data collected as part of this SOW. 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.

8. 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.

9. Data compiled under this Task shall be presented in a set of GIS-based maps of the study area showing existing channel conditions with morphological classification, the spatial distribution

of channel morphology and geomorphic processes and the zones in which different sets of geomorphic processes dominate. Any maps on which results are extrapolated from an individual GMS to the broader study reach shall include language both on the map and in the report text noting that the information is extrapolated to the broader reach from the individual GMS.

10. **OPTION 4**: Contractor shall complete the above Tasks 4.6.1 through 4.6.4 using the 2020 aerial imagery. Additionally, Contractor shall compare field-staked top of bank locations with bankline locations delineated using 2020 aerial imagery for all cross sections within each GMS. The difference in delineated bankline location versus the field-staked top of bank location for each bank in each cross section shall be calculated and summary statistics indicating the differences between the two for each river system shall be shown in tabular format. This information may help inform error estimations for the digitized bankline locations.

4.7 System Variability Assessment

One goal of this monitoring effort is to gain a better understanding of how the system has changed over time in the pre-project timeframe so that any measurable change in the system post-project can be evaluated by the GMT to determine if the Project was a primary driver of those changes. As part of this Task, the Contractor shall evaluate and describe the range of dynamic variability in the system based on observations that were collected as part of the WEST (2012 and 2019) studies as well as this current study.

System characteristics that shall be evaluated include, but are not limited to, ranges of overbank deposition, lateral bank movement, vertical channel bottom movement, depositional features, and bank slumping. Tables shall be included that summarize the system's variability observed to date and shall reference the flood magnitudes that resulted in these variability ranges.

Descriptive and summary statements based on field observations and analysis of the tables shall be provided by the Contractor. If larger floods than those that occurred during the evaluation timeframe would result in larger ranges in variability, statements to this effect shall also be made. This assessment will improve understanding of variability in the system prior to Project construction.

4.8 Future Conditions Effects Analysis

As part of this Task, the Contractor shall:

1. Compare measured changes in morphology between sampling years.

2. Update predicted morphological changes due to these future conditions including possible succession of the river channels according to the Rosgen (2006) System. A discussion of the relative results and the importance of the findings shall be included in the final report.

3. Update predicted impacts resulting from the change in the hydrology as a result of the Project to the riparian vegetation and deposition on and/or erosion from adjacent lands and relate to changes in morphology. Attachment I provides the figures showing maximum flooding depths and durations under both existing and proposed conditions for the area south of the Red River/Wild Rice River confluence for the following events: 10% ACE, 5% ACE, 1% ACE, and 0.2% ACE to assist in updating the predicted impacts. Future condition effects shall focus on both areas upstream and downstream of the proposed dam and upstream and downstream of the proposed diversion channel, which includes aqueduct structures crossing the diversion channel.

4. Incorporate "Draft Red River of the North Basin Long-Term Flood Solutions and Flood Risk Reduction Study, Fargo, ND: Qualitative Assessment of Climate Change" (USACE, 2020) into Future Conditions Effects Analysis to discuss if climate change will impact the geomorphology within the project area. If it is deemed to impact the geomorphology, additional conclusions shall be drawn as to what additional impacts, if any, the Project may cause as a result.

4.9 Reports

As part of this Task, the Contractor shall:

1. Present the findings of the geomorphology study in a technical report documenting all the above Tasks with supporting figures, maps, and data.

2. Provide Project datum geo-referenced mapping data and models in an electronic format.

3. Produce and present maps and figures in file formats compatible with ArcGIS version 10.3 or later.

4. This SOW, minus the attachments, shall be included as an appendix to the report. The SOW attachments shall be included as references to the main report if they are referenced in the report text.

5. Provide one (1) electronic copy via email and one (1) hard copy of the draft report to the Contracting Officer. Field collection data/notes, photo logs, and photographs shall be provided as report appendices. The Contractor shall be responsible for any revisions to the draft report required by the Contracting Officer.

6. Provide one (1) electronic copy via email and three (3) hard copies of the final report to the Contracting Officer. External hard drives with all data and field sheets shall be provided to the USACE at the time the final report is submitted.

4.10 Quality Control and Quality Assurance Reviews

As part of this Task, the Contractor shall:

1. Develop a Quality Control Plan for the work including (but not limited to) all field investigations, modeling work, computations, and documentation. Provide the Quality Control Plan for approval to the USACE. The Quality Control Plan must include:
   a. Names and credentials of individuals who will perform the Contractor's quality control review (reviewers shall be senior in experience to person performing work and not be directly involved in the study)
   b. Documentation plan for comments and responses
   c. Submission plan for interim review documentation to the USACE as each Task is completed (the USACE primarily reviews interim reports/results and reserves review of actual computations and models on an as needed basis)

2. Quality control reviews of the draft and final report, conducted by the Contractor, shall be a section of the Final Report and shall contain documentation on the reviewers and their credentials, products reviewed, review comments, and responses to the comments.

3. Quality assurance reviews of the draft and final report, conducted by the USACE, shall be a section of the Final Report and shall contain documentation on the reviewers and their credentials, products reviewed, review comments, and responses to the comments.

4. Models and their outputs and all computations need to be organized such that the USACE can review them if necessary. For instance, if complete computations are not included in the report(s) they shall be included in report appendices in an electronic format referencing both the point of contact for the work and the section(s) of the final report they support.

4.11 Meetings

As part of this Task, the Contractor shall:

1. Prepare for and participate in post-draft report meeting/teleconference(s) of up to eight (8) hours total in duration.

2. Prepare for and participate in up to one face-to-face agency meeting of eight (8) hours in duration in the Fargo-Moorhead area to describe the geomorphology study, with travel to and from the meeting location the day prior and after the meeting, respectively. In addition, prepare for and participate in teleconference(s) of up to four (4) hours total in duration for similar purpose.

4.12 Coordination and Project Management

Coordination of these activities is critical to the successful completion of this Task Order. The Contractor shall assure that resources are provided for all coordination and management of the work under this Task Order. Every effort shall be made to resolve critical issues in a timely manner before they become problems. Communication by telephone and email shall be used. The Contractor Project Manager shall review and process monthly invoices, provide monthly progress reports and, if necessary, update the Project schedule. Progress reports shall detail, at a minimum, the following: (i) work completed on each subtask during the month the progress report covers; (ii) projected submittal date for each subtask listed in the project schedule shown in Table 2; (iii) anticipated work efforts on each subtask for the next month; and (iv) items or information requested from USACE (if any).

5 GOVERNMENT-FURNISHED PROPERTY

The USACE will not furnish any Government property in order to perform the work required under this Task Order except those explicitly listed in this SOW.

6 METHOD OF PAYMENT

Payments will be made in accordance with the payments clause of the base contract. Each invoice shall be submitted by the Contractor to the Contracting Officer. The Contractor shall submit with any payment requests a brief summary of the activities accomplished in the payment period.

7 RELEASE OF INFORMATION

The Contractor shall not make available to the news media or publicly disclose any data generated or reviewed under this Task Order. Reports and data produced under this Task Order shall become the property of the USACE and distribution to any other source by the Contractor is prohibited, unless authorized in writing by the Contracting Officer. The Contractor shall direct all questions from the public and media to the Contracting Officer. The Contractor shall be allowed to explain its actions in the field but must inform the Contracting Officer of this public contact within one (1) workday.

8 GENERAL INFORMATION

8.1 Safety

All work shall adhere to pertinent provisions of the U.S. Army Corps of Engineers Safety and Health Requirements Manual, EM 385-1-1, dated 30 November 2014 (and all subsequent revisions).

8.2 Survey

Work shall be done in rivers with moving water and variable clarity, obstructions and bottom conditions. Adequate safety precautions shall be taken to minimize the risk of bodily injury or damage to equipment.

8.3 Rights of Entry and Easements

The Non-Federal Project Sponsor obtained rights-of-entry (ROE) or easements for properties needed to access GMSs for the Base Task and will obtain such ROE or easements prior to the exercise of Options 1, 2, and/or 3. This allows direct access from specified properties without a legal road access. The USACE will provide the Contractor rights-of-entry/easements/public access information for each GMS. The set of signed ROEs/easements for this Task Order along with contact information for each parcel are provided in Attachment J, while the GIS shapefiles containing the extents of each ROE, easement, and parcel are provided in Attachment A. Additional signed ROEs/easements will be provided for Options 1, 2, and/or 3 if those options are exercised.

1. The Contractor shall follow the requirements laid out in the individual parcel ROEs or easements. **The Contractor shall only enter properties where a ROE or an easement has been granted and the Contractor has a copy of the ROE or easement in hand.**

2. In any instance that the Contractor needs to utilize private property to access a monitoring site, the Contractor shall contact the landowner in advance of the first access by phone or email if the phone number or email has been provided. Individual ROEs and easements may specify a number of days in advance of a visit that notification is required or other requirements, and these notification requirements shall be followed by the Contractor. During notification, the Contractor shall provide an estimate of when and how long the Contractor may be on the property each day and over the course of the field investigation effort.

3. ROE or easement access on most sites may be limited to portable equipment on private property.

4. Disturbance to vegetation is to be limited and no trees shall be cut during field work.

5. It is assumed that site access for all Red River sites would be by boat ramp. Contractor must plan appropriately for sampling in such conditions. The Contractor can select how they wish to legally access survey sites, whether from public access (e.g., boat landings), public road crossings, or private property (where a ROE or easement has been obtained).

6. The Sheyenne River and Red River are navigable waterways. Therefore, work along either of these rivers can be conducted at elevations below ordinary high water (OHW) even if a ROE or an easement has not been obtained. For example, if a geomorphic monitoring cross section located on the Red River spans a North Dakota parcel for which access has been obtained and a Minnesota parcel for which access has not been obtained, crews shall limit work to the North

Dakota overbank through the channel up to OHW on the Minnesota side when evaluating a geomorphic monitoring cross section. Under this example, the Contractor shall not place any temporary or permanent markings, stakes, lathes, or any other material above OHW on the Minnesota side of cross sections. Under this example, the USACE will only survey data up to this point on the Minnesota side, which will limit the completeness of the surveys and subsequent analysis on those properties without ROE or public access.

8.4 Permits

The Contractor shall be responsible for securing all applicable sampling permits from both State and Federal Governments.

8.5 Agency Participation

Natural resource agency representatives (e.g., North Dakota State Water Commission, North Dakota Department of Health, USACE, U.S. Fish and Wildlife Service, North Dakota Game and Fish, Minnesota Department of Natural Resources, US Geological Survey, Minnesota Pollution Control Agency) will be invited by the USACE to observe all aspects of field work. Agency participation is critical for transparency, developing confidence in study results, and providing oversight that sampling is done in a reasonable and reliable manor. Agency observations of field work will generally occur from the river bank. Agency participation could occur with any aspect of reconnaissance site visits, geomorphic sampling and physical habitat assessment. The level of participation is unknown and could range from no outside agency participation to regular visits from multiple agencies. The Contractor shall contact the Contracting Officer at least one week in advance of any field work to identify dates of work and determine logistics of agency participation with the Contractor.

8.6 Training and Experience

Rosgen training through the Level III channel stability assessment by one of the team would be helpful. The standard Level III assessment is not entirely applicable to the Red River due to the very fine texture of the sediment and associated geomorphology, but some of the data collected will be useful for tracking changes over time. There are additional peer reviewed references to consider in addition to the Rosgen method for a comprehensive analysis of the system. This Task Order does not include training of any type to complete the requirements outlined.

The Contractor must ensure that sample collection, identification, analysis and report preparation are performed by fully-qualified individuals. The field assessment crew lead 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.

9 SCHEDULE

The Contractor shall furnish sufficient technical, supervisory, and administrative personnel to ensure completion of work in accordance with the schedule shown in Table 2. The Contractor shall keep the Contracting Officer fully advised at all times concerning delays or difficulties which may prohibit completion of any or all of the work according to the schedule shown in Table 2. Options 1, 2, and 3 may be exercised on or before 3 August 2020 and shall be completed in accordance with the schedule shown in Table 2. Option 4 may be exercised on or before 1 March 2021 and shall be completed by 30 April 2021.

Table 2 – Scope of Work Schedule

Task	Completed By	Completion Date
Notice to Proceed (NTP)	USACE	--
Task 4.10, Item 1 – Quality Control Plan	Contractor	7/31/2020
Task 4.1 – Document and Data Review	Contractor	8/14/2020
Task 4.2.1 – Pre-Field Work Teleconference	Contractor	8/28/2020
Task 4.2.2 – GMS Reconnaissance	Contractor	9/4/2020
Monument All Existing Monitoring Cross Sections	USACE	9/4/2020
Task 4.2.3 - Contractor Establish New Long Term Monitoring Cross Sections	Contractor	10/9/2020
Task 4.2.4, Item 1 through Item 7 - Cross Section Sampling	Contractor	10/9/2020
Tasks 4.2.5, Item 1 through Item 3 – Sediment Sampling	Contractor	10/9/2020
Install new monuments, survey cross sections and longitudinal profiles, and provide survey data to Contractor	USACE	11/23/2020
Task 4.2.6 – Review of Collected Survey Data	Contractor	12/11/2020
Task 4.2 - Field Investigations Data Submittal	Contractor	12/25/2020
Tasks 4.3, 4.4, 4.5, 4.6, 4.7, and 4.8 and Draft Report Submittal	Contractor	4/30/2021
Quality Assurance Review Comments on Draft Report	USACE	5/28/2021
Final Report Submittal	Contractor	6/18/2021
Task 4.11 – Agency Meetings	Contractor	7/16/2021
Task 4.12 – Coordination and Project Management	Contractor	Progress Reports

10 PAYMENT SCHEDULE

The Payment Schedule shall be as shown in Table 3.

Table 3 – Scope of Work Payment Schedule

Tasks/Milestone	Percent of Contract Amount
Task 4.2.5, Item 4 – Sediment Sample Analysis Data Submittal	5
Task 4.2 - Field Investigations Data Submittal	45
USACE Acceptance of Draft Report	35
USACE Acceptance of Final Report	10
Task 4.11 – Agency Meetings Complete	5

11 REFERENCES

Heo, J., Duc, T., Cho, H., Choi, S., 2009. Characterization and Prediction of Meandering Channel Migration in the GIS Environment: A Case Study of the Sabine River in the USA. *Environmental Monitoring and Assessment*. 152:155–165.

Rosgen, D., 2006. Watershed Assessment of River Stability and Sediment Supply (WARSSS). Wildland Hydrology, Fort Collins, CO.

Smith, E., 2002. BACI Design. *Encyclopedia of Environmetrics*. 1:141-148. Eds. Abdel H. El-Saharawi and Walter W. Piegorsch. Wiley, Chichester.

United States Army Corps of Engineers, St. Paul District (USACE), 2019. Fargo-Moorhead Flood Risk Management Project, Supplemental Environmental Assessment, Appendix G: Adaptive Management and Mitigation Plan.

United States Army Corps of Engineers, St. Paul District (USACE), 2020. Draft Red River of the North Basin Long-Term Flood Solutions and Flood Risk Reduction Study, Fargo, ND: Qualitative Assessment of Climate Change.

WEST Consultants, Inc. (WEST), 2012. Geomorphology Study of the Fargo, ND & Moorhead, MN Flood Risk Management Project. Prepared for US Army Corps of Engineers, St. Paul District.

WEST Consultants, Inc. (WEST), 2019. Geomorphology Study of the Fargo, ND & Moorhead, MN Flood Risk Management Project. Prepared for US Army Corps of Engineers, St. Paul District.

12 ATTACHMENTS

A. GIS Shapefiles: GMSs, Cross Sections, Parcels, Easements, Rights of Entry, Monuments, Access Points, Dam, Diversion, River Centerline

B. USACE 2019 SH-06A Survey Data

C. Project Documents

D. GMS PDF Maps

E. USGS Gage Controls

F. Minnesota Department of Natural Resources Western Area Cross-Sectional Bankfull Flow Area Spreadsheet

G. Non-Federal Sponsor Aerial Imagery

H. Non-Federal Sponsor 2.5-foot Resolution Digital Elevation Model from LiDAR

I. Pre-Project and Post-Project Flood Maps: 10% ACE, 5% ACE, 1% ACE, and 0.2% ACE Events

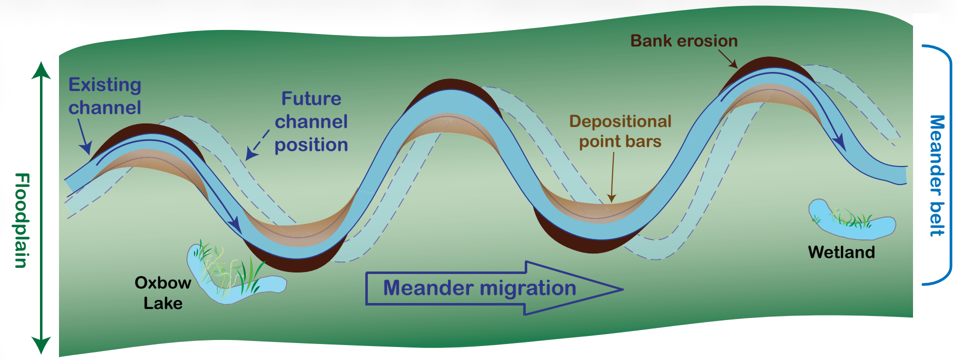
J. Signed Easements, Rights of Entries, and Landowner Contact Information

Appendix B: Resource Sheet 1: Streambank Erosion and Restoration (Minnesota DNR)

Resource Sheet 1: Streambank Erosion and Restoration

Why is my streambank eroding?

In order to determine why a streambank is eroding and to develop a restoration approach, it is necessary to understand stream behavior. All streams are dynamic, gradually changing shape as they erode, transport, and deposit sediment. A natural stream will have slowly eroding banks, developing sandbars, migrating meanders, and channels reshaped by flood flows. They are in a state of *dynamic equilibrium*, where the stream is able to maintain a stable shape (dimension, pattern, and profile) over time without excessive erosion or sedimentation even as natural changes or artificial changes occur in the watershed (see informational sheet Understanding Our Streams and Rivers). A stream system maintains this dynamic equilibrium when its natural flexibility and a functional connection to the floodplain are preserved (see figure).



A natural, healthy stream channel meanders from bend to bend within a *meander belt*. This meandering (seen here from above) is known as the stream's *pattern*.

Many streams are artificially confined; consequently, they cannot adjust or regain their equilibrium within their meander belt or floodplain after a disturbance. Streams are increasingly confined by agriculture, infrastructure, and development in the floodplain. When ditches and levees, roads, bridges and culverts, rock revetments, and other structures are placed in the floodplain, the state of dynamic equilibrium is interrupted. Confined streams can no longer self-mend, which results in instability where bed and bank erosion is a common consequence.

Land use change and channelization: The floodplain and stream corridor are impinged by agricultural fields. The meanders are disconnected after straightening by channelization.

Common causes of stream instability

Land use changes

Land use activities throughout the watershed lead to stream instability by changing the watershed's *hydrology*. Land use changes force a stream to adjust to changes in *discharge*, water *velocities*, or *sediment load*. For example, both urban storm drains and agricultural tile funnel rainfall quickly and directly into streams. These practices dramatically increase the peak discharge and water velocity of a stream. Additionally, this direct flow is low-sediment or "sediment-hungry" runoff and is very erosive. Another land use change that impacts hydrology is draining wetlands. By removing natural water storage, streams are further burdened with water that is no longer retained on the landscape. Consequently, affected streams are unstable, usually degraded and incised, and must eventually adjust their shape to accommodate the flashy discharge events with un-naturally high peak flows.

Vegetation changes

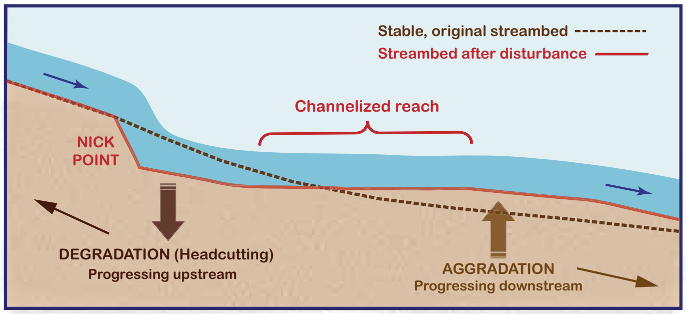
Streambank instability, erosion, and bank failure also result from a lack or loss of natural vegetation along streambanks. Deep, dense-rooting, and flood-tolerant native plants strengthen and stabilize the banks and slow floodwaters. (See additional benefits explained in Resource Sheet #2.) The loss or degradation of natural riparian vegetation can be caused by livestock overgrazing, row crops without vegetative buffers, herbicide applications, deforestation, or development. Once streambanks are degraded the potential for accelerated erosion is greatly increased because the banks are weak and unstable. Common practices of repairing banks with riprap are expensive, less stable, and lack the biological benefits of a vegetated bank.

Definitions:

aggradation: *rising streambed, sedimentation*
degradation: *lowering streambed, erosion*
discharge: *volume of water carried by a stream per unit time*
headcut: *downcutting of streambed in upstream direction*
hydrology: *movement of water through the hydrologic cycle*
nickpoint: *sudden change in the slope of the streambed*
sediment load: *amount of sediment carried by a stream*
slumping: *block(s) of bank slips down*
velocity: *speed of flow*

In-channel changes

In-channel alterations of stream shape directly disrupt stream balance resulting in *aggradation* and *degradation*. For instance, ditching or channelizing a stream replaces a long, sinuous stream reach with a short, straight, smooth channel. Such a change steepens the slope and removes roughness from the streambed. The sudden increase in speed and erosive energy of the streamflow will degrade the streambed within the straightened reach. Upstream the channel will begin to incise at the *nickpoint*. This forms an active *headcut* that migrates upstream (referred to as headcutting). Over time, the streambed continues to deepen and the entire stream reach becomes incised and disconnected from its floodplain.



In-channel changes: As shown in this side view, channelizing a stream may cause headcutting upstream and aggradation downstream.

The effects of channelization are widespread and impact the entire stream network. A headcut can initiate headcuts in the tributaries. This leads to excessive erosion and instability upstream into the basin. As excessive sediment is released into the stream system, the instability will extend downstream as the newly eroded sediment aggrades in flatter valley reaches.

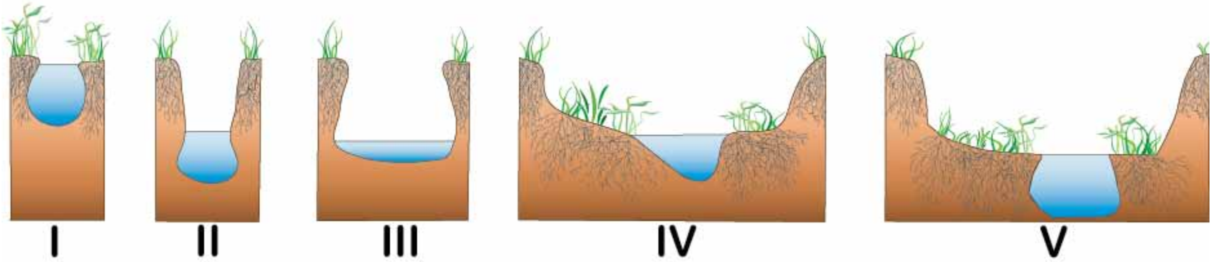
In-channel structures such as dams, bridges, and culverts interrupt the natural stream shape by creating unnatural reservoirs or passageways. For instance, culverts are commonly too small, set improperly, and do not emulate the natural channel pattern. Stream instability is the result as demonstrated by flooding upstream and erosion downstream of these structures.

Headcut & nickpoint: An active headcut degrades the bed of an Illinois stream.

Stream responses to disturbances

A disturbance such as ditching, development, or deforestation that changes the hydrology, stream shape, or riparian vegetation causes a stream to lose its equilibrium. When a stream is in disequilibrium, the stream channel actively adjusts toward a more stable form by going through transitional phases. Channel evolution can progress through many phases, where each phase could persist for years to centuries depending on stream and valley slope, geology, and hydrology. One of the more common channel degradation progressions is illustrated below.

Channel evolution



I. A properly shaped stream in **equilibrium** and connected to its floodplain prior to disturbance.
II. Channel incision from ditching or by a headcut originating in a channelized reach due to increased slope and flow.
III. Channel widening as the channel begins to meander again.
IV. A more properly shaped stream as it evolves to re-establish equilibrium and rebuild a new floodplain.
V. A new, properly shaped channel in equilibrium with a lowered floodplain.

The first section below describes an undisturbed stream in equilibrium. The next three sections describe common responses to stream instability after a disturbance. These responses vary greatly in extent and duration depending on the disturbance and the channel's recovery potential.

Equilibrium

A stream in equilibrium (Stage I in Channel evolution figure above) can transport water and sediment and dissipate the water's energy while maintaining its shape over time without excessive degradation or aggradation. A stream channel in equilibrium has these shape features:

- Pattern: a sinuous pattern that increases the stream's length, thereby decreasing its gradient and stream flows
- Profile: an alternation between riffles that help control stream gradient and pools that absorb the water's energy
- Dimension: the proper width and depth to effectively transport water and sediment supplied by the watershed

Furthermore, the channel is connected to the floodplain during high flows, the riparian zone is well vegetated, and the channel is not confined throughout the meander belt. As a result, channel movement (meander migration) and streambed and streambank erosion are minimal.

Resource Sheet 1: Streambank Erosion and Restoration

Channel incision

When a channel is incising (Stage II in Channel evolution figure), the streambed is actively eroding, downcutting, or degrading in response to disturbances such as:

- changes in the watershed (urban stormwater drains, ditching, tiling, draining wetlands) that introduce higher volumes of water or low-sediment ("sediment hungry") runoff,
- erosion by low-sediment water flowing over a dam or out of a reservoir,
- improperly sized or placed bridges or culverts that constrict flow and effectively act as dams,
- increased streamflow velocities because of disturbances such as channelization or urbanization, or
- a headcut that originated downstream.

An incised channel is disconnected from its floodplain. During high flows, the channel must transport the total volume of water because it cannot access the floodplain that, under natural conditions, could store and slow down the floodwaters. The banks of an incised channel are actively eroding (see Channel widening, below). Consequently, excessive erosion of the streambed and streambanks occurs and often results in long-term instability. As degradation continues, streambank heights and angles increase, which further reduces bank stability resulting in weak banks prone to failure and *slumping*.

Channel widening

Channel widening is lateral erosion of the streambanks (Stage III in Channel evolution figure). It can be caused by one or more of the following: channel incision; scour below culverts, bridges, or dams; flood flows in incised channels; weakened banks; increased streamflows due to watershed changes; aggradation; or construction of over-wide channels.

Channel widening occurs in an incised or scoured stream reach that attempts to find a new equilibrium by reforming and amplifying meanders to decrease the slope of the streambed and stream velocities. Also during this process, developing point bars establish a new floodplain that corresponds to the channel's new, lower streambed elevation. (For more detail, refer to the MN DNR website for the brochure, "The Shape of Healthy Rivers.")

Restoration philosophy

Incision is a common stream channel condition in Minnesota due to the prevalence of activities such as ditching and draining wetlands. It is also a systemic problem that results in stream instabilities throughout the watershed. During this response stage the channel will continue to unwind (degrade) until a new equilibrium is established. To reach equilibrium, the channel will go through successional stages that erode the banks to develop meanders, rebuild a new floodplain, and develop a properly sized channel that can effectively transport water and sediment. This process can be advanced artificially by constructing a properly shaped channel with a new lowered floodplain. Another method involves installing riffles and rock weirs that incrementally elevate the streambed to reconnect the channel to the original floodplain. These structures, unlike check dams, maintain sediment transport and are submerged during a bankfull event.

Widening is a successional stage following incision or aggradation when the channel is in disequilibrium. Restoration approaches depend on the cause, the extent of incision or aggradation, and future impacts. A restoration design could include the following:

- address upstream impacts by restoring upstream reaches (e.g. replace improperly placed culverts),
- restoring riparian vegetation,
- installing woody material and structures to add roughness, narrow the channel, and protect the banks,
- reshaping cutbanks with a bankfull bench,
- installing tree or rootwad revetments,
- excavating a properly shaped channel, or
- excavating a new floodplain.

Aggradation in Minnesota most commonly occurs downstream of channelized reaches. To re-establish equilibrium, an aggraded stream reach must develop a properly shaped channel (sinuous, deep, and narrow) through the aggraded sediment, which becomes the new floodplain. A restoration approach would be similar to that described above for an over-wide channel and similarly would depend on the cause, the extent of aggradation, recovery potential, and future circumstances.

(left) *Incision*: Extreme field erosion and an active headcut resulting from unbuffered runoff. (right) *Aggradation*: Downstream of the headcut, the flow of water slowed where the terrain flattened and deposited sediment, forming a delta.

Channel aggradation

Channel aggradation is the raising of the streambed elevation as sediment is deposited from upstream erosion along the flatter valley reaches, making the channel too shallow or over-wide. An aggraded stream reach will continue to fill and widen because the channel dimensions are out of balance with the amount of sediment that needs to be transported by the stream. More sediment settles out, further aggrading the stream bed. The channel becomes increasingly shallow, water extends laterally and erodes the banks, and stream flows more readily cause flooding.

Resource Sheet 1: Streambank Erosion and Restoration

What are the steps to address streambank erosion?

Extreme streambank erosion indicates an unstable, unhealthy stream. The instability stems from a change in the stream's shape, flow, or connectivity (see info sheet Understanding Our Streams and Rivers). These changes can be direct (ditching, dredging, straightening, dams) or the results of land use changes within the watershed (degradation of natural riparian vegetation, urbanization, logging, agriculture). Explained below are the recommended steps for restoring an eroding streambank with naturally designed approaches.

Identify the underlying cause

The first step is to determine the cause of stream instability. Are there disturbances in or along the stream; or are there destabilizing activities in the watershed? Individual landowners may not be able to control activities in a watershed that affect a stream, but landowners and citizens can have a voice in promoting and advocating natural channel design. In any situation, restoration and protection of natural riparian zones is a positive step for landowners to take to prevent or reduce streambank erosion and promote good stewardship of the watershed.

Additional adverse impacts to stream health

Channel incision, widening, and aggradation not only affect stream **shape** and **flow** but also degrade the other components of stream health:

- **Biology.** Loss and degradation of aquatic and riparian habitat (e.g. sedimentation in riffles and pools, degraded riparian vegetation).
- **Water quality.** Higher turbidity and nutrient concentrations from erosion and land inputs. Warmer water temperatures in aggraded reaches and in reservoirs.
- **Connectivity.** Disconnection from floodplain habitat (lateral) in incised streams. Disconnection from upstream and downstream reaches (longitudinal) due to dams and culverts. Increased flood risk in aggraded streams.

Adopt a natural design approach

Below is a list of recommended designs and approaches that can be used in combination to stabilize the soils in a streambank, protect the banks and floodplain, accelerate recovery, and ultimately restore stream stability. The keys to a successful bank stabilization project are:

- Allow the stream to maintain its dynamic equilibrium by not confining the channel.
- Design streambank structures to temporarily protect the banks while they stabilize.
- Consider future watershed conditions in a project design to assess how the stream will need to adjust with time.

The structures and materials listed in the box below are explained in more detail in following resource sheets.

Natural design approaches

Landscape scale
- Preserve and re-establish natural riparian and floodplain vegetation buffers
- Re-establish and protect the floodplain with compatible land use practices

Streambank stabilization and protection *(Resouce Sheet #2)*
- Vegetation: seed or plant native, deep-rooting vegetation on banks
- Biodegradable erosion-control blankets or hydroseeding
- Brush mattresses
- Biologs, wattles, or fiber rolls
- Tree revetments
- Toe wood-sod mat

In-stream bank protection
- Root wad revetments
- Bankfull bench
- J-hooks and rock vanes

Grade control (to decrease slope and reconnect channel to floodplain)
- Riffles and rock weirs

Large-scale restoration
- Re-meander straightened reach
- Remove or modify dams or improperly place culverts
- Excavate properly shaped channel
- Excavate new floodplain
- Reestablish and protect a functional floodplain with compatible land use practices
- Promote best management practices for runoff including: wetland restoration; minimum tillage; grassed waterways on agricultural land; and rain gardens and pervious pavement in urban areas

*These approaches are described in following resource sheets in this **Understanding Our Streams** series (in development).*

Consult with a professional and determine what permits you need

Contact a representative of the Stream Habitat Program from DNR Ecological Resources, your Area Hydrologist from DNR Waters, or your local soil and water conservation district to discuss what you can do on your streambank and within the watershed to minimize or correct streambank erosion. Before attempting any stabilization project, obtain the applicable permits from the DNR or other agencies. The permits you need can be identified when you contact your DNR Area Hydrologist and representatives from other agencies.

Contact Information

DNR Ecological Resources in St. Paul:
500 Lafayette Road, Box 25, St. Paul, MN 55155, (651) 259-5900
Stream Habitat Program website:
http://mndnr.gov/eco/streamhab
DNR Waters in St. Paul: 500 Lafayette Road, Box 32, St. Paul, MN 55155, (651) 259-5700
DNR Waters website:
http://mndnr.gov/waters

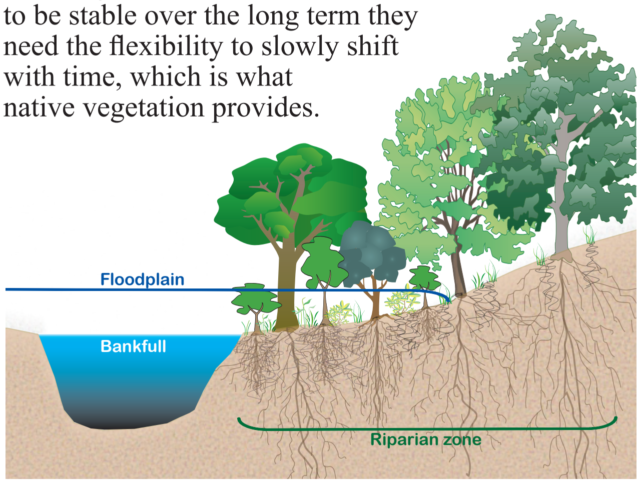
Appendix C: Resource Sheet 2: Streambank Erosion and Restoration (Minnesota DNR)

Resource Sheet 2: The Value and Use of Vegetation

Why is vegetation so important?

Naturally vegetated stream banks, riparian zones, and floodplains are crucial to streambank and channel stability, stream condition and function, water quality, and overall ecosystem health. Healthy streams provide, among many things, clean drinking water and a diversity of fish. The loss and degradation of native riparian vegetation through human activities is a common cause of streambank erosion and failure. These activities include cultivation, deforestation, watershed development, livestock overgrazing, herbicide application, and streambank armoring.

The most simple, inexpensive, and valuable form of streambank stabilization is the preservation and restoration of native riparian and floodplain vegetation. Vegetation, in addition to natural materials and structures, are rudiments of the natural channel design approach that naturally stabilize and protect streambanks. Larger materials such as logs and root wads provide strength and structure and gradually decompose giving streambanks time to re-vegetate and stabilize. For channels to be stable over the long term they need the flexibility to slowly shift with time, which is what native vegetation provides.



The benefits of streambank vegetation

Riparian zones, or buffers, along the banks naturally consist of deep-rooting, flood-tolerant plants and trees that provide multiple benefits:

Streambank stabilization
- Native riparian vegetation has dense, deep, intertwined root systems that physically strengthen soils.
- Riparian root systems remove excess moisture from the soil, making banks more resistant to erosion or slumping.
- Exposed root systems provide roughness that dissipates the water's erosive energy along the banks while the plant stems and leaves provide roughness during flood flows.

Water quality protection
- Vegetated buffers intercept and filter out much of the overland flow of water, nutrients, sediment, and pollutants; accordingly, wider corridors are more effective at protecting water quality and promoting ground-water recharge.

Riparian habitat benefits
- Diverse riparian vegetation provides shade, shelter, leafy or woody debris, and other nutrients needed by fish and other aquatic organisms.
- Wide, continuous, vegetated floodplains help dissipate flood flows, provide storage for floodwaters, retain sediment and nutrients, and provide shelter, forage, and migration corridors for wildlife.

Natural channel design fundamentals

Restoring and conserving native vegetation in the riparian zone and throughout the floodplain and meander belt is fundamental to bank stability and stream health because of the many benefits provided (see text box above). In situations where erosion is not severe and the grade is not too steep, restoring vegetation may be the only step required. In cases where erosion is more severe (e.g. cutbanks, incised channel), re-vegetation remains an essential component of a restoration involving more complex methods and structures, which are explained in following resource sheets.

Prior to planting native vegetation, non-native and nuisance species must be completely removed and the bank may need to be re-graded if the bank slope is too steep or unstable. Re-vegetation techniques include planting seeds, seedlings/saplings, live cuttings, and shrubs and hydroseeding. Live cuttings are branches cut from readily sprouting tree species, such as black willow or dogwood, preferably from nearby vegetation that is adapted to the site. These species will grow and root quickly, thereby providing immediate soil strength and erosion protection. The seeds, plants, disturbed soil, and bank toe should be protected from runoff and stream flow during the rooting process. Such erosion control products and methods are described next.

Disadvantages of hard armoring

Hard armoring banks with rock (riprap), timber walls, sheet piling, or waste concrete (which is not allowed) is a common bank protection approach; however, there are many disadvantages and undesirable impacts.
- Hard armored banks transfer the problem downstream by strengthening and redirecting stream flows downstream of the armor and into the next bend or meander resulting in bank erosion and failure, particularly along downstream bend(s).
- From an ecological standpoint, armoring does not provide aquatic or terrestrial habitat (shade, shelter, food) and has no ability to filter or process nutrients and sediments, which negatively impacts stream health.
- Armored banks can negatively affect long-term stability because they lock the channel into place preventing it from adjusting to changes in the watershed.
- Lastly, riprap is expensive to install and looks unnatural.

Resource Sheet 2: The Value and Use of Vegetation

In choosing suitable native plant species, consider local habitat type (e.g. forest, prairie, wetland) and habitat components such as shade, soil type, moisture, and climate. Resources available to identify plant species suitable for various habitat types and desired purposes, such as erosion control, aesthetics, and wildlife habitat include: local nurseries, extension offices, soil and water conservation districts, the "Restore Your Shore" CD-ROM (info at http://mndnr.gov/restoreyourshore) and MN DNR website http://mndnr.gov/gardens/nativeplants. Vegetative stabilization has all the benefits of restoring native vegetation (strengthen and stabilize stream banks, runoff buffer, provide habitat, aesthetic value) in addition to low cost, low maintenance, lack of structural complexity, and endurance. Below is a list of plant species native to Minnesota that are recommended for streambank restorations.


Canada anemone


Swamp milkweed


Golden alexanders

Common name	Scientific name	Life form	Habitat
Blue vervain	*Verbena hastata*	F	W, UM
Canada anemone	*Anemone canadensis*	F	W, UM
Golden alexanders	*Zizia aurea*	F	W, UM
Grass-leaved goldenrod	*Euthamia graminifolia*	F	W, UM
Monkey flower	*Mimulus ringens*	F	W
Obedient plant	*Physostegia virginiana*	F	W, UM
Swamp milkweed	*Asclepias incarnata*	F	W, UM
Fowl manna grass	*Glyceria striata*	G	W
Fox sedge	*Carex vulpinoidea*	G	W, UM
Hardstem bulrush	*Scirpus acutus*	G	A, W
Porcupine sedge	*Carex hystericina*	G	W
River bulrush	*Scirpus fluviatilis*	G	A, W
Softstem bulrush	*Scirpus validus*	G	A, W
Tall manna grass	*Glyceria grandis*	G	W
Virginia wild-rye	*Elymus virginicus*	G	W
Basswood	*Tilia americana*	T	UM, UD
Black willow	*Salix nigra*	T	W
Red-osier dogwood	*Cornus sericea (stolonifera)*	T	W, UM, UD
Silver maple	*Acer saccharinum*	T	W, UM

Native Minnesota plant species recommended for stream bank restorations throughout the state (sorted by Life form then Common name).
***F**: forb (flower)* ***G**: grass or grass-like* ***T**: woody vegetation*
***A**: aquatic* ***W**: wet/transitional* ***UM**: upland moist* ***UD**: upland dry*


Fox sedge


Porcupine sedge


Red-osier dogwood

Natural materials and structures

Natural materials and structures can be used in addition to native vegetation to:

- ☆ protect seed & plantings from overland and stream flows,
- ☆ protect the toe of the streambank,
- ☆ prevent erosion on slopes,
- ☆ promote trapping of sediment,
- ☆ quickly develop dense roots and sprouts, & provide habitat.

The following six techniques are effective on small to medium streams. They are of moderate cost and can be installed by most landowners with a bit of direction. Landowners should consult an area hydrologist as project approval or a permit is required by the DNR and other agencies.

Biodegradable erosion control blankets (ECBs)

» Biodegradable ECBs are made of: jute (a vegetable fiber) mesh (*in photo*), coconut/coir fiber, straw, or excelsior (fine wood fiber) that are woven into a fiber matrix. ECBs are designed to temporarily provide erosion protection and assist with vegetation establishment as they degrade over 1-3 years leaving a vegetated bank. Products with polypropylene materials are not recommended because they do not degrade and can entangle wildlife in the rigid knitting.

✖ ECBs are placed over re-graded and re-seeded streambanks (use more durable netting for steeper banks). Wood stakes or live cuttings are used to secure the fabric in place (instead of metal anchor pins). Blankets should be installed promptly after the restoration to provide immediate erosion protection.

Resource Sheet 2: The Value and Use of Vegetation

Broadcast seeding and hydroseeding

» Broadcast seeding is the scattering of native seed mixes by hand or mechanically over prepared soil. Good seed to soil contact, protection (ECBs, mulch, oats or rye as a cover crop), and watering are important.

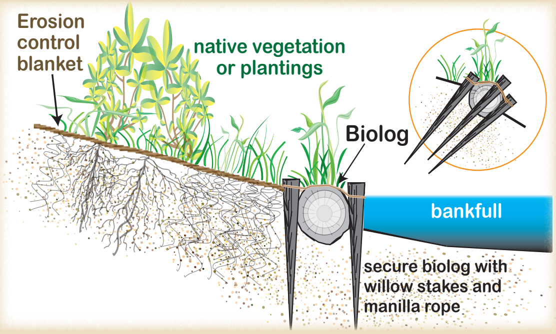
» Hydroseeding is a planting process that uses a mixture of water, seed, fertilizer, mulch, and tackifiers that is sprayed over renovated banks or slopes. Native seeds that are suitable to the habitat should be used in the mix. This mixture can be applied to the upper slopes, even on steeper slopes. The mixture should not be applied too close to the channel to avoid fertilizer from polluting the stream or seed from being washed away.

Staking and live cuttings

» Stakes and live cuttings from readily sprouting, local, healthy tree species such as black willow, dogwood, and alder are used to quickly vegetate restored streambanks. Staking can be applied on all types of banks and in addition to other techniques.

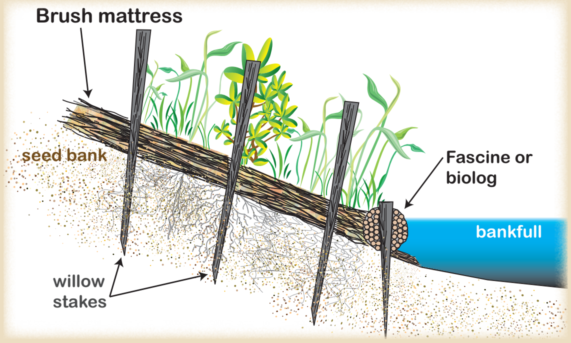
✖ The cuttings or stakes (branch sections without twigs or leaves) are cut and planted while dormant, late fall through early spring. Stakes are 2'+ in length and ½ - 3" in diameter with one end cut at a 45° angle. Stakes are planted 1 - 2' deep in soft soils or into a pilot hole in harder soils ensuring the stake is deep enough to reach permanently wet soils. Stakes are planted 1 - 2' apart depending on the size of the stakes to ensure successful survival and sufficient cover.

Biologs, coir fiber rolls, wattles, fascines



» Biologs and coir fiber rolls are made of coconut fiber, straw, or excelsior fiber. Wattles and fascines are cylindrical bundles of wheat or rice straw or cuttings. They are strong, flexible rolls (8-10' long, 8-12" diameter) of biodegradable material used to protect the toe of banks and to stabilize slopes . These structures work best where scour is not too severe and where flows will infrequently flow over the toe protection.

✖ The logs, rolls, or bundles are staked and tied into a shallow trench along the toe of the streambank to deflect flows and wave energy, retain sediment, and provide a stable structure for plant growth (substrate). Native vegetation is planted on and around the structures, then as the vegetation or cuttings becomes established, the natural materials will degrade in 2 to 6 years leaving a vegetated bank.



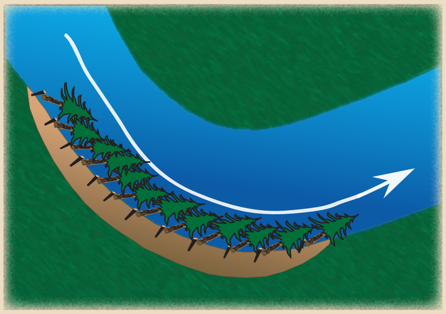
✖ Additional rows can be installed (placed in shallow trenches secured by wood stakes) upslope parallel to the toe of the bank for additional bank stabilization.

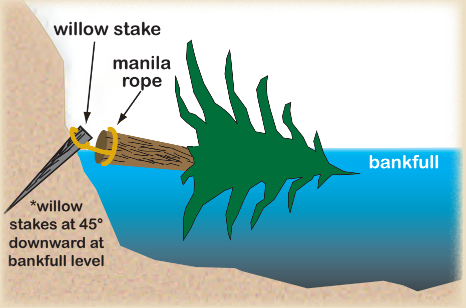
Brush mattresses

» Brush mattresses consist of a layer of interlaced dormant cuttings (e.g. willow, dogwood, alder) that are laid perpendicular to the toe and staked over a gently sloped streambank, often with a fascine or biolog at the base as toe protection.

✖ These structures work on most banks. They require good soil contact to support brush growth; base flows to keep the basal ends of the cuttings moist; and installation during the non-growing season, preferably early spring.

Tree revetments





» Tree revetments involve anchoring coniferous (such as Christmas trees) or hardwood trees along an outside bend where erosion is excessive.

✖ The trees are tied by the trunks with natural filament rope to wooden stakes placed at the bankfull level with the treetops pointing downstream. Tree revetments dissipate outside meander flows and collect sediment, thereby reducing erosion and promoting deposition.

✖ Tree revetments work best in small to medium streams with high sand or gravel loads because sediment deposition is important to the long-range goal of rebuilding and protecting the bank.

⇨ These structures provide habitat and as they degrade and accumulate sediment they become a natural, structural part of the bank.

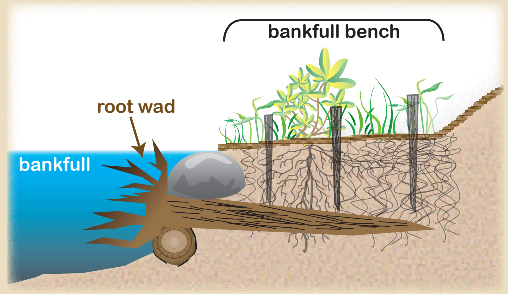
Root wad revetments

» Root wad revetments are more complex structures built into exposed cutbanks where erosion is actively cutting away the bank. These revetments commonly involve the construction of a bankfull bench to help accommodate and dissipate flood flows. This design is especially useful where there is infrastructure on the bank that needs to be protected from bank loss or slumping. These revetments can be scaled to the size of the stream (e.g., root wads can be stacked in large streams). They are not recommended in sandy soils where it is difficult to drive the trunks into the bank and the sand is more erodible.

✖ Large tree trunks with root wads are driven into a renovated cutbank so that the trunks angle upstream and the root wads are positioned below bankfull level directed into the flow. The trunks are secured with large boulders and a matrix of logs. Live cuttings are staked, natural vegetation planted or seeded, and erosion control fabric is staked on the bankfull bench and restored bank.

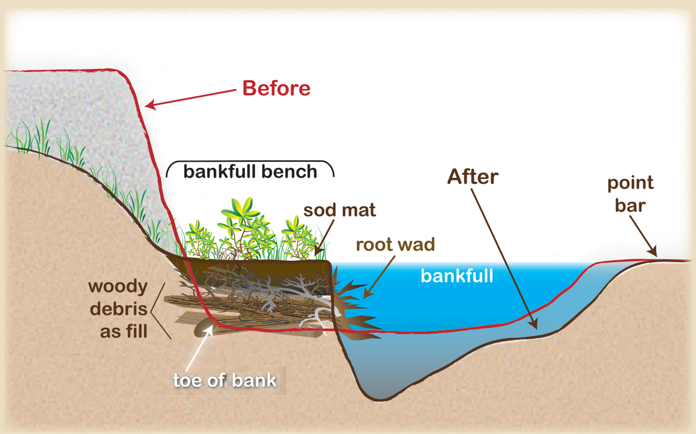
⇨These revetments protect the banks over a range of flows, provide substrate for invertebrates and refuge for fish, and will slowly degrade while becoming a natural part of the streambank.

Variations of this design have been used through the years. For more specific design details see Applied River Morphology by Dave Rosgen, 1996.



Installation of root wads using an excavator to drive tree trunks into the bankfull bench (looking upstream).

Root wad revetment and a revegetated bankfull bench built to stabilize a cutbank encroaching on Interstate 94, two years after construction (looking downstream).



Toe wood-sod mats *(see fact sheet for more details)*

» Toe wood-sod mats involve similar design elements to the root wad revetments. This approach can be scaled to all stream sizes.

✖ Cutbanks are renovated with a bankfull bench consisting of layers of logs, branches, brush, roots, and fill. Root wads can be incorporated to provide additional roughness and habitat. These layers are then covered with sod mats, willow cuttings, and transplants set at bankfull stage.

⇨ This structure design restores the connection to the floodplain with a bankfull shelf, restores channel dimensions, protects a once vulnerable and unstable cutbank, provides habitat (both aquatic and terrestrial), and is relatively inexpensive.

Variations of this design have been used through the years. General design details are credited to Dave Rosgen of Wildland Hydrology.

Review and advanced restoration designs

Bank restorations utilizing vegetation, erosion-control blankets, biologs, wattles, revetments, and mats or combinations thereof, can effectively protect and rebuild banks if properly placed and established. These approaches utilize all natural materials that do not artificially confine the channel, they are relatively inexpensive, and can be applied to all stream varieties (forested, prairie, steep, gentle, rocky, sandy). As explained in Resource Sheet #1, the cause(s) of stream instability and future watershed conditions should be considered. Most projects will need permits and professional assistance.

In some cases in-channel structures can also be used to protect restored or unstable banks. These include rock structures such as rock vanes, J-hooks, and riffles that are effective at properly slowing and deflecting flows from the streambanks. Installation of these structures requires professional assistance because proper placement is absolutely essential for successful streambank protection and restoration. This requires stream and watershed monitoring and assessments. These in-channel structures are explained in more detail in the following resource sheets.

Contact Information

DNR Ecological Resources:
Stream Habitat Program
Ecosystem Restoration
500 Lafayette Road, Box 25
St. Paul, MN 55155
(651) 259-5900

DNR Waters:
Public Water Permit Requirements
500 Lafayette Road, Box 32
St. Paul, MN 55155
(651) 259-5700

DNR website:
http://mndnr.gov

Appendix D: Stream Restoration: Toe Wood-Sod Mat (Minnesota DNR)

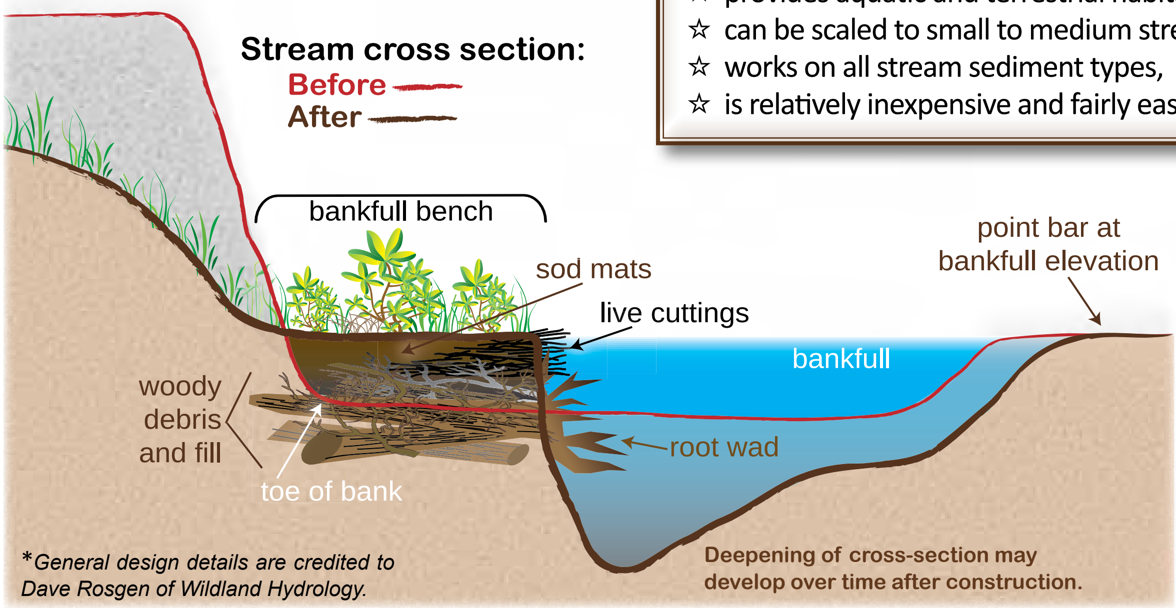
Stream Restoration: Toe Wood-Sod Mat

Purpose of a Toe Wood-Sod Mat

All streambank restoration project goals should be to: 1) restore channel function, dimensions and connection to the floodplain, 2) provide short-term protection that promotes natural long-term stability, 3) allow the channel to adjust over the long-term, 4) protect meanders (a.k.a., sinuosity) of a stream to prevent a meander cutoff. A toe wood-sod mat provides the opportunity to add stability, habitat, and streambank protection where it is needed.

The toe wood-sod mat is a preferred design because it:

- ☆ restores channel dimensions (width & depth),
- ☆ protects a once vulnerable and unstable cutbank,
- ☆ restores the connection to the floodplain with a bankfull bench,
- ☆ incorporates transplanted sod mat(s) and live cuttings that grow quickly and develop dense roots,
- ☆ utilizes all natural materials using local vegetation and sod,
- ☆ provides aquatic and terrestrial habitat,
- ☆ can be scaled to small to medium streams,
- ☆ works on all stream sediment types,
- ☆ is relatively inexpensive and fairly easy to install.



Construction of a Toe Wood-Sod Mat:

The cutbank is renovated by angling back the upper bank and excavating or filling in (depending on stream width and site restrictions) the lower bank with a bankfull bench. The bench consists of a bottom layer of logs, branches, brush, roots and soil as fill. Root wads can be incorporated to provide additional roughness and habitat. The fill is covered with a layer of live cuttings then with a top layer of sod mats and transplants set at *bankfull stage* (*the flow at which the channel fills the banks and just begins to overflow onto the floodplain*), which is level with the point bar. The stream bed may deepen with time as the stream develops its proper dimensions. In some cases, rock vanes may be installed up and downstream of the mat depending on how flow is impacted. A permit is needed from the DNR to construct a toe wood-sod mat. Permits may also be required from local and federal agencies. Contact your DNR Area Hydrologist for permit information.

Streambank restoration fundamentals:

Several factors need to be considered when proposing a streambank restoration project, like a toe wood-sod mat:

Evaluate the current and future watershed condition. Often, the presence of cutbanks indicates watershed-scale channel incision due to channel straightening, changes in the watershed that have introduced low-sediment water (dam, urbanization, tiling), or increased flood magnitude (see Resource Sheet #1). Before taking action, consider the purpose and scale of a restoration.

Determine if there really is an erosion problem. Channel erosion is natural channel adjustment to change. Occasional cutbanks are a natural stream feature that provide unique habitat. For example, a straightened ditch that is forming new meanders is adjusting towards a more stable form. Yet there are cases where local protection of infrastructure is necessary, and so determining if erosion is a problem is important.

Contact Information

DNR Ecological & Water Resources:

Stream Habitat Program
500 Lafayette Road, Box 25
St. Paul, MN 55155, (651) 259-5100

Public Water Work Permit Program
500 Lafayette Road, Box 32
St. Paul, MN 55155
(651) 259-5700

DNR website:
http://mndnr.gov

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.

Appendix E: Chapter 11 of National Engineering Handbook 654 (Natural Resources Conservation Service)

United States
Department of
Agriculture

**Natural
Resources
Conservation
Service**

Part 654 Stream Restoration Design
National Engineering Handbook

Chapter 11 Rosgen Geomorphic Channel Design

Issued August 2007

Cover photo: Stream restoration project, South Fork of the Mitchell River, NC, three months after project completion. The Rosgen natural stream design process uses a detailed 40-step approach.

Advisory Note

Techniques and approaches contained in this handbook are not all-inclusive, nor universally applicable. Designing stream restorations requires appropriate training and experience, especially to identify conditions where various approaches, tools, and techniques are most applicable, as well as their limitations for design. Note also that product names are included only to show type and availability and do not constitute endorsement for their specific use.

Chapter 11 Rosgen Geomorphic Channel Design

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Chapter 11 Rosgen Geomorphic Channel Design

654.1100 Purpose

This chapter outlines a channel design technique based on the morphological and morphometric qualities of the Rosgen classification system. While this approach is written in a series of steps, it is not a cookbook. This approach is often referred to as the Rosgen design approach. The essence for this design approach is based on measured morphological relations associated with bankfull flow, geomorphic valley type, and geomorphic stream type. This channel design technique involves a combination of hydraulic geometry, analytical calculation, regionalized validated relationships, and analogy in a precise series of steps. While this technique may appear to be straightforward in its application, it actually requires a series of precise measurements and assessments. It is important for the reader to recognize that the successful application of this design approach requires extensive training and experience.

The contents of this chapter were submitted to the technical editors of this handbook as a manuscript titled Natural Channel Design Using a Geomorphic Approach, by Dave Rosgen, Wildland Hydrology, Fort Collins, Colorado. This material was edited to fit the style and format of this handbook. The approaches and techniques presented herein are not universally applicable, just as other approaches and techniques presented in this handbook are not necessarily appropriate in all circumstances. However, the Rosgen Geomorphic Approach for Natural Channel Design has been implemented in many locations and is cited as the methodology of choice for stream restoration by several state and local governments.

654.1101 Introduction

River restoration based on the principles of the Rosgen geomorphic channel design approach is most commonly accomplished by restoring the dimension, pattern, and profile of a disturbed river system by emulating the natural, stable river. Restoring rivers involves securing their physical stability and biological function, rather than the unlikely ability to return the river to a pristine state. Restoration, as used in this chapter, will be used synonymously with the term rehabilitation. Any river restoration design must first identify the multiple specific objectives, desires, and benefits of the proposed restoration. The causes and consequences of stream channel problems must then be assessed.

Natural channel design using the Rosgen geomorphic channel design approach incorporates a combination of analog, empirical, and analytical methods for assessment and design. Because all rivers within a wide range of valley types do not exhibit similar morphological, sedimentological, hydraulic, or biological characteristics, it is necessary to group rivers of similar characteristics into discreet stream types. Such characteristics are obtained from stable reference reach locations by discreet valley types, and then are converted to dimensionless ratios for extrapolation to disturbed stream reaches of various sizes.

The proper utilization of this approach requires fundamental training and experience using this geomorphic method. Not only is a strong background in geomorphology, hydrology, and engineering required, but the restoration specialist also must have the ability to implement the design in the field. The methodology is divided into eight major sequential phases:

I Define specific restoration objectives associated with physical, biological, and/or chemical process.

II Develop regional and localized specific information on geomorphologic characterization, hydrology, and hydraulics.

III Conduct a watershed/river assessment to determine river potential; current state; and the nature, magnitude, direction, duration, and consequences of change. Review land use history and time trends of river change. Isolate the primary causes of instability and/or loss of physical and biological function. Collect and analyze field data including reference reach data to define sedimentological, hydraulic, and morphological parameters. Obtain concurrent biological data (limiting factor analysis) on a parallel track with the physical data.

IV Initially consider passive restoration recommendations based on land use change in lieu of mechanical restoration. If passive methods are reasonable to meet objectives, skip to the monitoring phase (VIII). If passive efforts and/or recovery potential do not meet stated multiple objectives, proceed with the following phases.

V Initiate natural channel design with subsequent analytical testing of hydraulic and sediment transport relations (competence and capacity).

VI Select and design stabilization/enhancement/vegetative establishment measures and materials to maintain dimension, pattern, and profile to meet stated objectives.

VII Implement the proposed design and stabilization measures involving layout, water quality control, and construction staging.

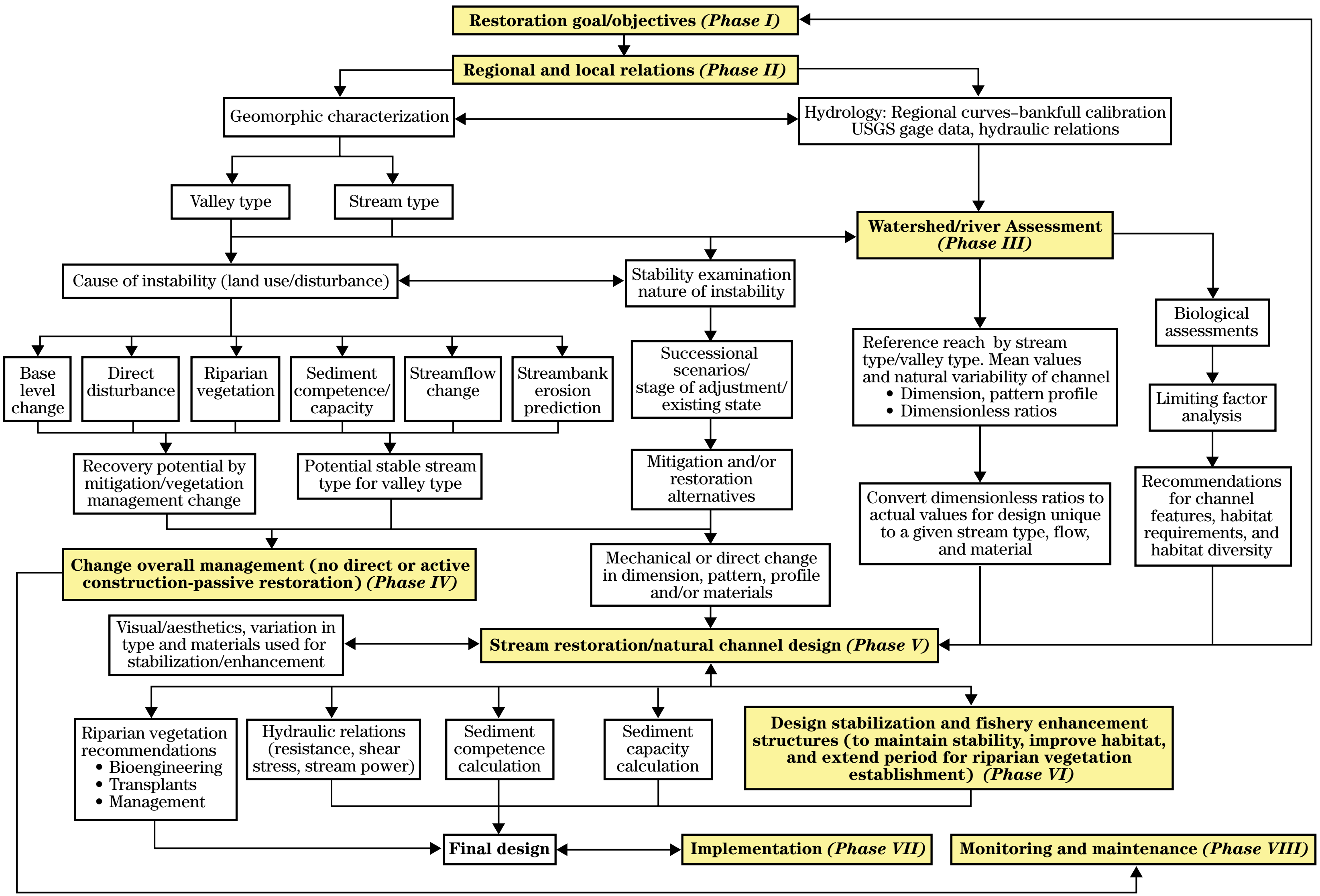
VIII Design a plan for effectiveness, validation, and implementation monitoring to ensure stated objectives are met, prediction methods are appropriate, and the construction is implemented as designed. Design and implement a maintenance plan.

The conceptual layout for the phases of the Rosgen geomorphic channel design approach is shown in figure 11–1. The various phases listed above are indicated on this generalized layout. The flowchart is indicative of the full extent and complexity associated with this method.

Because of the complexity and uncertainty of natural systems, it becomes imperative to monitor each restoration project. The following are three objectives of such monitoring:

- Ensure correct implementation of the design variables and construction details.
- Validate the analog, empirical, and analytical methods used for the assessment and design.
- Determine effectiveness of the restoration methods to the stated physical and biological restoration objectives.

Figure 11–1 River restoration using Rosgen geomorphic channel design approach



654.1102 Restoration phases

(a) Phase I—Restoration objectives

It is very important to obtain clear and concise statements of restoration objectives to appropriately design the solution(s). The potential of a certain stream to meet specific objectives must be assessed early on in the planning phases so that the initial restoration direction is appropriate. The common objectives are:

- flood level reduction
- streambank stability
- reduce sediment supply, land loss, and attached nutrients
- improve visual values
- improve fish habitat and biological diversity
- create a natural stable river
- withstand floods
- be self-maintaining
- be cost-effective
- improve water quality
- improve wetlands

It is essential to fully describe and understand the restoration objectives. The importance of formulating clear, achievable, and measurable objectives is described in detail in NEH654.02. Often the objectives can be competing or be in conflict with one another. Conflict resolution must be initiated and can often be offset by varying the design and/or the nature of stabilization methods or materials planned.

The assessment required must also reflect the restoration objectives to ensure various related processes are thoroughly evaluated. For example, if improved fishery abundance, size, and species are desired, a limiting factor analysis of habitat and fish populations must be linked with the morphological and sedimentological characteristics.

(b) Phase II—Developing local and regional relations in geomorphic characterization, hydrology, and hydraulics

Geomorphic characterization

The relations mapped at this phase are the geomorphic characterization and description levels for stream classification (Rosgen 1994, 1996). Valley types (table 11–1) are mapped prior to stream classification to ensure reference reach data are appropriately applied for the respective valley types being studied. Morphological relations associated with stream types are presented in figures 11–2 (Rosgen 1994) and 11–3 (Rosgen 1996) and summarized in table 11–2. In natural channel design using the Rosgen geomorphic channel design approach, it is often advantageous to have an undisturbed and/or stable river reach immediately upstream of the restoration reach. Reference reach data are obtained and converted to dimensionless ratio relations to extrapolate channel dimension, pattern, profile, and channel material data to rivers and valleys of the same type, but of different size. If an undisturbed/stable river reach is not upstream of the restoration reach, extrapolation of morphological and dimensionless ratio relations by valley and stream type is required for both assessment and design.

An example of the form used to organize reference reach data, including dimensionless ratios for a given stream type, is presented in table 11–3. Specific design variables use reference reach data for extrapolation purposes, assuming the same valley and stream type as represented. These relations are only representative of a similar stable stream type within a valley type of the disturbed stream.

Hydrology

The hydrology of the basin is often determined from regional curves constructed from long-term stream gage records. Relationships of flow-duration curves and flood-frequency data are used for computations in both the assessment and design phases. Stream Hydrology is also addressed in NEH654.05. Relations are converted to dimensionless formats using bankfull discharge as the normalization parameter. Bankfull discharge and dimensions associated with stream gages are plotted as a function of drainage area for extrapolation to ungaged sites in similar hydro-physiographic provinces. A key requirement in the development of

Table 11–1 Valley types used in geomorphic characterization

Valley types	Summary description of valley types
I	Steep, confined, V-notched canyons, rejuvenated side slopes
II	Moderately steep, gentle-sloping side slopes often in colluvial valleys
III	Alluvial fans and debris cones
IV	Gentle gradient canyons, gorges, and confined alluvial and bedrock-controlled valleys
V	Moderately steep, U-shaped glacial-trough valleys
VI	Moderately steep, fault, joint, or bedrock (structural) controlled valleys
VII	Steep, fluvial dissected, high-drainage density alluvial slopes
VIII	Wide, gentle valley slope with well-developed flood plain adjacent to river and/or glacial terraces
IX	Broad, moderate to gentle slopes, associated with glacial outwash and/or eolian sand dunes
X	Very broad and gentle valley slope, associated with glacio- and nonglacio-lacustrine deposits
XI	Deltas

Figure 11–2 Broad-level stream classification delineation showing longitudinal, cross-sectional, and plan views of major stream types

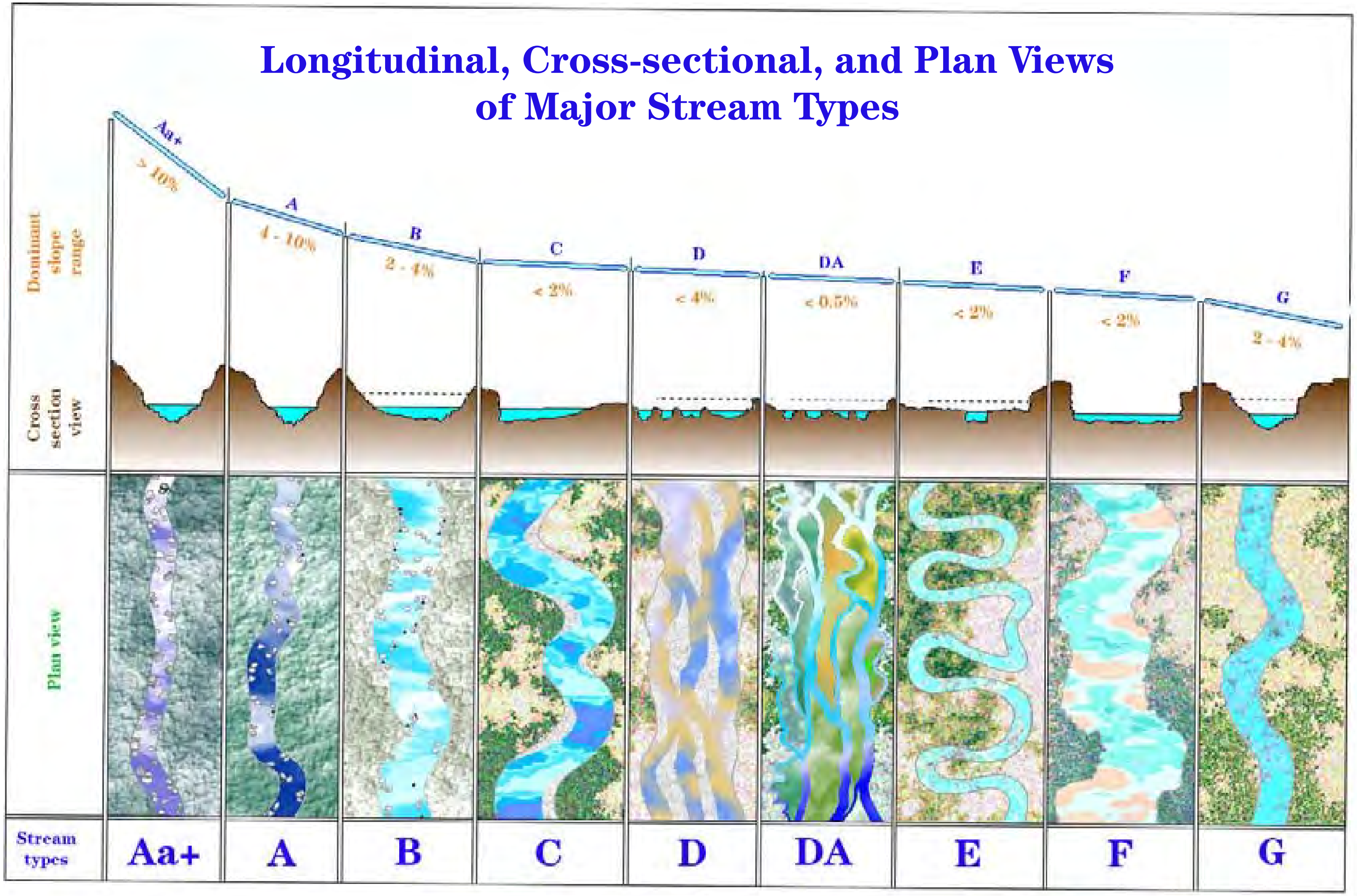
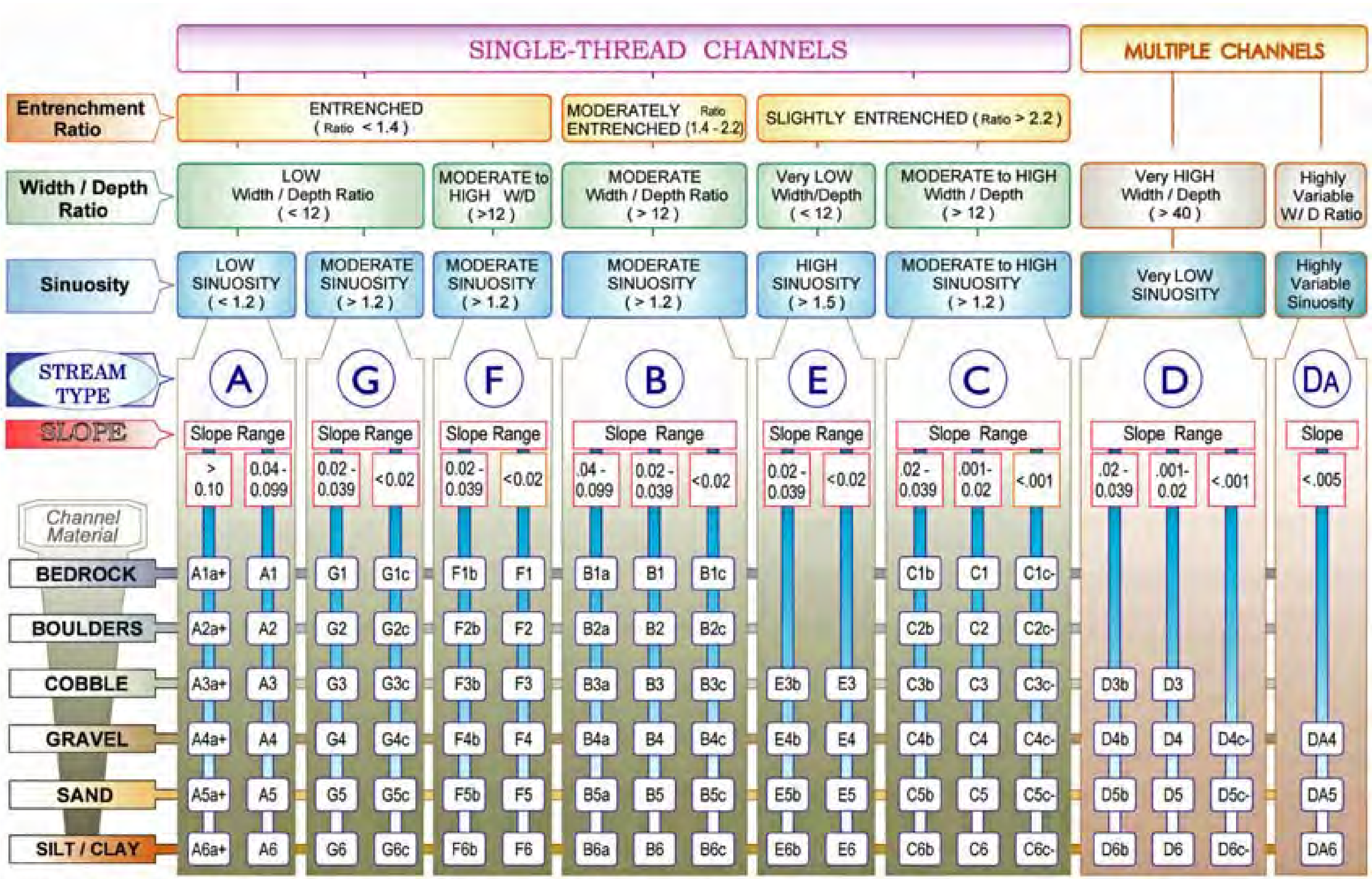


Figure 11–3 Classification key for natural rivers



KEY to the ROSGEN CLASSIFICATION of NATURAL RIVERS. As a function of the *"continuum of physical variables"* within stream reaches, values of ***Entrenchment*** and ***Sinuosity*** ratios can vary by +/- 0.2 units; while values for ***Width / Depth*** ratios can vary by +/- 2.0 units.

Table 11–2 General stream type descriptions and delineative criteria for broad-level classification (level 1)

Stream type	General description	Entrench-ment ratio	W/d ratio	Sinuosity	Slope	Landform/ soils/features
Aa+	Very steep, deeply entrenched, debris transport, torrent streams	<1.4	<12	1.0 to 1.1	>.10	Very high relief. Erosional, bedrock, or depositional features; debris flow potential. Deeply entrenched streams. Vertical steps with deep scour pools; waterfalls
A	Steep, entrenched, cascading, step-pool streams. High energy/ debris transport associated with depositional soils. Very stable if bedrock or boulder-dominated channel	<1.4	<12	1.0 to 1.2	.04 to .10	High relief. Erosional or depositional and bedrock forms. Entrenched and confined streams with cascading reaches. Frequently spaced, deep pools in associated step-pool bed morphology
B	Moderately entrenched, moderate gradient, riffle dominated channel with infrequently spaced pools. Very stable plan and profile. Stable banks	1.4 to 2.2	>12	>1.2	.02 to .039	Moderate relief, colluvial deposition and/or structural. Moderate entrenchment and width-to-depth ratio. Narrow, gently sloping valleys. Rapids predominate with scour pools
C	Low gradient, meandering, point bar, riffle/pool, alluvial channels with broad, well-defined flood plains	>2.2	>12	>1.2	<.02	Broad valleys with terraces, in association with flood plains, alluvial soils. Slightly entrenched with well-defined meandering channels. Riffle/ pool bed morphology
D	Braided channel with long-itudinal and transverse bars. Very wide channel with eroding banks	n/a	>40	n/a	<.04	Broad valleys with alluvium, steeper fans. Glacial debris and depositional features. Active lateral adjustment with abundance of sediment supply. Convergence/divergence bed features, aggradational processes, high bed load and bank erosion
DA	Anastomizing (multiple channels) narrow and deep with extensive, well-vegetated flood plains and associated wetlands. Very gentle relief with highly variable sinuosities and width-to-depth ratios. Very stable streambanks	>2.2	Highly variable	Highly variable	<.005	Broad, low-gradient valleys with fine alluvium and/or lacustrine soils. Anastomized (multiple channel) geologic control creating fine deposition with well-vegetated bars that are laterally stable with broad wetland flood plains. Very low bed-load, high wash load sediment
E	Low gradient, meandering riffle/pool stream with low width-to-depth ratio and little deposition. Very efficient and stable. High meander width ratio	>2.2	<12	>1.5	<.02	Broad valley/meadows. Alluvial materials with flood plains. Highly sinuous with stable, well-vegetated banks. Riffle/pool morphology with very low width-to-depth ratios
F	Entrenched meandering riffle/pool channel on low gradients with high width-to-depth ratio	<1.4	>12	>1.2	<.02	Entrenched in highly weathered material. Gentle gradients with a high width-to-depth ratio. Meandering, laterally unstable with high bank erosion rates. Riffle/pool morphology
G	Entrenched gully step-pool and low width-to-depth ratio on moderate gradients	<1.4	<12	>1.2	.02 to .039	Gullies, step-pool morphology with moderate slopes and low width-to-depth ratio. Narrow valleys, or deeply incised in alluvial or colluvial materials (fans or deltas). Unstable, with grade control problems and high bank erosion rates

Table 11–3 Reference reach summary data form

River Reach Summary Data

Channel dimension

Mean riffle depth (d_{bkf})		ft	Riffle width (W_{bkf})		ft	Riffle area (A_{bkf})		ft^2
Mean pool depth (d_{bkfp})		ft	Pool width (W_{bkfp})		ft	Pool area (A_{bkfp})		ft^2
Mean pool depth/mean riffle depth		d_{bkfp}/(d_{bkf})	Pool width/riffle width		W_{bkfp}/W_{bkf}	Pool area/riffle area		A_{bkfp}/A_{bkf}
Max riffle depth (d_{mbkf})		ft	Max pool depth (d_{mbkfp})		ft	Max riffle depth/mean riffle depth		
Max pool depth/mean riffle depth						Point bar slope		
Streamflow: estimated mean velocity at bankfull stage (u_{bkf})					ft/s	Estimation method		
Streamflow: estimated discharge at bankfull stage (Q_{bkf})					ft^3/s	Drainage area		mi^2

Channel pattern

Geometry	Mean	Min.	Max.		Dimensionless geometry ratios	Mean	Min.	Max.
Meander length (Lm)				ft	Meander length ratio (Lm/W_{bkf})			
Radius of curvature (Rc)				ft	Radius of curvature/riffle width (Rc/W_{bkf})			
Belt width (W_{blt})				ft	Meander width ratio (W_{blt}/W_{bkf})			
Individual pool length				ft	Pool length/riffle width			
Pool to pool spacing				ft	Pool to pool spacing/riffle width			

Channel profile

Valley slope (VS)		ft/ft	Average water surface slope (S)		ft/ft	Sinuosity (VS/S)	
Stream length (SL)		ft	Valley length (VL)		ft	Sinuosity (SL/VL)	
Low bank height (LBH) start		ft	Max riffle depth start		ft	Bank height ratio (LBH/max riffle depth) start	
Low bank height (LBH) end		ft	Max riffle depth end		ft	Bank height ratio (LBH/max riffle depth) end	

Facet slopes	Mean	Min.	Max.		Dimensionless geometry ratios	Mean	Min.	Max.
Riffle slope (S_{rif})				ft/ft	Riffle slope/average water surface slope (S_{rif}/S)			
Run slope (S_{run})				ft/ft	Run slope/average water surface slope (S_{run}/S)			
Pool slope (S_p)				ft/ft	Pool slope/average water surface slope (S_p/S)			
Glide slope (S_g)				ft/ft	Glide slope/average water surface slope (S_g/S)			

Feature midpoint[a/]	Mean	Min.	Max.		Dimensionless geometry ratios	Mean	Min.	Max.
Riffle depth (d_{rif})				ft	Riffle depth/mean riffle depth (d_{rif}/d_{bkf})			
Run depth (d_{run})				ft	Run depth/mean riffle depth (d_{run}/d_{bkf})			
Pool depth (d_p)				ft	Pool depth/mean riffle depth (d_p/d_{bkf})			
Glide depth (d_g)				ft	Glide depth/mean riffle depth (d_g/d_{bkf})			

Channel materials

Geometry		Reach[b/]	Riffle[c/]	Bar		Reach[b/]	Riffle[c/]	Bar	
% Silt/clay					D_{16}				mm
% Sand					D_{35}				mm
% Gravel					D_{50}				mm
% Cobble					D_{84}				mm
% Boulder					D_{95}				mm
% Bedrock					D_{100}				mm

a/ Minimum, maximum, mean depths are the average midpoint values except pools which are taken at deepest part of pool
b/ Composite sample of riffles and pools within the designated reach
c/ Active bed of a riffle

such relations is the necessity to field-calibrate the bankfull stage at each gage within a hydro-physiographic province (a drainage basin similar in precipitation/runoff relations due to precipitation/elevation, lithology and land uses).

Regional curves—The field-calibrated bankfull stage is used to obtain the return period associated with the bankfull discharge. Regional curves of bankfull discharge versus drainage area are developed (fig. 11–4) (adapted from Dunne and Leopold 1978)). To plot bankfull dimensions by drainage area, the U.S. Geological Survey (USGS) 9–207 data (summary of stream discharge measurements at the gage) are obtained to plot the at-a-station hydraulic geometry relations (fig. 11–5 (adapted from Rosgen 1996; Rosgen and Silvey 2005)). These data are then converted to dimensionless hydraulic geometry data by dividing each value by their respective bankfull value. These relations are used during assessment and design to indicate the shape of the various cross sections from low flow to high flow. In the development of the dimensionless hydraulic geometry data, current meter measurements must be stratified by stream type (Rosgen 1994, 1996) and for specific bed features such as riffles, glides, runs, or pools.

Figure 11–4 Regional curves from stream gaging stations showing bankfull discharge (ft^3/s) vs. drainage area (mi^2)

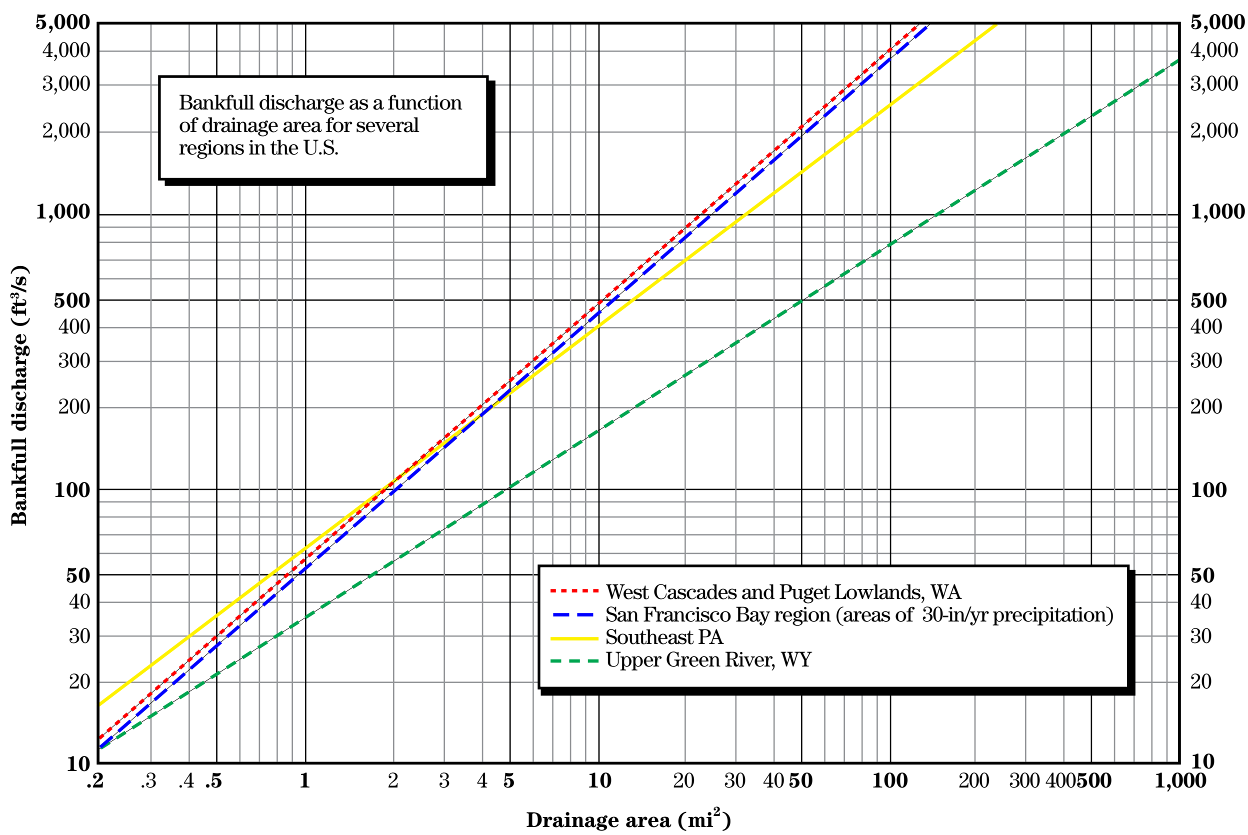
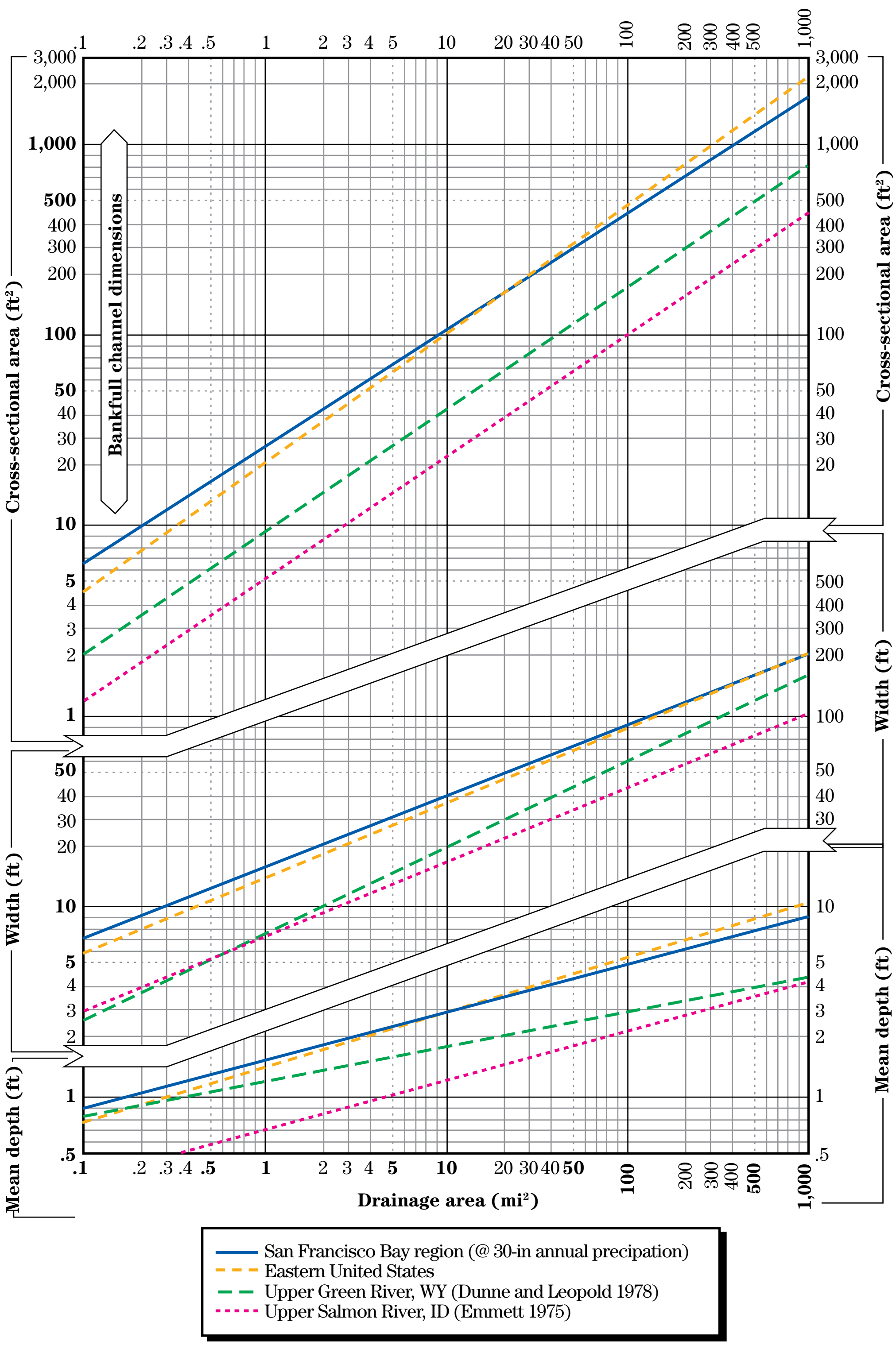


Figure 11–5 Regional curves from stream gage stations showing bankfull dimensions (width, depth, and cross-sectional area) vs. drainage area (mi^2)



Hydraulic relations

Hydraulic relations are validated using resistance equations for velocity prediction at ungaged sites. (Stream Hydraulics is addressed in more detail in NEH654.06) Validation is accomplished by back calculating relative roughness (R/D_{84}) and a friction factor (u/u^*) from actual measured velocity for a range of streamflows including bankfull:

$$u = \left[2.83 + 5.66 \log\left(\frac{R}{D_{84}}\right)\right] u* \qquad \text{(eq. 11–1)}$$

where:
u = mean velocity (ft/s)
R = hydraulic radius
D_{84} = diameter of bed material of the 84th percentile of riffles
u^* = shear velocity $(gRS)^{1/2}$
g = gravitational acceleration
S = slope

Measured velocity, slope, channel material, and hydraulic radius data from various Colorado rivers using this friction factor (u/u^*) and relative roughness (R/D_{84}) relation are shown in figure 11–6 (Rosgen, Leopold, and Silvey 1998; Rosgen and Silvey 2005).

Manning's *n* (roughness coefficient) can also be back-calculated from measured velocity, slope, and hydraulic radius. Another approach to predict velocity at ungaged sites is to predict Manning's *n* from a friction factor back-calculated from relative roughness shown in figure 11–7 (Rosgen, Leopold, and Silvey 1998; Rosgen and Silvey 2005). Manning's *n* can also be estimated at the bankfull stage by stream type as shown in the relationship from gaged, large streams in figure 11–8. Vegetative influence is also depicted in these data (Rosgen 1994).

Dimensionless flow-duration curves—Flow-duration curves (based on mean daily discharge) are also obtained from gage stations then converted to dimensionless form using bankfull discharge as the normalization parameter (fig. 11–9 (Emmett 1975)). The purpose of this form is to allow the user to extrapolate flow-duration curves to ungaged basins. This relationship is needed for the annual suspended and bed-load sediment yield calculation along with channel hydraulic variables.

(c) Phase III—Watershed and river assessment

Land use history is a critical part of watershed assessment to understand the nature and extent of potential impacts to the water resources. Past erosional/depositional processes related to changes in vegetative cover, direct disturbance, and flow and sediment regime changes provide insight into the direction and detail for assessment procedures required for restoration. Time series of aerial photos are of particular value to understand the nature, direction, magnitude, and rate of change. This is very helpful, as it assists in assessing both short-term, as well as long-term river problems.

Assessment of river stability and sediment supply

River stability (equilibrium or quasi-equilibrium) is defined as the ability of a river, over time, in the present climate to transport the flows and sediment produced by its watershed in such a manner that the stream maintains its dimension, pattern, and profile without either aggrading or degrading (Rosgen 1994, 1996, 2001d). A stream channel stability analysis is conducted along with riparian vegetation inventory, flow and sediment regime changes, limiting factor analysis compared to biological potential, sources/causes of instability, and adverse consequences to physical and biological function. Procedures for this assessment are described in detail by Rosgen (1996, 2001d) and in Watershed Assessment and River Stability for Sediment Supply (WARSSS) (Rosgen 1999, 2005).

It is important to realize the difference between the dynamic nature of streams and natural adjustment processes compared to an acceleration of such adjustments. For example, bank erosion is a natural channel process; however, accelerated streambank erosion must be understood when the rate increases and creates a disequilibrium condition. Many stable rivers naturally adjust laterally, such as the "wandering" river. While it may meet certain local objectives to stabilize high risk banks, it would be inadvisable to try to "control" or "fix in place" such a river.

In many instances, a braided river and/or anastomizing river type is the stable form. Designing all stream systems to be a single-thread meandering stream may not properly represent the natural stable form. Valley types are a key part of river assessment to understand

Figure 11–6 Relation of channel bed particle size to hydraulic resistance with river data from a variety of eastern and western streams

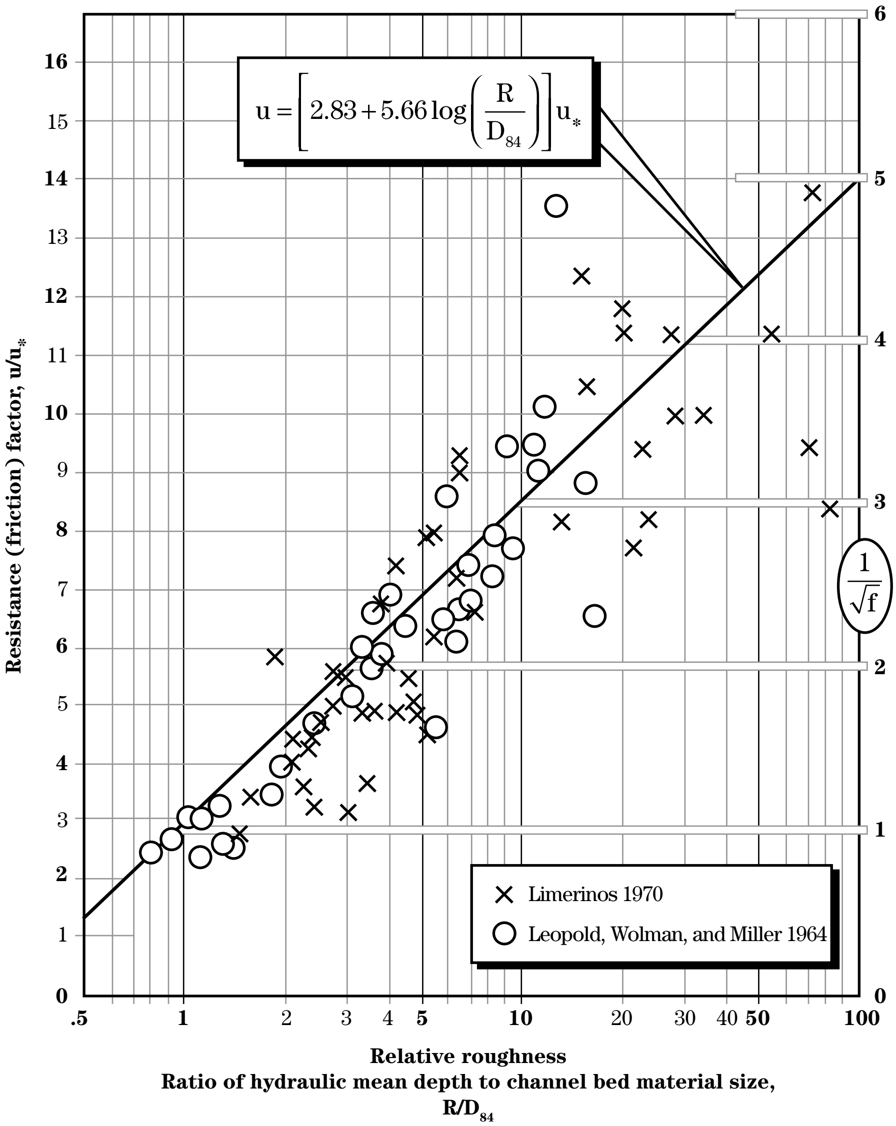


Figure 11–7 Prediction of Manning's *n* roughness coefficient

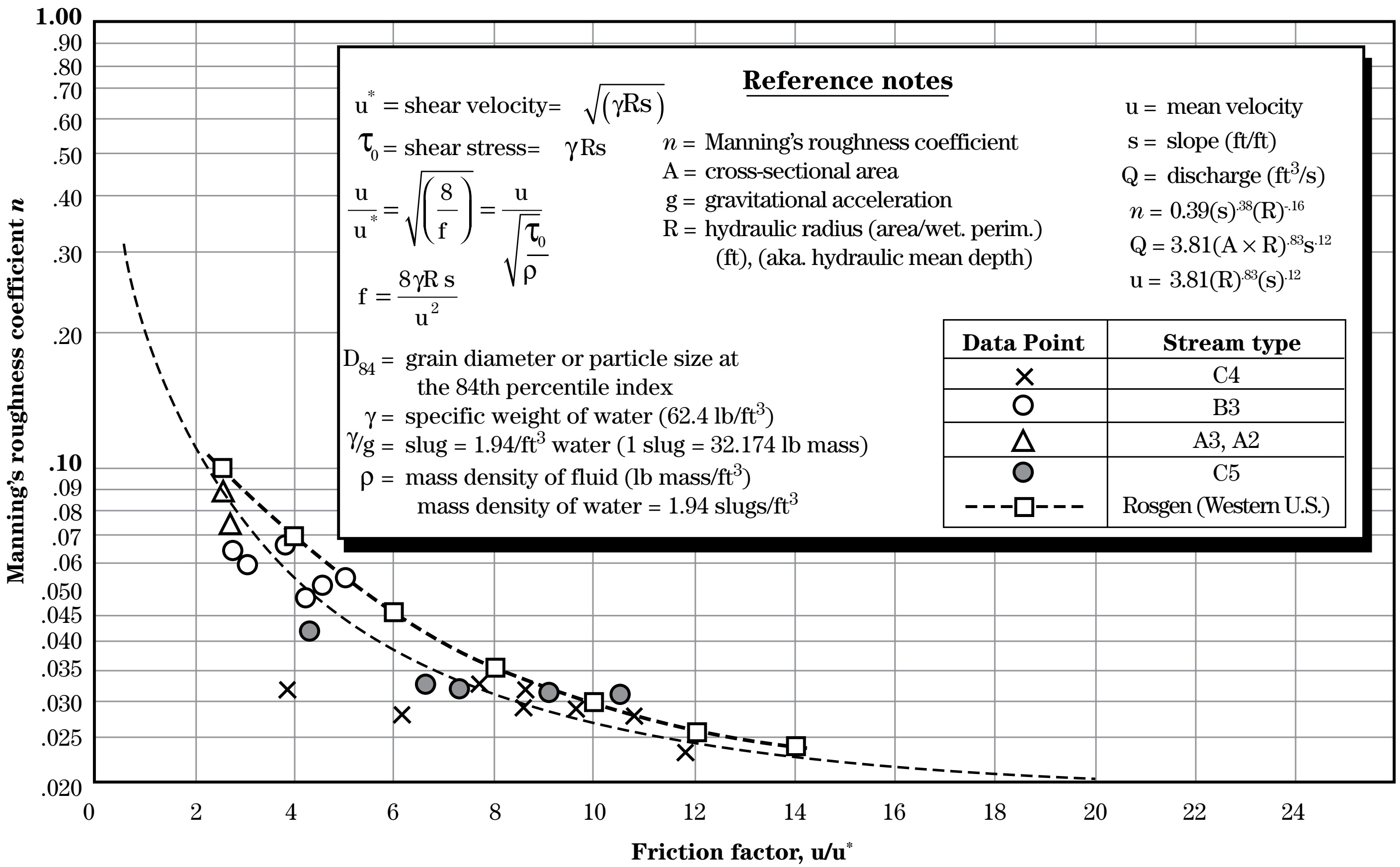
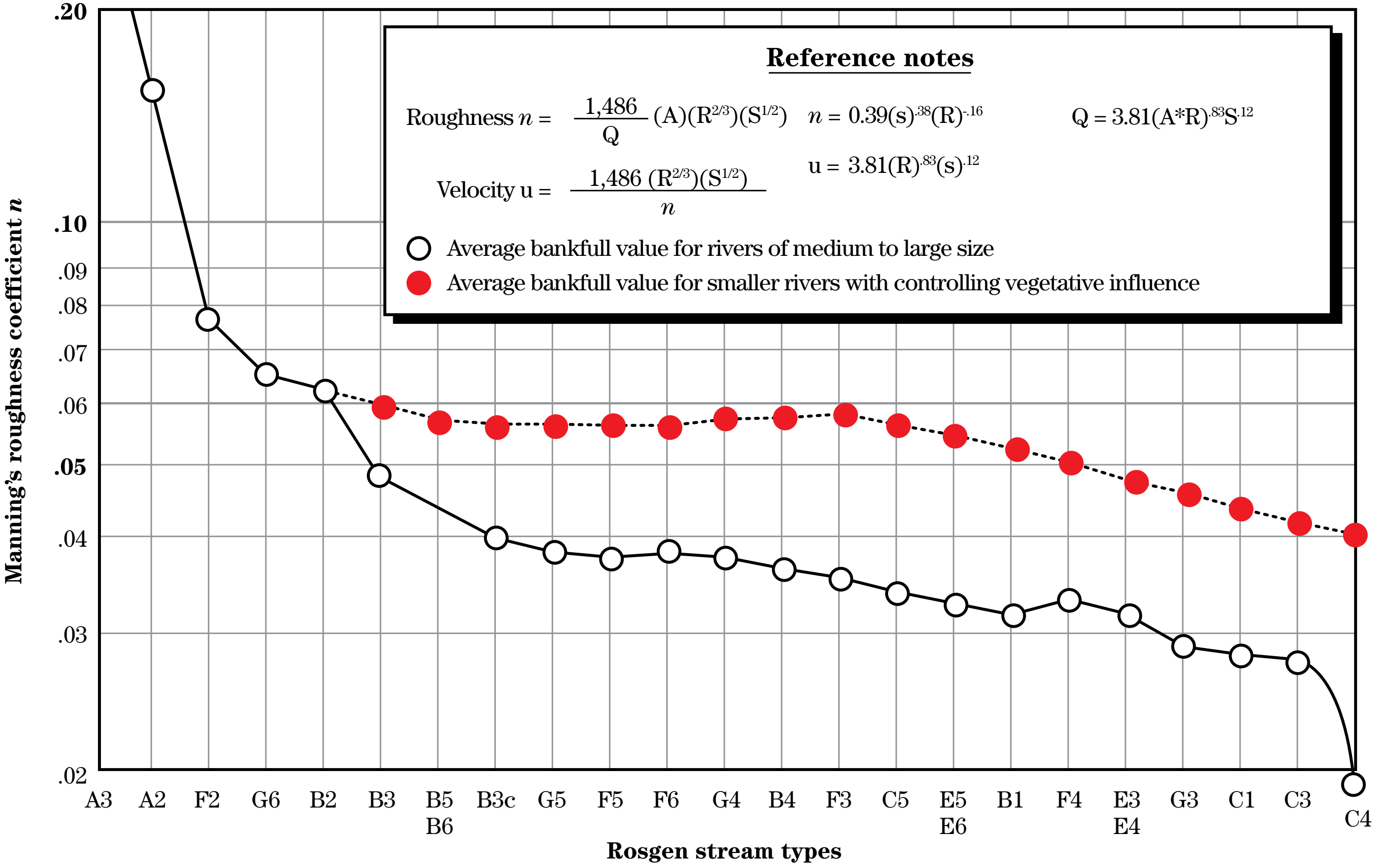


Figure 11–8 Bankfull stage roughness coefficients (n values) by stream type for 140 streams in the United States and New Zealand

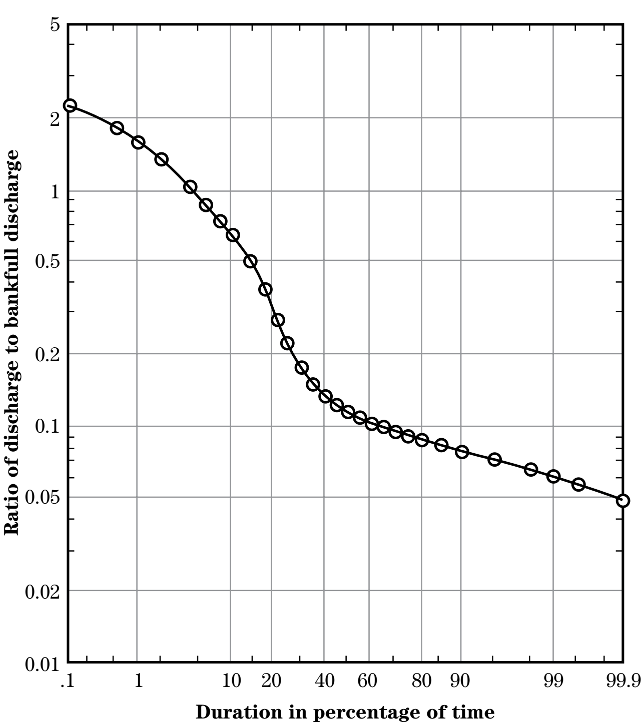


which stream types are stable within a variety of valley types in their geomorphic settings. Reference reaches that represent the stable form have to be measured and characterized only for use in similar valley types. This prevents applying good data to the *wrong* stream type.

Time-trend data using aerial photography is very valuable at documenting channel change. Field evidence using dendrochronology, stratigraphy, carbon dating, paleochannels, or evidence of avulsion and avulsion dates can help the field observer to understand rate, direction, and consequence of channel change.

The field inventory and the number of variables required to conduct a watershed and river stability assessment is substantial. The flowchart in figure 11–10 represents a general summary of the various elements used for assessing channel stability as used in this methodology. The assessment effort is one of the key procedural steps in a sound restoration plan, as it

Figure 11–9 Dimensionless flow-duration curve for streamflow in the upper Salmon River area



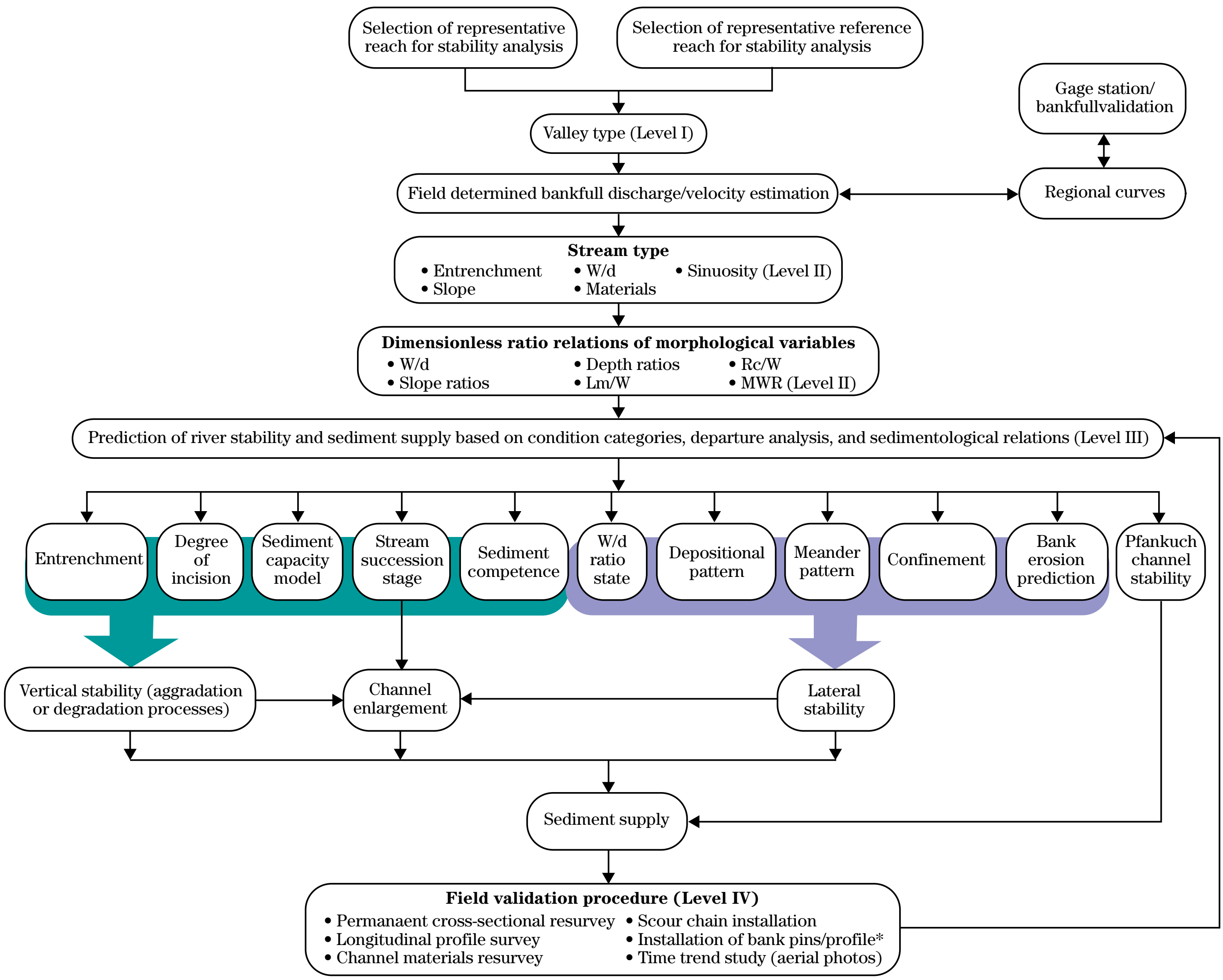
identifies the causes and consequences of the problems leading to loss of physical and biological river function. Some of the major variables are described to provide a *general* overview.

Streamflow change—Streamflow alteration (magnitude, duration, and timing) due to land use changes, such as percent impervious cover, must be determined at this phase. Streamflow models, such as the unit hydrograph approach, must be calibrated by back-calculating what precipitation probability generates bankfull discharge for various antecedent soil moisture and runoff curve numbers. It is critical to separate bankfull discharge from flood flows, as each flow category, including flood flow, has a separate dimension, pattern, and profile. This varies by stream type and the lateral and vertical constraints imposed within the valley (or urban "valley").

Flow-duration curves by similar hydro-physiographic provinces from gaged stations are converted to bankfull dimensionless flow duration for use in the annual sediment yield calculation. Snowmelt watershed flow prediction output (Troendle, Swanson, and Nankervis 2005) is generally shown in flow-duration changes, rather than an annual hydrograph. Similar model outputs using flow-duration changes are shown in Water Resources Evaluation of Nonpoint Silvicultural Sources (U.S. Environmental Protection Agency (EPA) 1980).

Sediment competence—Sedimentological data are obtained by a field measurement of the size of bar and bed material, bed-load sediment transport, suspended sediment transport, and bankfull discharge measurements at the bankfull stage. Sediment relations are established by collecting energy slope, hydraulic radius, bed material, bar material, and the largest particle produced by the drainage immediately upstream of the assessment reach. Critical dimensionless shear stress is calculated from field data to determine *sediment competence* (ability to move the largest particle made available to the channel). Procedures for this field inventory are presented in Andrews (1984) and Rosgen (2001a, 2001d, 2005). Potential aggradation, degradation, and channel enlargement are predicted for the disturbed reach, comparing the required depth and slope necessary to transport the largest size sediment available. These calculations can be accomplished by hand, spreadsheet, or by commercially available computer programs.

Figure 11–10 Generalized flowchart of application of various assessment levels of channel morphology, stability ratings, and sediment supply



*Optional: sediment measurements (largest size moved at bankfull, D_i)

Changes in channel dimension, pattern, and profile are reflected in changes of velocity, depth, and slope. These changes in the hydraulic variables are reflected in values of shear stress. Shear stress is defined as:

$$\tau = \gamma RS \qquad \text{(eq. 11–2)}$$

where:
τ = bankfull shear stress (lb/ft^2)
γ = specific weight of water = 62.4 lb/ft^3
R = hydraulic radius of riffle cross section (ft)
S = average water surface slope (ft/ft)

Use the calculated value of τ (lb/ft^2) and the Shields diagram as revised with the Colorado data (fig. 11–11 (Rosgen and Silvey 2005)) to predict the moveable particle size (mm) at bankfull shear stress.

Another relationship used in assessment and in design is the use of dimensionless shear stress (τ^*_{ci}) to determine particle entrainment. Dimensionless shear stress is defined as:

$$\tau^* = 0.0834\left(\frac{D_{50}}{\hat{D}_{50}}\right)^{-0.872} \qquad \text{(eq. 11–3)}$$

where:
τ^* = dimensionless shear stress
D_{50} = median diameter of the riffle bed (from 100 count in the riffle or pavement sample)
$\hat{D}_{50}$ = median diameter of the bar sample (or subpavement sample)

If the ratio $\frac{D_{50}}{\hat{D}_{50}}$ is between the values of 3.0 and 7.0, calculate the critical dimensionless shear stress using equation 11–3 (modifications adapted from Andrews 1983, 1984; Andrews and Erman 1986).

If the ratio $\frac{D_{50}}{\hat{D}_{50}}$ is **not** between the values of 3.0 and 7.0, calculate the ratio $\frac{D_{max}}{D_{50}}$

where:
D_{max} = largest particle from the bar sample (or the subpavement sample)
D_{50} = median diameter of the riffle bed (from 100 count in the riffle or the pavement sample)

If the ratio $\frac{D_{max}}{D_{50}}$ is between the value of 1.3 and 3.0, calculate the critical dimensionless shear stress:

$$\tau^* = 0.0384\left(\frac{D_{max}}{D_{50}}\right)^{-0.887} \qquad \text{(eq. 11–4)}$$

Once the dimensionless shear stress is determined, the bankfull mean depth required for entrainment of the largest particle in the bar sample (or subpavement sample) is calculated using equation 11–5:

$$d_{bkf} = 1.65\tau^* \frac{D_{max}}{S} \qquad \text{(eq. 11–5)}$$

where:
d_{bkf} = required bankfull mean depth (ft)
1.65 = submerged specific weight of sediment
τ^* = dimensionless shear stress
D_{max} = largest particle from bar sample (or subpavement sample) (ft)
S = bankfull water surface slope (ft/ft)

The bankfull water surface slope required for entrainment of the largest particle can be calculated using equation 11–6:

$$S = 1.65\tau^* \frac{D_{max}}{d_{bkf}} \qquad \text{(eq. 11–6)}$$

Equations 11–5 and 11–6 are derived from the basic Shields relation.

If the protrusion ratios are out of the usable range as stated, another option is to calculate sediment entrainment using dimensional bankfull shear stress (eq. 11–2 and fig. 11–11).

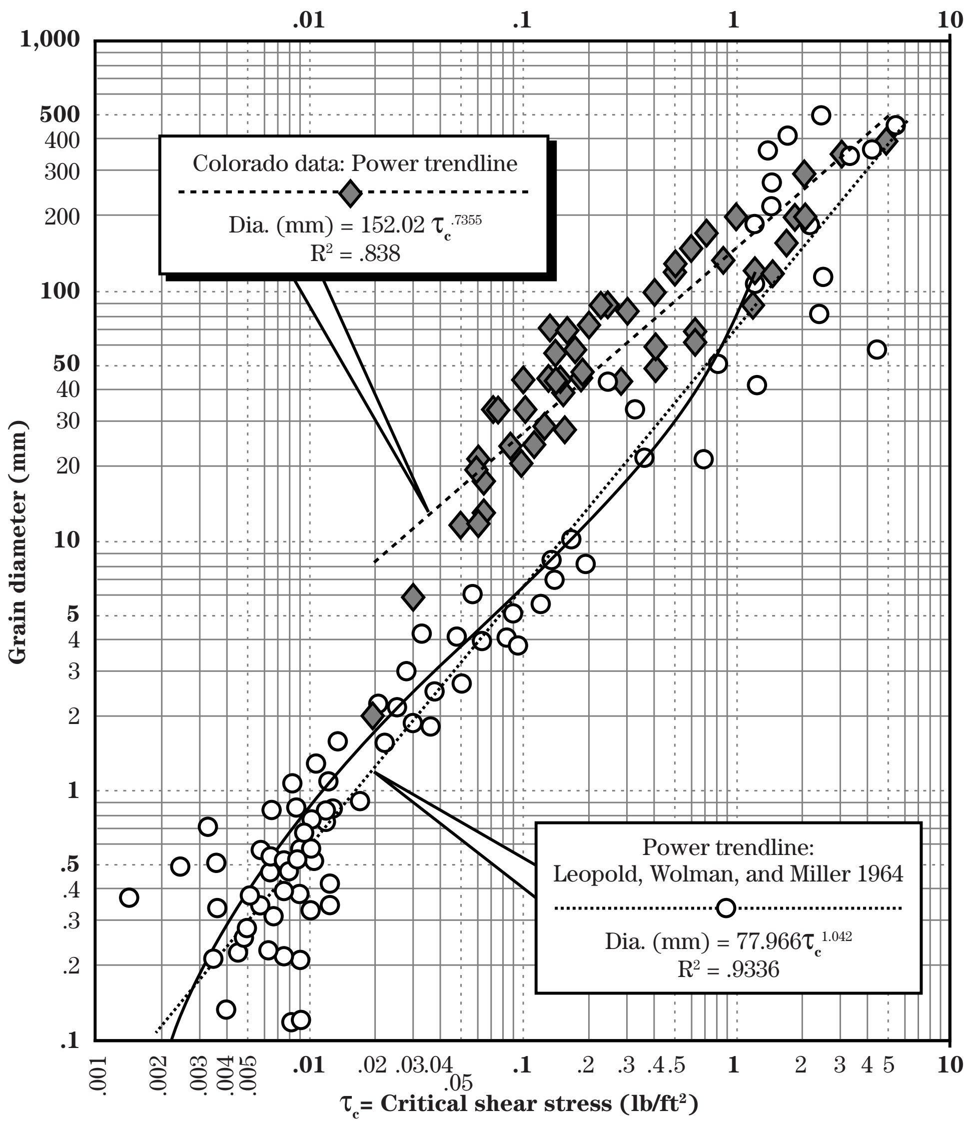
Sediment capacity—In addition to sediment competence, sediment capacity is important to predict river stability. Unit stream power is also utilized to determine the distribution of energy associated with changes in the dimension, pattern, profile, and materials of stream channels. Unit stream power is defined as shear stress times mean velocity:

$$\omega = \tau u \qquad \text{(eq. 11–7)}$$

where:
ω = unit stream power (lb/ft/s)
τ = shear stress (lb/ft^2)
u = mean velocity (ft/s)

Predicted sediment rating curves are converted to unit stream power for the same range of discharges by individual cells to demonstrate reduction or increase in coarse sediment transport.

Figure 11–11 Relation between grain diameter for entrainment and shear stress using Shields relations



Laboratory and field data on critical shear stress required to initiate movement of grains (Leopold, Wolman, and Miller 1964). The solid line is the Shields curve of *the threshold of motion;* transposed from the θ versus R_g form into the present form, in which critical shear is plotted as a function of grain diameter.

○ Leopold, Wolman, and Miller 1964
◆ Colorado data (Wildland Hydrology)

The use of reference dimensionless sediment rating curves by stream type and stability rating, (Troendle et al. 2001), as well as hydrology and hydraulic data, are all needed for the stability and design phases. Additional information will be presented in the respective sequential, analytical steps of each phase of the procedure. Local suspended sediment and bed-load data can be converted to regional sediment curves by plotting bankfull and suspended sediment data by drainage area. Examples of suspended sediment data plotted by 1.5-year recurrence interval discharge/drainage area for many regions of the United States as developed from USGS gage data by the U.S. Department of Agriculture (USDA), Agricultural Research Service (ARS) are presented in Simon, Dickerson, and Heins (2004). These relations can be used if a direct measurement of bankfull sediment cannot be obtained for subsequent analysis. Caution should be exercised in using an arbitrary bankfull value without field calibration of the bankfull discharge. The 1.5-year recurrence interval discharge is often greater than the actual bankfull value in wet climates and urban areas.

The disadvantage of using various suspended and bed load equations for the Rosgen geomorphic channel design methodology is the difficulty of determining sediment supply for sediment rating curves. It is common in the use of these models to have predicted values of many orders of magnitude different than observed values. The use of developed dimensionless ratio sediment rating curves for both suspended (less wash load) and bed load by stream type and stability is the improvement of predicted versus observed values. Results of an independent test of predicted versus observed values for a variety of USGS gage sites are shown in figures 11–12, 11–13, and 11–14. These figures show that predicted sediment rating curves match observed values for a wide range of flows. The model for bed-load transport reflects sediment transport based on changes in the channel hydraulics from a reference condition.

Validation of sediment competence or entrainment relations can also assist in the development and application of subsequent analysis. These data can be collected by installing scour chains and actual measurements of bed-load transport grain size for a given shear stress using Helley-Smith bed-load samplers. Plotting existing data collected by others in this manner can also help in developing a data base used in later analysis.

The use of reference dimensionless ratio sediment rating curves (bed load and suspended less wash load) requires field measured bankfull sediment and dis-

Figure 11–12 Comparison of predicted sediment rating curve to observed values from the Tanana River, AK, using the Pagosa Springs dimensionless ratio relation

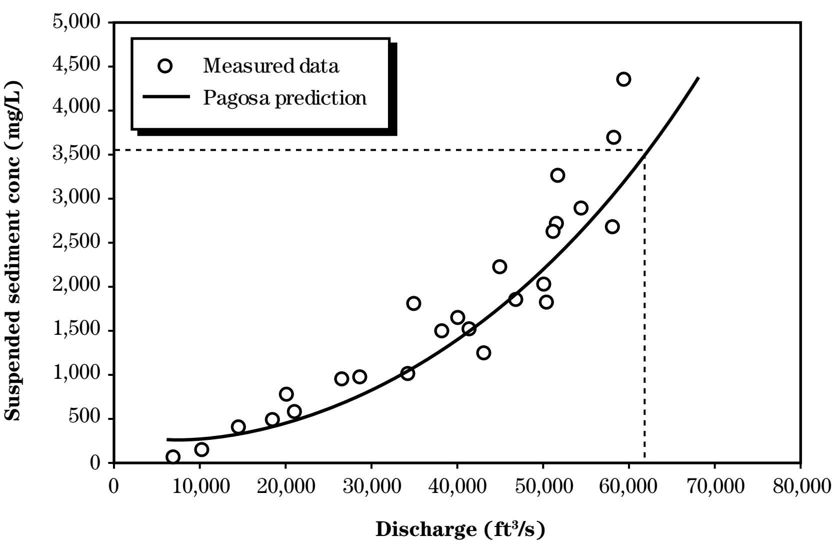
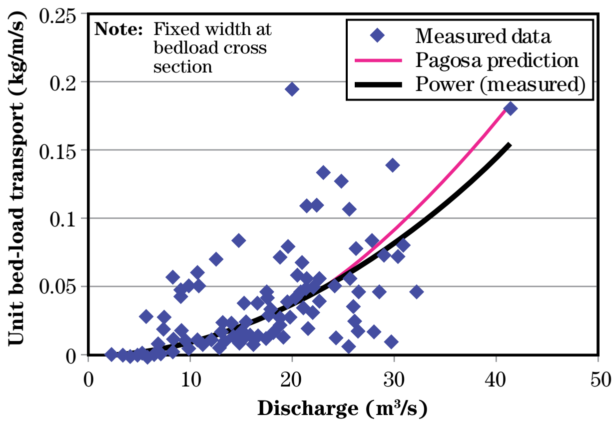
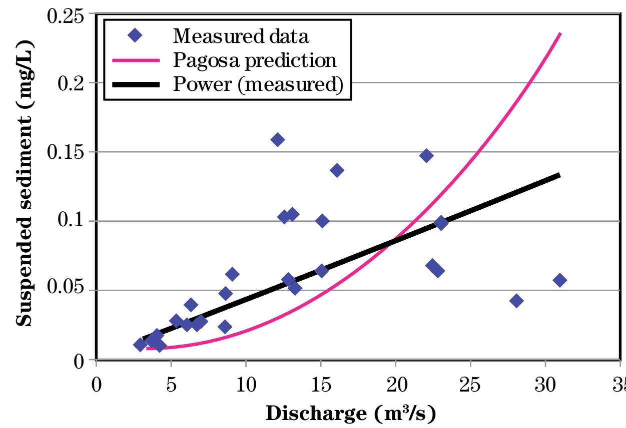


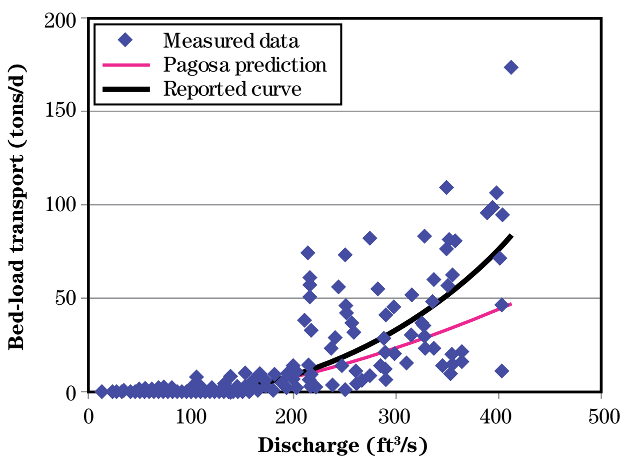
Figure 11–13 Predicted vs. measured sediment data using reference dimensionless rating curve (data from Leopold and Emmett 1997; Ryan and Emmett 2002)

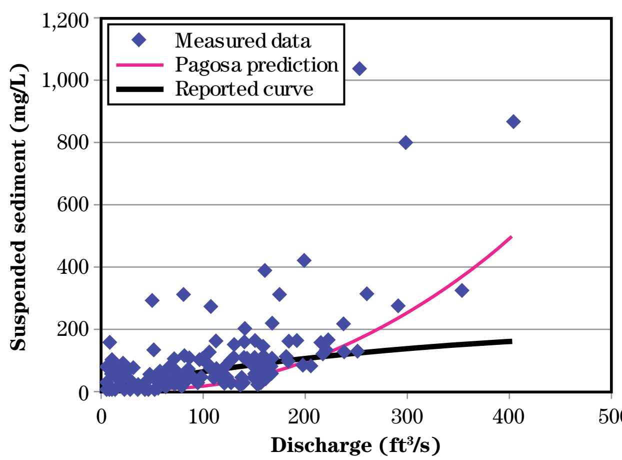
East Fork River near Big Sandy, WY (from Leopold and Emmett 1997)



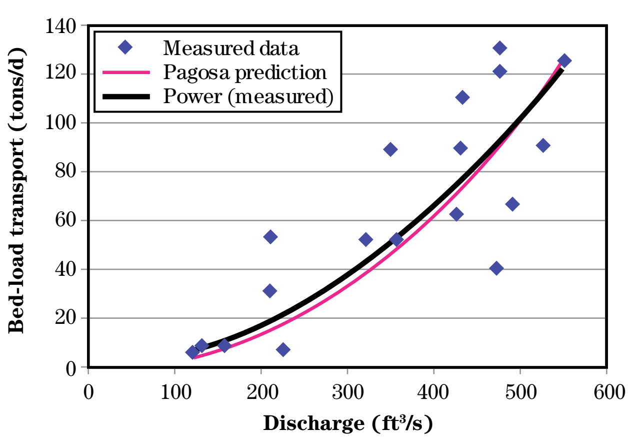


Little Granite Creek near Bondurant, WY (from Ryan and Emmett 2002)





Maggie Creek (F4)—NV



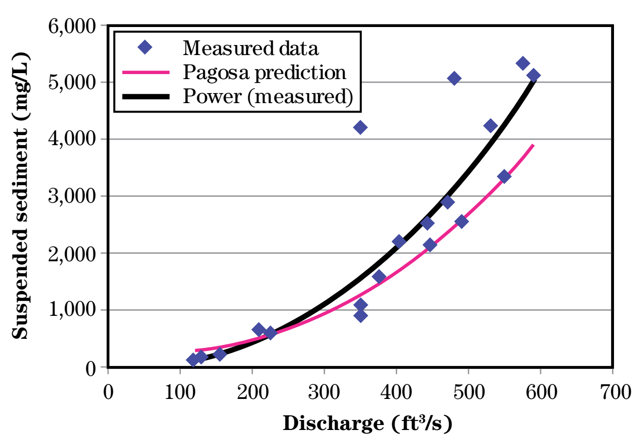
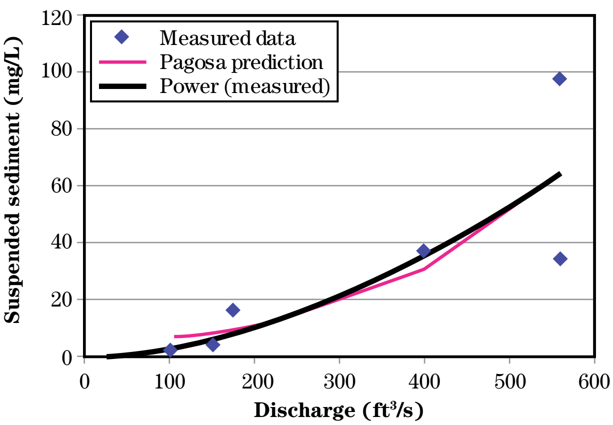
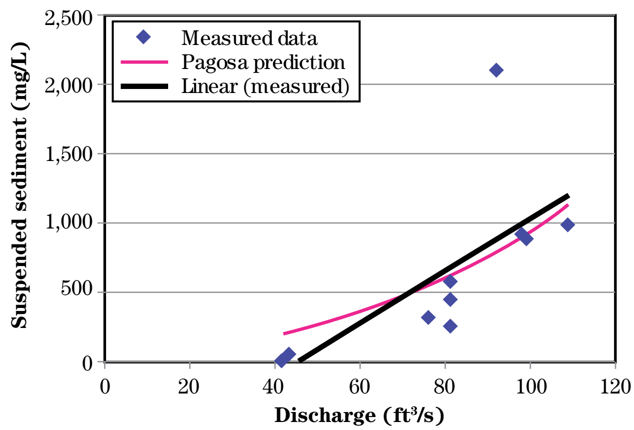


Figure 11–14 Predicted vs. measured suspended sediment data using dimensionless reference curve (data from Emmett 1975)

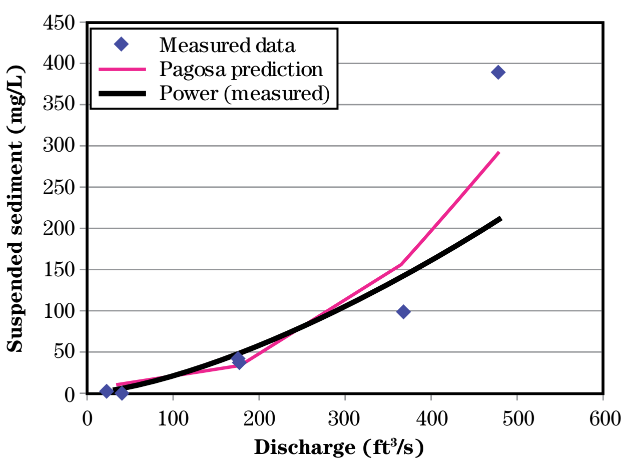
Warm Springs Creek near Clayton, ID 13297000



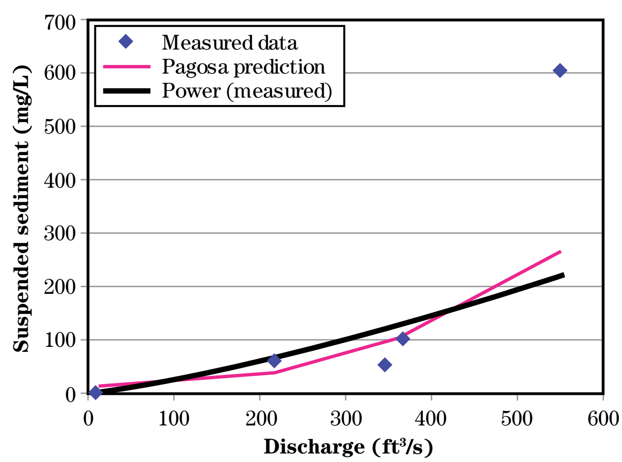
Upper Salmon Watershed 13297250



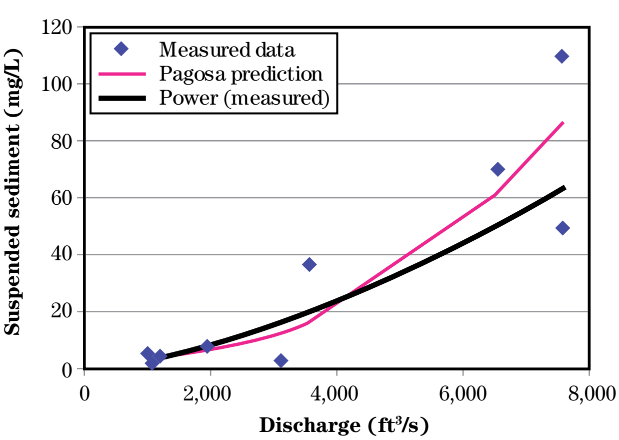
Upper Salmon Watershed 13297340



Upper Salmon Watershed 13297360



Upper Salmon Watershed 13297380



Upper Salmon Watershed 13297425

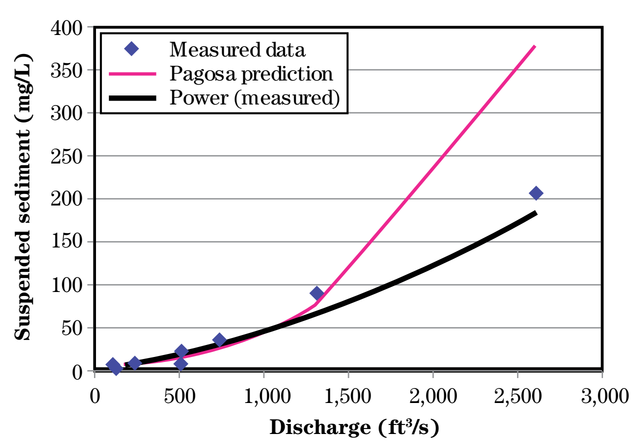
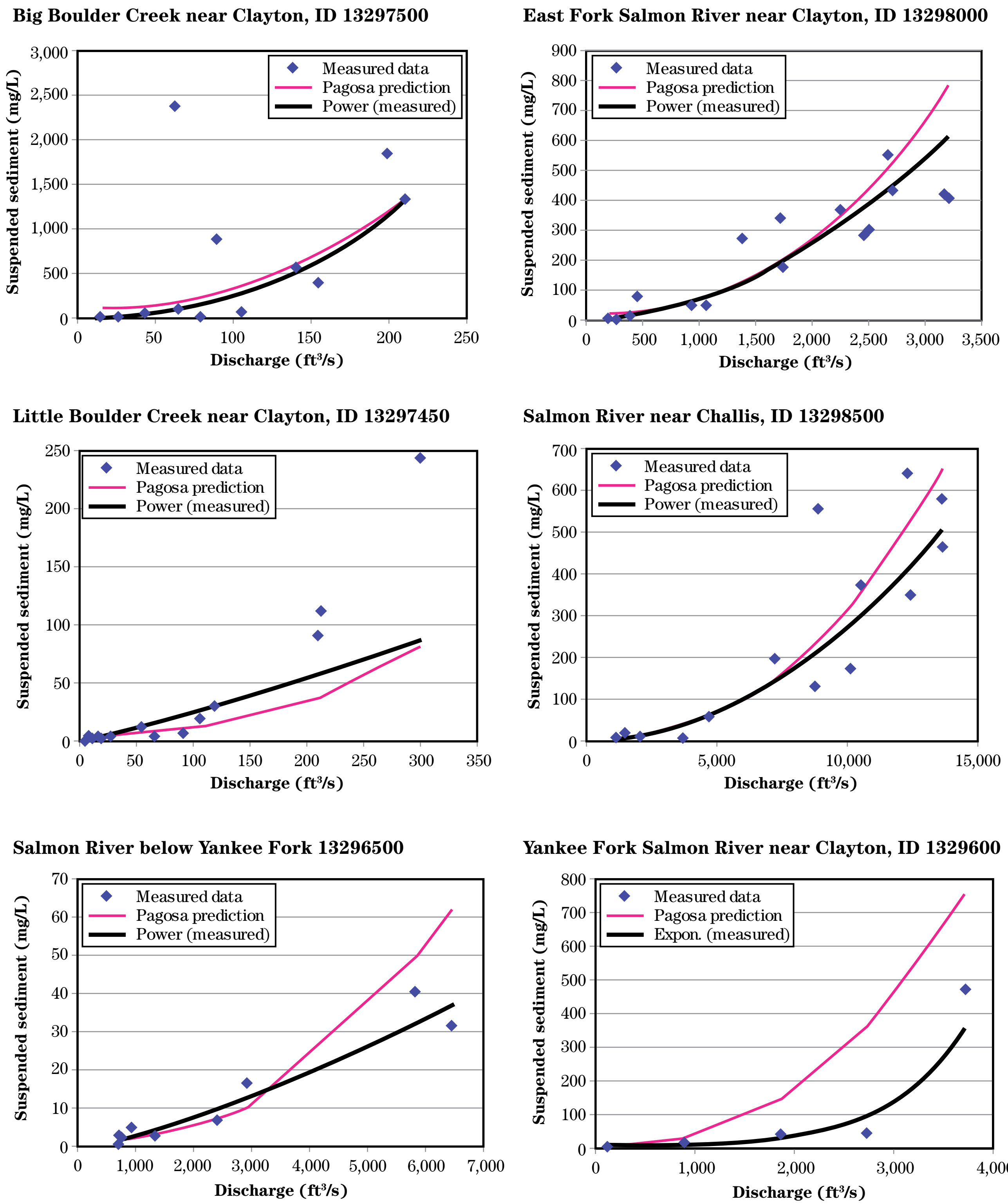


Figure 11–14 Examples of predicted vs. measured suspended sediment data using dimensionless reference curve (data from Emmett 1975)—Continued



charge. Regional bankfull sediment relations versus drainage area may be substituted if actual bankfull measurements are impossible to obtain, but must be extrapolated from streams of similar lithology, stream type, and stability. Examples of such relations using 1.5-year recurrence interval discharge for suspended sediment are shown in Simon, Dickerson, and Heins (2004). Dimensionless flow-duration curves are also used to produce total annual sediment yield once dimensionless ratio sediment and flow-duration curves are converted to dimensional relations. The examples of predicted sediment rating curves to observed values using a dimensionless sediment rating curve were presented in figures 11–12 to 11–14. Changes in unit stream power (eq. 11–7) are calculated to determine changes in transport rate due to change in depth, slope, and/or velocity. Dimensionless flow-duration curves are used to generate total annual sediment yield from the generated sediment rating curves and bed-load transport by unit stream power.

Streambank erosion—Streambank erosion rate (lateral erosion rate and sediment, tons/yr) is predicted as part of the river stability assessment. The influence of vegetative change, direct disturbance, and other causes of bank instability is quantitatively assessed. One of the major consequences of stream channel instability is accelerated streambank erosion and associated land loss. Fish habitat is adversely affected not only due to increased sediment supply but also by changes in pool quality, substrate materials, imbrication, and other physical habitat loss. Water temperatures are also adversely affected due to increases in width-to-depth ratio due to lateral accretion. The prediction methodology is presented in Rosgen (1996) and in Rosgen (2001d) utilizing a Bank Erodibility Hazard Index (BEHI) and Near Bank Stress (NBS) calculations.

Successional stages of channel evolution—A useful tool at this phase is the determination of various stream type scenarios and stages of channel evolution as depicted in figure 11–15. It is imperative to identify the present stage of the stream and predict the direction and consequence of change. The various stages and scenarios depicted in figure 11–15 assist the observer in this assessment. River channels undergo morphological change due to various disturbance and/or recovery (Rosgen 1996, 2001d, 2005). The assessment phase must identify current states and scenarios. For each state within a scenario, there are specific morphological, sedimentological, hydraulic, and biological relations depicted. The associated interpretations of these relations assist in river assessments.

River stability analysis—Additional stability variables are required for assessment, including the influence of large woody material, flow regime, depositional features, meander patterns, riparian vegetation, and channel stability ratings by stream type, and are summarized in the form shown in table 11–4.

Figure 11–15 Various stream type succession scenarios

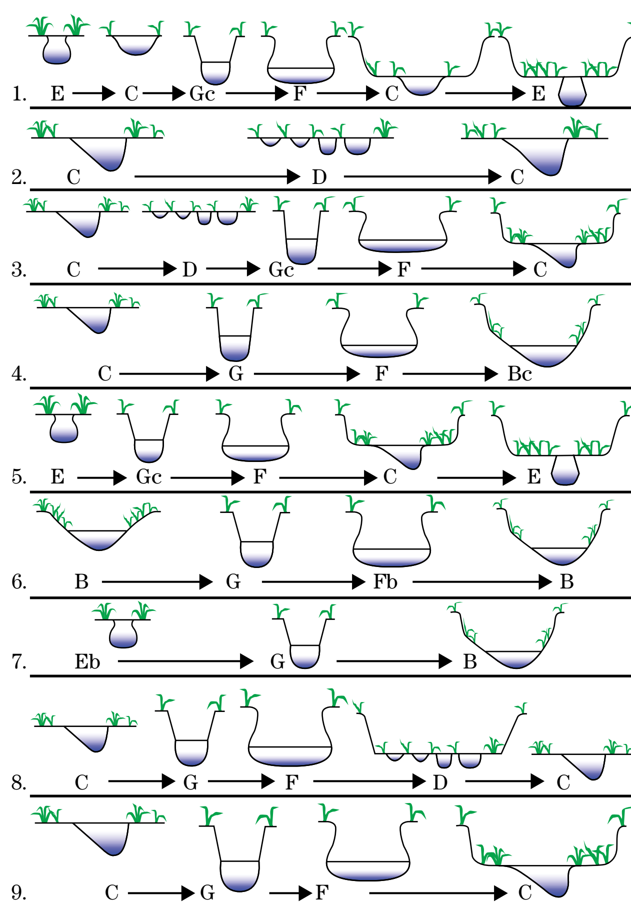


Table 11–4 Stream channel stability assessment summary form

Stream		**Stream**		**Date**		**Observers**								
Level III variables	Stream type		Flow regime		Stream size		Stream order		Meander pattern		Depositional pattern		Debris/channel blockage	
	Riparian vegetation	Current composition/density		Potential composition/density		Altered channel state (dimension, pattern, profile, materials)								
Channel dimension	Mean bankfull depth (ft)		Mean bankfull width (ft)		Cross section area (ft^2)		Remarks							
Channel dimension relationships	Width/depth ratio (W/D)		Reference condition width/depth ratio (W/D_{ref})		$(W/D)/(W/D_{ref})$		Circle	Stable	Moderately unstable	Unstable	Highly unstable			
Channel pattern	Mean (range)	MWR		Lm/W_{bkf}		Rc/W_{bkf}		Sinuosity						
River profile and bed features	Circle		Riffle/pool	Step/pool	Plane bed	Convergence/divergence	Dune/antidunes/smooth bed							
	Max bankfull depth (ft)	Riffle	Pool	Depth ratio (max/mean)	Riffle	Pool	Pool to pool spacing		Slope: Valley		Slope: Average bankfull			
Channel stability rating	Pfankuch rating		Pfankuch adjusted by stream type (use potential/reference reach)											
Bank erosion summary	Length of reach studied (ft)		Annual streambank erosion rate	(ton/yr)		ton/yr/ft	Curved used		Remarks					
Degree of confinement	Reference MWR		MWR/ Reference MWR		Unconfined (1.0–0.80)	Moderately confined (0.79–0.30)	Confined (0.29–0.1)	Severely confined (<0.1)						
Lateral stability	Circle		Stable		Moderately unstable		Unstable		Highly unstable (accelerated lateral erosion)					
Sediment capacity	Sufficient capacity		Insufficient capacity											
Stream channel scour/deposition	Largest particle-bar sample (mm)		τ_{ci}		Existing $depth_{bkf}$		Required $depth_{bkf}$		Existing $slope_{bkf}$		Required $slope_{bkf}$			
Degree of incision	Bank height ratio		Stable (no incision)	Slightly incised	Moderately incised	Deeply incised	Width of flood prone area (ft)		Entrenchment ratio					
Channel enlargement	Circle		Stable		Slight		Moderate		Extensive					
Stream successional stage		→		→		→		→		→		Existing stream state (type)		Potential stream state (type)
Vertical stability	Circle		Stable		Aggradation		Degradation							
Sediment supply (channel source)	Circle		Very high	High	Moderate	Low	Score		Remarks/causes					

Base-level change—A key part of channel stability analysis. Degree of channel incision (lowering of local base level) is determined by the ratio of the lowest bank height divided by maximum bankfull depth, called the bank height ratio. A stream may not be entrenched (vertically constrained), but may be partially incised, leading to entrenchment. A grade-control structure requirement is often associated with partially incised channels (Rosgen 1997a).

Direct disturbance and riparian vegetation—The direct disturbance of stream channels must be offset by correcting dimension, pattern, profile, and often channel materials. Levees adjacent to both banks should be set back allowing room for a flood plain. Riparian vegetation change is not only a major cause of instability and loss of function, but is a key solution in restoration and natural channel design. Riparian vegetation reestablishment should contain the correct overstory and understory species to be compatible for a self-sustaining, long-term solution.

Biological assessments—Biological assessments that describe fish species, food chains, diversity with broad categories of ecoregions, and stream types (habitat units) are currently collected with the assessment level for identifying biological potential. Limiting factor analysis provides information that identifies specific problems that may be corrected by changed management and/or restoration.

It is readily apparent that this procedure involves extensive field observations and an extensive data base followed by a thorough and detailed analysis. All of this must be completed prior to restoration planning, as it forms much of the foundation for what follows.

It is important to understand the various causes of instability responsible for loss of physical and biological function and corresponding loss of value. Recommendations that follow are critically linked to land uses, disturbance regime, and other problem sources. The flowchart (fig. 11–10) depicts the assessment criteria of channel stability.

(d) Phase IV—Passive recommendations for restoration

A first priority in restoration is to seek a natural recovery solution based on changes in the variables causing the instability and/or loss of physical and biological function. Changes in land use management can influence riparian vegetation composition, density and vigor, flow modifications (diversions, storage, and reservoir release schedule modifications based on the operational hydrology), flood control measures, road closures/stabilization, hillslope erosional processes, and other process influences of river stability. Often, a change in management strategies can be very effective in securing stability and function. This often has to be determined based on the recovery potential of various stream types and the short- and long-term goals associated with the stated objectives (including costs). The alternative of self-stabilization is always a key consideration in any stability assessment. The time-trend aerial photography from phase III may help to provide insight into stream recovery potential following disturbance.

Successional stages of channel adjustment (fig. 11–15) can also assist at looking at natural recovery potential. It is very important to ensure that objectives are met through effectiveness monitoring required to provide the documentation on the nature, magnitude, rate, and consequences of natural recovery. If natural recovery potential is poor and/or does not meet specific objectives, phase V would be appropriate (Rosgen geomorphic channel design methodology).

(e) Phase V—The stream restoration and natural channel design using the Rosgen geomorphic channel design methodology

Phase V involves combining the results of the previous phases. A good design can only follow a good assessment. It is preferred not to patch symptoms, but rather provide solutions to restoration that will offset the cause of the problem and allow for the river to be self-maintaining. The practitioner must be very familiar with the processes involved in hydrology, hydraulics, sedimentology, geomorphology, soil science, aquatic habitat, and riparian vegetation. Due to the inherent complexity, it is usually necessary to obtain technical assistance for assessment and design, depending on the practitioner's experience and training.

The conceptual, generalized flowchart shown in figure 11–16 depicts the general sequence of the mixed use of analog, empirical, and analytical methods in this design procedure. The early sequence is required to determine the existing valley type and potential stream type of the stable form. The proposed channel type must be converted to a dimension, pattern, and profile to initially test whether the hydraulic and sediment relations associated with the watershed are compatible prior to advancing through all of the procedural steps.

The watershed and river assessment that predicts the consequence of streamflow, sediment supply, and channel change is reflected in figure 11–17. The procedure is incorporated into the following sequential analysis steps.

Figure 11–16 Generalized flowchart representing Rosgen geomorphic channel design utilizing analog, analytical, and empirical methodologies

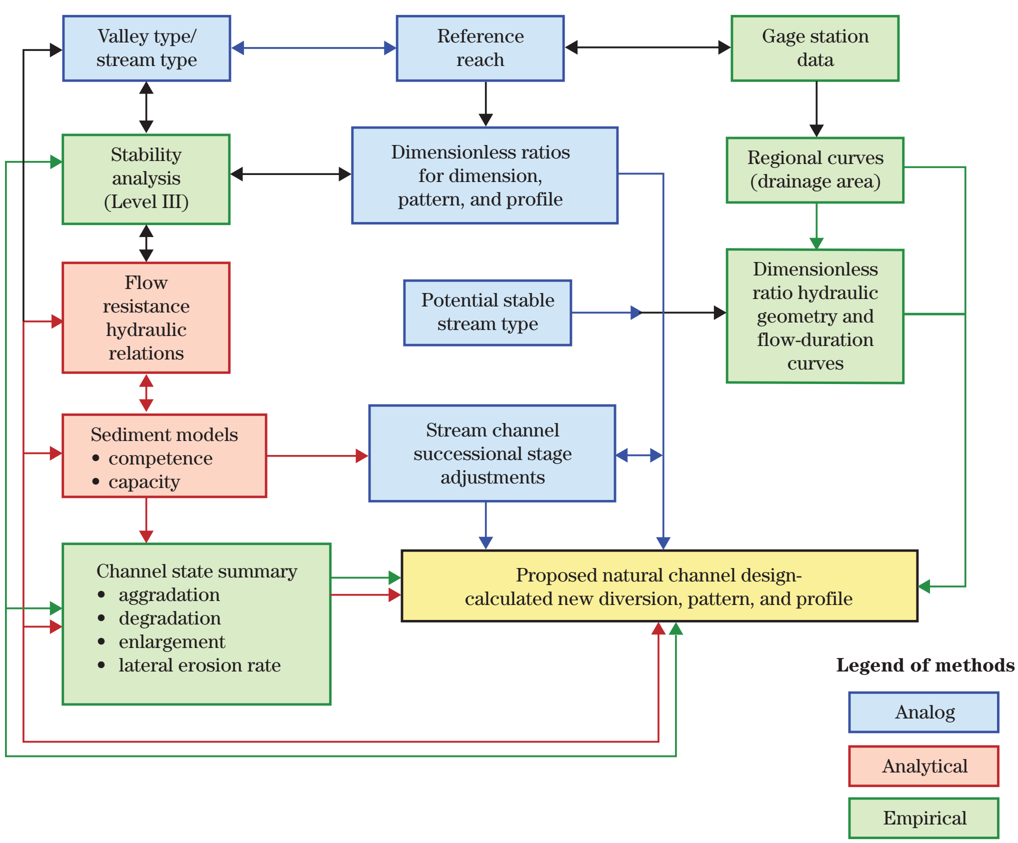
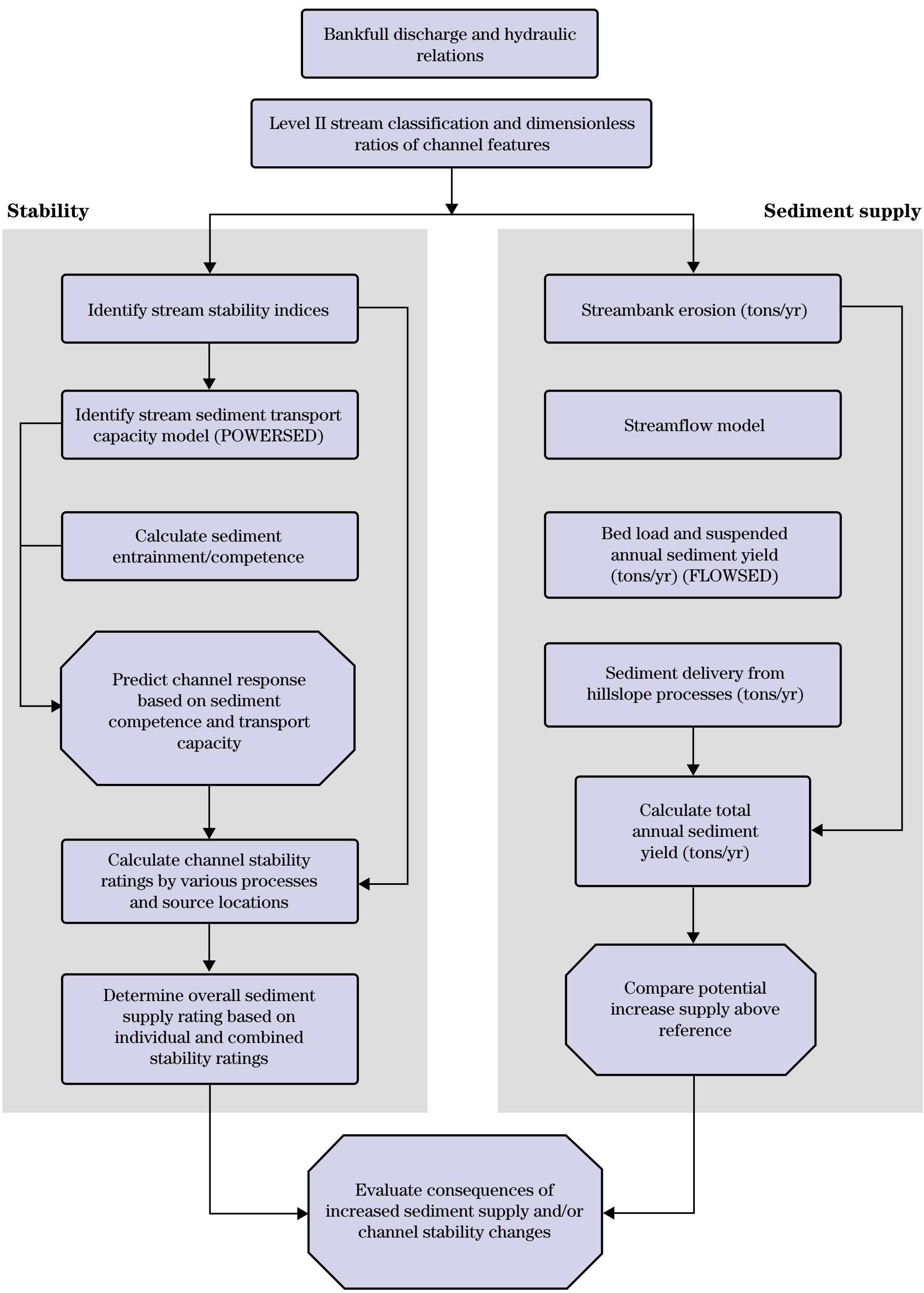


Figure 11–17 Flowchart for determining sediment supply and stability consequences for river assessment



The procedural sequence utilized in the Rosgen geomorphic channel design methodology is shown in the following operational steps:

Step 1 Obtain and/or verify regional curves (bankfull discharge, cross-sectional area, width and depth versus drainage area). The regional curves must be located in the same hydro-physiographic province as that of the restoration reach.

Step 2 Obtain hydraulic geometry (USGS 9–207 forms, summary of current meter measurements) from the gage station stratified by stream type and bed features.

Step 3 Create dimensionless hydraulic geometry by dividing all values by the bankfull value.

Step 4 Obtain flow-duration curves from the gage station for a representative hydro-physiographic region.

Step 5 Create dimensionless flow-duration curve by dividing all flow values by the bankfull discharge.

Step 6 Identify the valley type for the restoration reach(s). Identify stream type(s) of the restoration reach.

Step 7 Obtain corresponding reference reach data for the same valley and stream type. The reference reach is not required to be located within the same watershed or hydro-physiographic province. Examples of the dimensionless ratio and other reference reach data by stream type/valley type are presented in table 11–3.

Step 8 Complete and/or review the stability examination data for the restoration reach (fig. 11–10 and table 11–4). Evaluate variables/states that represent instability relations (width, depth, and slope values that do not meet sediment transport requirements).

Step 9 Select appropriate scenario of successional stages of channel adjustment for channel evolution scenario (fig. 11–15). This determines the stream type of the current state and the potential state to match the valley type. (This step is completed in the stability phase, phase III).

Step 10 Obtain drainage area (mi^2) for the restoration reach.

Step 11 Obtain bankfull cross-sectional area (A_{bkf}) from the regional curves (step 1).

Step 12 Obtain reference reach width-to-depth ratio associated with the stable design stream type commensurate with the valley type (step 7).

Step 13 Calculate design bankfull channel width of riffle reach:

$$W_{bkf} = \left[\left(\frac{W_{bkf}}{d_{bkf}}\right)_{ref} A_{bkf}\right]^{\frac{1}{2}} \qquad \text{(eq. 11– 8)}$$

Step 14 Calculate mean riffle depth:

$$d_{bkf} = \frac{A_{bkf}}{W_{bkf}} \quad \text{or} \quad \left[\frac{W_{bkf}}{\left(\frac{W_{bkf}}{d_{bkf}}\right)_{ref}}\right] \qquad \text{(eq. 11–9)}$$

Step 15 Calculate meander wavelength (Lm) for average and range of values. Obtain meander length ratio average and range of values, where:

$$MLR = \left[\left(\frac{Lm}{W_{bkf}}\right)_{ref}\right] \text{ from reference reach data (step 7, table 11–3).}$$

$$Lm = \left[\left(MLR_{ref}\right)\right] W_{bkf} \text{ (from step 13)} \qquad \text{(eq. 11–10)}$$

Step 16 Calculate belt width (W_{blt}) for average and range of values from meander width ratios (MWR).

$$MWR = \left[\left(\frac{W_{blt}}{W_{bkf}}\right)_{ref}\right] \quad \text{(step 7, table 11–3).}$$

$$W_{blt} = [(MWR)_{ref}]\ W_{bkf} \qquad \text{(eq. 11–11)}$$

Step 17 Calculate radius of curvature (Rc) for average and a range of values from ratio of radius of curvature ratio. (step 7, table 11–3).

$$Rc = \left[\left(\frac{Rc}{W_{bkf}}\right)_{ref}\right] W_{bkf} \qquad \text{(eq. 11–12)}$$

Step 18 Obtain an aerial photo depicting vegetation, channel features and terrain character. Layout the range of values for meander length (Lm), belt width (W_{blt}) and radius of curvature (Rc) on aerial photo or detailed topographic map. Adjust pattern to utilize terrain features and existing vegetation where possible within the range of the pattern variables. Once the preliminary layout is complete, measure stream length (SL) of the proposed channel. Measure valley length (VL) by following the fall line of the valley, rather than straight line segments between meanders.

Step 19 Calculate sinuosity (k) of the proposed channel where:

$$k = \frac{SL}{VL} \quad \text{(eq. 11–13)}$$

Step 20 Calculate valley slope (S_{val}). Measure the water surface elevation difference (DE) between the same bed features along the fall line of the valley using valley length (VL), where:

$$S_{val} = \frac{DE}{VL} \quad \text{(eq. 11–14)}$$

Step 21 Calculate proposed channel average slope (S):

$$S = \frac{S_{val}}{k} \quad \text{(eq. 11–15)}$$

Step 22 Calculate bankfull channel velocity (u_{bkf}) and check design bankfull discharge with velocity, cross-sectional area (continuity) regional curves:

$$uA = Q \quad \text{(eq. 11–16)}$$

$$\frac{Q}{A} = u \quad \text{Compare to regional curve (step 1)} \quad \text{(eq. 11–17)}$$

Steps 23 through 26 Predict stream competence (entrainment) by utilizing particle entrainment computations. A general flowchart depicting the procedural steps is shown in figure 11–18.

First, obtain bar sample gradation from field sampling and sieving procedure upstream of the proposed restoration (Rosgen 1996). A field procedure for bar sampling, pavement/subpavement sample and wet-sieving onsite is presented in tables 11–5 and 11–6. The user is advised to review additional details of particle size sampling by Bunte and Abt (2001). Sediment sampling is also addressed in NEH654 TS13A. Bar samples are field-sieved and recorded in the entrainment worksheet (table 11–7).

The sediment competence computations that determine bed stability (aggradation/degradation) are completed and summarized in table 11–8. This method has shown consistency when actual bed-load/scour chain data are compared to predicted values. Use the value of the largest particle in the bar sample (or subpavement sample), D_{max} in millimeters, and the revised Shields diagram to predict the shear stress required to initiate movement of the largest particle in the bar and/or subpavement (fig. 11–11).

If the protrusion ratios described in equations 11–3 or 11–4 are outside the ranges indicated in table 11–8, the user should use the shear stress equation (eq. 11–2) and apply it with a revised Shields relation using Colorado data or local data if available (fig. 11–11).

$$\tau^* = 0.0834\left(\frac{D_{50}}{\hat{D}_{50}}\right)^{-0.872} \quad \text{(eq. 11–3)}$$

$$\tau^* = 0.0384\left(\frac{D_{max}}{D_{50}}\right)^{-0.887} \quad \text{(eq. 11–4)}$$

$$\tau = \gamma RS \quad \text{(eq. 11–2)}$$

A grain size corresponding with shear stress is selected to determine what sizes the river can potentially move. Based on measured bed-load sizes, in a heterogeneous mixture of bed material comprised of a mixture of sand to gravel and cobble, the previously published Shields relation generally underestimates particle sizes of heterogeneous bed material in the shear stress range of 0.05 pounds per square foot to 1.5 pounds per square foot. The Shields relationship is appropriately used for entrainment sizes below and/or above this value range. Without this adjustment, most computations underestimate the largest sizes of heterogeneous bed material moved during bankfull discharge. The measured data in figure 11–11 indicate the magnitude of the underestimate of particle size entrainment from comparing published relations to measured values.

To determine the ability of the existing stream reach to transport the largest clast size of the bed-load sediment, it is necessary to calculate the bankfull dimensionless shear stress (τ*). This calculation determines the depth and slope necessary to mobilize and transport the largest particle made available to the channel. The dimensionless shear stress at bankfull stage is used in the entrainment

Figure 11–18 Generalized flowchart depicting procedural steps for sediment competence calculations

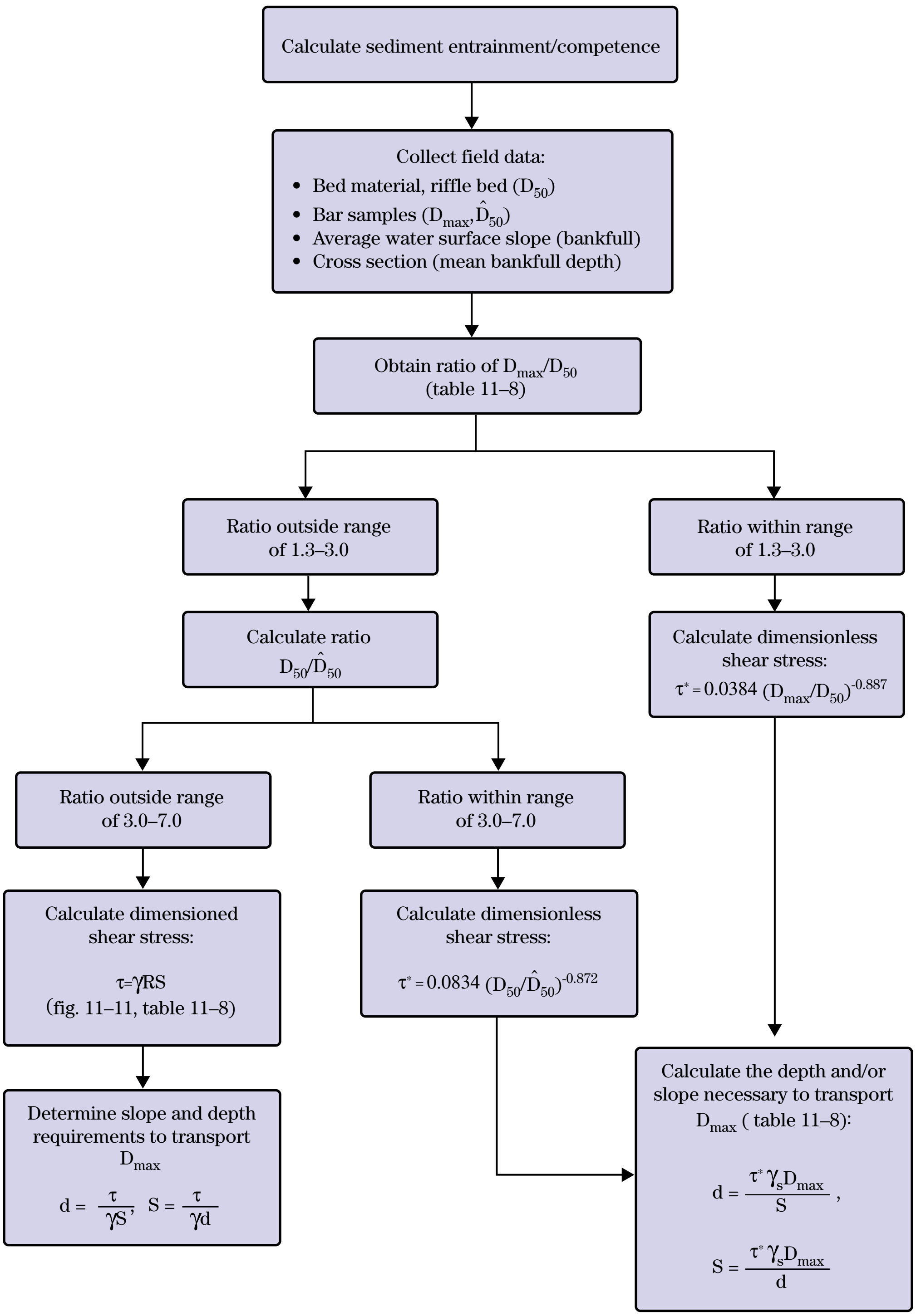


Table 11–5 Field procedure for bar samples*

Bar sample field procedure
Collect sediment core samples from point bars along the project and reference reaches. At least one sample should be collected from each reach associated with a change in stream type. Conduct a critical shear stress analysis using the following procedures:
Locate a sampling point on the downstream a third of a meander bend. The sample location on the point bar is halfway between the thalweg elevation (the point of maximum depth) and the bankfull stage elevation. Scan the point bar in this area to determine the sampling location by observing the maximum particles on the surface of the bar.
Place a 5-gallon bottomless bucket at the sampling location over one of the representative larger particles that are observed on the lower third of the point bar. Remove the two largest particles from the surface covered by the bottomless bucket. Measure the intermediate axis for each particle and individually weigh the particles. Record these values. The largest particle obtained is D_{max}, the largest particle from the bar sample. Push the bottomless bucket into the bar material. Excavate the materials from the bottomless bucket to a depth that is equal to twice the intermediate axis width of the largest surface particle. Place these materials in a bucket or bag for sieving and weighing.
For fine bar materials, follow the directions above, except that when the bottomless bucket is pushed into the bar material, excavate materials from the bucket to a depth of 4 to 6 inches. Place these materials in a bucket or bag for sieving and weighing.
Wet-sieve the collected bar materials using water and a standard sieve set with a 2-millimeter screen size for the bottom sieve. Weigh the bucket with sand after draining off as much water as possible. Subtract the tare weight of the bucket to obtain the net weight of the sand.
Weigh the sieved materials and record weights (less tare weight) by size class. Be sure to include the intermediate axis measurements and individual weights of the two largest particles that were collected.
Determine a material size class distribution for all of the collected materials. The data represents the range of channel materials subject to movement or transport as bed-load sediment materials at bankfull discharge.
Plot data; determine size-class indices, D_{16}, D_{35}, D_{50}, D_{84}, D_{95}. The D_{100} should represent the actual intermediate axis width and weight (not the tray size) when plotted. The largest size measured will be plotted at the D_{100} point (Note: $D_{100} = D_{max}$). The intermediate axis measurement of the second largest particle will be the top end of the catch range for the last sieve that retains material (use the record data in the entrainment worksheet, table 11–7).
Survey a typical cross section of a riffle reach at a location where the stream is free to adjust its boundaries. Plot the survey data. Determine the hydraulic radius of the cross section.
Conduct a Wolman Pebble Count (100 count in riffle) of the bed material in the coarsest portion of the wetted riffle area (active channel). The pebble count should be conducted at multiple transects that represent the riffle. Plot data and determine the size-class indices.

*Sediment sampling is also addressed in NEH654 TS13A.

Table 11–6 Field procedure for pavement/sub-pavement samples

Pavement/subpavement sample field procedure (alternate procedures for obtaining a pavement/sub-pavement sample if you are unable to collect a bar sample)
Locate a sampling point in the same riffle where cross-sectional survey was conducted. The sampling point should be to the left or right of the thalweg, not in the thalweg, in a coarse-grain size portion of the riffle.
Push a 5-gallon bottomless bucket into the riffle at the sampling location to cut off the streamflow. The diameter of the bucket (sample size) should be at least twice the diameter of the largest rock on the bed of the riffle.
Remove the pavement material (surface layer only) by removing the smallest to the coarsest particles. Measure the intermediate axis and weight of the largest and second largest particles. Record these values. Place the remaining pavement materials into a bucket or bag for sieving and weighing.
Remove the sub-pavement material to a depth that is equal to twice the intermediate axis width of the largest particle in the pavement layer, or at least 150-millimeter depth. Caution: if a coarser bed material persists under the sub-pavement, it generally is material remnant of the previous bed. Stop at this condition and do not excavate deeper, even if the depth is not at twice the maximum pavement particle diameter. This residual layer is generally not associated with the size distribution of bed load transported at the bankfull stage. Collect the sub-pavement materials into a separate bucket or a bag. Measure the intermediate axis and weight of the two largest particles in the sub-pavement sample. Record these values. Sieve and weigh the remaining sub-pavement materials. The sub-pavement sample is the equivalent of the bar sample; therefore, use the largest particle from the sub-pavement sample in lieu of the largest particle from a bar sample in the entrainment calculations. Note: If the largest particle collected from the sub-pavement is larger than the pavement layer, the largest rock should be discarded from the sub-pavement layer. Drop back to the next largest particle size to determine the largest particle size to be used in the entrainment calculation.
Wet-sieve the collected pavement materials and then the subpavement materials using water and a standard sieve set with a 2-millimeter screen size for the bottom sieve. Weigh the bucket with sand after draining off as much water as possible. Subtract the tare weight of the bucket to obtain the net weight of the sand.
Weigh the sieved materials and record weights (less tare weight) by size class for both the pavement and sub-pavement samples. Be sure to include the mean intermediate axis width and individual net weights of the two largest particles that were collected (table 11–7).
Determine a material size-class distribution for the materials. The subpavement data represent the range of channel materials subject to movement or transport as bed-load sediment materials at bankfull discharge.
Plot data; determine size-class indices, D_{16}, D_{35}, D_{50}, D_{84}, D_{95}. The D_{100}, should represent the actual intermediate axis width and weight (not the tray size) when plotted. The largest size measured will be plotted at the D_{100} point. (Note: $D_{100} = D_{max}$). The intermediate axis measurement of the second largest particle will be the top end of the catch range for the last sieve that retains material.
The pavement material size class distribution may be used to determine the D_{50} of the riffle bed instead of doing the 100 count in the riffle bed.
Determine the average bankfull slope (approximated by the average water surface slope) for the study reach from the longitudinal profile.
Calculate the bankfull dimensionless shear stress required to mobilize and transport the largest particle from the bar sample (or sub-pavement sample). Use the equations and record the data in the entrainment worksheet (table 11–8).

Table 11–7 Bar sample data collection and sieve analysis form

Point / Side BAR-BULK MATERIALS SAMPLE DATA: Size Distribution Analysis	Party:
Location:	Date:	Notes:

SUB SAMPLES	Sieve SIZE		Sieve SIZE		Sieve SIZE		Sieve SIZE		Sieve SIZE		Sieve SIZE		Sieve SIZE		Sieve SIZE		Sieve SIZE	
	Tare Weight		Tare Weight		Tare Weight		Tare Weight		Tare Weight		Tare Weight		Tare Weight		Tare Weight		Tare Weight	
	Sample Weights		Sample Weights		Sample Weights		Sample Weights		Sample Weights		Sample Weights		Sample Weights		Sample Weights		Sample Weights	
	Total	Net	Total	Net	Total	Net	Total	Net	Total	Net	Total	Net	Total	Net	Total	Net	Total	Net
1																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		
9																		
10																		
11																		
12																		
13																		
14																		
15																		
Net Wt. Total																		
% Grand Tot.																		
Accum. % =<																		

SURFACE MATERIALS DATA
(Two Largest Particles)

No.	Dia.	WT.
1		
2		

Bucket
+ Materials
Weight____________

Bucket
Tare
Weight____________

Materials
Weight____________
(Materials less than:
____________mm.)

Be Sure to Add Separate Material Weights to Grand Total

GRAND TOTAL SAMPLE WEIGHT

NOTES

Table 11–8 Sediment competence calculation form to assess bed stability (steps 23–26)

Stream:		Reach:			
Observers:			Date:		
Enter required information					
	D_{50}	Riffle bed material D_{50} (mm)			
	$\hat{D}_{50}$	Bar sample D_{50} (mm)			
	D_{max}	Largest particle from bar sample (ft)		**(mm)**	304.8 mm/ft
	S	Existing bankfull water surface slope (ft/ft)			
	d	Existing bankfull mean depth (ft)			
1.65	γ_s	Submerged specific weight of sediment			

Select the appropriate equation and calculate critical dimensionless shear stress				
	$D_{50} / \hat{D}_{50}$	Range: 3 – 7	Use equation 1:	$\tau^* = 0.0834 \left(\frac{D_{50}}{\hat{D}_{50}} \right)^{-0.872}$
	D_{max} / D_{50}	Range: 1.3 – 3.0	Use equation 2:	$\tau^* = 0.0384 \left(\frac{D_{max}}{D_{50}} \right)^{-0.887}$
	τ^*	Bankfull dimensionless shear stress	Equation used:	

Calculate bankfull mean depth required for entrainment of largest particle in bar sample			
	d	Required bankfull mean depth (ft)	$d = \frac{\tau^* \gamma_s D_{max}}{S}$
	Circle:	Stable Aggrading Degrading	

Calculate bankfull water surface slope required for entrainment of largest particle in bar sample			
	S	Required bankfull water surface slope (ft/ft)	$s = \frac{\tau^* \gamma_s D_{max}}{d}$
	Circle:	Stable Aggrading Degrading	

Sediment competence using dimensional shear stress	
	Bankfull shear stress $\tau = \gamma dS$ (lb/ft^2) (substitute hydraulic radius, R, with mean depth, d)
	Moveable particle size (mm) at bankfull shear stress **(**fig. 11-11**)**
	Predicted shear stress required to initiate movement of D_{max} (mm) (figure 11-11)
	Predicted mean depth required to initiate movement of D_{max} (mm) $d = \frac{\tau}{\gamma S}$
	Predicted slope required to initiate movement of D_{max} (mm) $S = \frac{\tau}{\gamma d}$

analysis for both the reference reach and project reach. This analysis of the reference, stable condition is compared to the potentially disturbed reach. To maintain stability, a stream must be competent to transport the largest size of sediment and have the capacity to transport the load (volume) on an annual basis. These calculations provide a prediction of sediment competence as required in steps 23 through 26.

Step 27 Compute sediment transport capacity. Following this analysis, the depth and/or slope may need to be adjusted by recalculating steps 14 through 27.

FLOWSED and POWERSED are sediment supply/sediment transport models that predict the following:

- total annual suspended sediment yield
- total annual suspended sand sediment yield
- total annual bed-load sediment yield
- potential aggradation and/or degradation
- flow-related annual sediment yield due to changes in streamflow magnitude and duration

The models are based on the use of dimensionless reference sediment rating and flow-duration curves. The normalization parameters include:

- bankfull discharge
- bankfull stage bed load
- suspended and suspended sand sediment

The appropriate dimensionless sediment curves are selected for representative stream types and stability ratings. The dimensionless flow-duration curves are developed from representative hydrophysiographic province data from USGS stream gage data.

The FLOWSED model reflects sediment supply and generates the total annual sediment yield for both suspended and bed load. Changes in flow are also reflected in flow-duration curves and corresponding sediment yield. To determine annual sediment yield, near-bankfull stage values must be field measured to convert dimensionless sediment and flow-duration curves to actual values.

The POWERSED model compares sediment transport capacity from a stable, reference condition by predicting transport rate change due to channel hydraulics. The hydraulics reflect potential change in morphological variables such as channel width, depth, and slope. The corresponding changes in flow resistance are used to predict velocity, shear stress, and unit stream power (velocity multiplied by shear stress). Sediment rating curves from the FLOWSED model are converted from discharge to unit stream power for a wide range of flows. Revised values of annual sediment transport can then be compared to the reference condition from the subsequent change in the hydraulic geometry of the stream channel and corresponding response in sediment transport. Any flow modifications can also be simulated by revised flow-duration curves.

Detailed descriptions and model tests are provided for FLOWSED/POWERSED in Rosgen (2006). This analysis is complicated and detailed. However, it can be computed by spreadsheet or commercially available computer programs (RIVERMorph® 4.0). The basis of the calculations and model descriptions, however, are described to better understand how the models work. Table 11–9 lists the data required to run the FLOWSED and POWERSED models. With these data, the user can generate average annual sediment yields (tons/yr).

Table 11–9 Data required to run the FLOWSED and POWERSED supply/sediment transport models

Data requirements for FLOWSED/POWERSED
• Background reference data (flow and sediment) – Dimensionless suspended sediment rating curves by stream type or stability – Dimensionless bed-load rating curves by stream type or stability – Dimensionless flow duration (from local or representative hydro-physiographic province) – Momentary maximum bankfull discharge – Mean daily bankfull discharge (the mean daily discharge the day bankfull occurs at a gage station) – Flow-duration curves indicating change in flow regime (increase and/or decrease)
• Field measured values (for both reference and impaired condition) – Cross section – Longitudinal profile – Pebble count on active riffle bed to obtain D_{50} and D_{84} of bed material – Stream classification (level II) – Pfankuch channel stability rating – Measured bankfull discharge (ft^3/s) – Measured suspended sediment (mg/L) – Measured suspended sand sediment (mg/L) – Measured bed-load sediment (kg/s) (Helley-Smith bed-load sampler)

FLOWSED

The FLOWSED model is graphically depicted in figures 11–19 and 11–20. The procedure in table 11–10 and accompanying worksheet depicted in table 11–11 provide a more detailed understanding of the model. The following provides insight into the basis of the model.

Predict runoff response—Several applicable models for runoff exist, including TR–55, WRENSS (EPA 1980), the unit hydrograph approach (U.S. Army Corps of Engineers (USACE) 1998b), and others (EPA 1980; Troendle, Swanson, and Nankervis 2005). This step also considers operational hydrology from reservoirs, diversions, and other flow modifications that influence the magnitude, duration, and timing of streamflow. The input variables for most models are precipitation data, a vegetation alteration map by aspect and elevation, drainage area computations, percent of drainage area in impervious condition, and similar data specified based on the specific model being selected. The output from these models needs to be in the form of flow-duration curves. Flow-duration curves must represent reference conditions (full hydrologic utilization or recovery) and existing departures from reference. Because few stream gages are located on smaller watersheds, dimensionless ratio procedures become essential for data extrapolation in flow models. The data are entered into the flow-duration portion of the FLOWSED worksheet (table 11–11).

Develop dimensionless flow-duration curves—If a water yield model or operational hydrology data with actual flow-duration curve data are not available, it will be necessary to utilize dimensionless flow-duration curves. This information is obtained from gage station data and made dimensionless by dividing the mean daily discharge data by bankfull discharge. Bankfull discharge data are divided into all of the ranges of mean daily discharge and then plotted; see figures 11–9 and 11–21 as an example of the application for Weminuche Creek. The user must develop dimensionless flow-duration curves from gaging stations that represent a hydro-physiographic region similar to the impaired stream being assessed. If the user is applying these relations to a stormflow-generated hydrograph, rather than snowmelt (as in the case of Weminuche Creek), the following changes are recommended:

- Convert bankfull discharge (momentary maximum discharge in ft^3/s) to mean daily bankfull. This is accomplished by obtaining the mean daily discharge on the day during which bankfull discharge occurs. This ratio of mean daily discharge divided by momentary maximum discharge is used to develop the dimensionless flow-duration curves for a stormflow-dominated region. For example, if the mean daily discharge from a gage in a stormflow-dominated hydrograph was 125 cubic feet per second, but bankfull was 550 cubic feet per second, the ratio is 0.227. This ratio would be multiplied by the bankfull discharge from the regional curves or from a flood-frequency curve relation to convert bankfull discharge from a momentary maximum to a mean daily discharge value.

- Divide the mean daily discharge values by mean daily bankfull to establish the dimensionless relations similar to those in figures 11–9 and 11–21.

- Convert from dimensionless to dimensioned mean daily bankfull values. The momentary maximum value must be adjusted by the appropriate ratio, then multiplied by the appropriate ratio value in the dimensionless flow-duration curve. The dimensioned flow-duration curve data are entered into the FLOWSED worksheet (table 11–11). This would be done separately for reference or baseline conditions, and then would be compared to impaired or impacted watershed conditions to calculate annual streamflow and sediment yield.

FLOWSED—Continued

Collect bankfull discharge, suspended sediment, and bed-load sediment—This step is eventually used to convert the reference dimensionless sediment rating curves to actual values. It is very important to capture the bankfull discharge and have several data points to compute an average of the flow and sediment values due to the high spatial and temporal variability of sediment movement. Field methods and equipment used should follow the procedures outlined in book 3, chapter C2 of Field Methods for Measurement of Fluvial Sediment (USGS 1999).

It may be necessary to separate the wash load (silt/clay fraction) from the total suspended sediment load for calculation and interpretation. For channel stability purposes, the silt/clay fraction is not energy limited or hydraulically controlled, and in some settings, it can be subtracted from the suspended sediment yield data for the prediction of potential aggradation. This would not be the case, however, if there were concerns over accelerated fine sediment deposition into extremely low-gradient streams, deltas, reservoirs, lakes, marshes, or estuaries. Colloidal sediments can present problems for impaired waters; thus, wash load may need to be retained in suspended sediment analysis. Enter these measurements in the FLOWSED worksheet (table 11–11).

Obtain or establish reference dimensionless suspended and bed-load rating curves—These curves should be developed for stable reference reach sites representing stable streams. A similar relation can be stratified for poor stability or unstable streams. These reference curves are used to establish sediment rating curves for the calculation of flow-related sediment increases and to establish an annual sediment yield estimate for proportioning contributing sediment sources. The equations for these curve relations are used in the FLOWSED worksheet (table 11–11).

Convert dimensionless suspended and bed-load sediment rating curves to actual (dimensioned) values—Convert dimensionless values by multiplying the field-measured bankfull discharge and sediment values by each of the ratios appropriate for the relation selected. Dimensionless ratio bed-load and suspended rating curves are used to convert data to dimensioned rating curves (fig. 11–20). Examples of dimensioned bed-load and suspended sediment rating curves are shown in figures 11–22 and 11–23 for the Weminuche Creek in Colorado. Tests of this relation are reported in the text in figures 11–13, 11–14, and 11–15, where reference dimensionless rating curves were used to establish sediment rating curves.

If it is not possible to obtain measured bankfull discharge, suspended sediment, and bed-load sediment data to convert dimensionless sediment rating curves to actual values, regional curves can be temporarily substituted. The user must obtain drainage area in square miles to calculate bankfull discharge from a similar hydro-physiographic province. The bankfull flow is used to convert the dimensionless flow-duration to dimensioned flow duration. The bankfull discharge is also used to convert the dimensionless discharge portion of the dimensionless bed-load and suspended rating curve to actual values. The sediment data obtained from the drainage area must be derived from existing measured bankfull suspended sediment and bed-load sediment data, then converted to unit area sediment values from the corresponding drainage area. These data need to represent the same lithology, stream type and stability condition of the stream being evaluated. These data are entered in the FLOWSED worksheet (table 11–11).

An example of unit area suspended sediment data from USGS sites throughout the United States is shown in Simon, Dickerson, and Heins (2004). These measured sediment values were separated by evolutionary stages. Additional stability or stream type data may help to identify appropriate relations for extrapolation. This drainage area extrapolation procedure represents only an interim procedure until measured bankfull values can be obtained.

FLOWSED—Continued

Convert dimensionless flow duration to dimensioned flow duration—The bankfull discharge is multiplied by each of the ratios to convert dimensionless data to actual discharge values representing mean daily discharge for each percentile. An example of a dimensioned flow-duration curve using bankfull discharge to convert from the dimensionless relation (fig. 11–21) is shown in figure 11–24.

Calculate annual sediment yield for both suspended and bed-load sediment—This is accomplished by taking the dimensioned flow-duration curve and multiplying flow increments for duration of time in days by the sediment yield associated with that flow. Enter these calculations in the FLOWSED worksheet (table 11–11).

Calculate flow-related sediment yield—This calculation is accomplished using the output of the flow-duration curves showing the increase in magnitude and duration of flow. The post-treatment flows are routed through the calculation in the FLOWSED worksheet (table 11–11). The excess water calculation output from the WRENSS snowmelt model (EPA 1980) or a similar model integrates the flow with flow-duration changes. Dimensionless flow-duration curves are also converted to dimensioned values by multiplication of the bankfull discharge value. Reference conditions for watersheds in relative hydrologic recovery are compared to watersheds where streamflow has been increased or decreased by change in vegetation or by reservoirs and/or diversions.

Stormflow models, such as TR–55, need to be used to compute new bankfull values, converting dimensionless values to new dimensioned flow durations. It is important to calibrate the bankfull discharge, as the precipitation probability for a given antecedent moisture content and runoff curve number that generates the bankfull discharge needs to be determined. Any greater flow will be distributed on flood plains or a flood-prone area if the stream is not entrenched. Thus, flow-related sediment changes are determined by the use of dimensionless sediment rating curves and dimensionless flow-duration curves. Other appropriate models can also be used for this step, based on the user's familiarity with the various models selected. The output required, regardless of the model, is bankfull discharge and pre- and post-treatment flow-duration curves.

Figure 11–19 General overview of the FLOWSED model

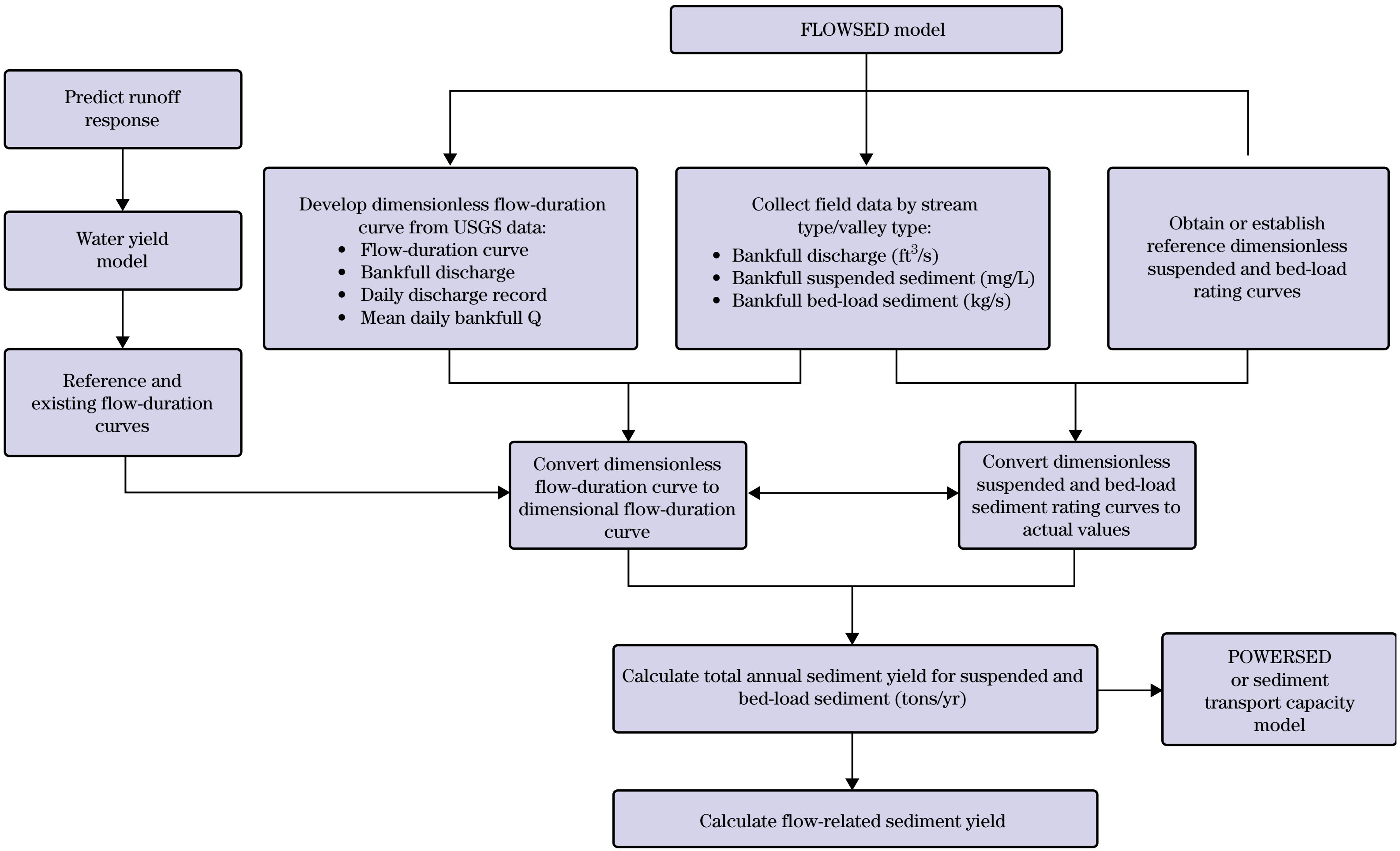


Figure 11–20 Graphical depiction of the FLOWSED model

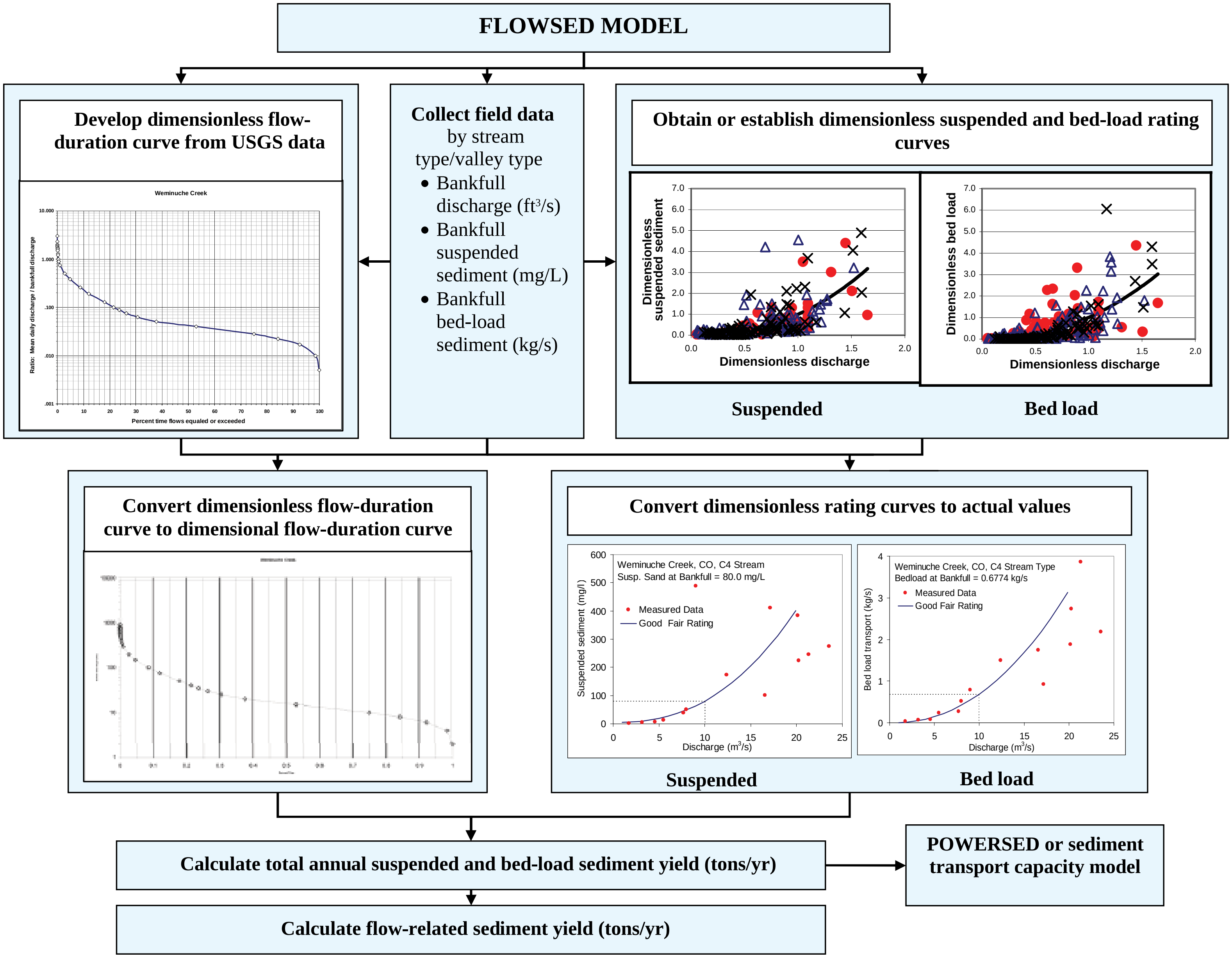


Table 11–10 FLOWSED model procedure to calculate annual bed-load and suspended sediment yield

FLOWSED procedure	
FS–1	Measure stream cross section (on riffle), profile, pattern, and materials.
FS–2	Measure bankfull width, mean depth, and velocity, and compute discharge.
FS–3	Measure suspended sediment at the bankfull stage; separate wash load in lab
FS–4	Measure bed-load sediment at the bankfull stage, sieve particle sizes, and measure largest size.
FS–5	Compute average water surface slope.
FS–6	Collect point bar sample, weigh by size fraction and record D_{50} and largest size (D_{max}).
FS–7	Collect pebble count on active riffle bed: obtain D_{50}, D_{84} sizes (mm).
FS–8	Determine stream type.
FS–9	Conduct channel stability assessment procedure, including Pfankuch channel stability rating.
FS–10	Obtain reference dimensionless bed-load sediment rating curve for appropriate stream type/stability rating.
FS–11	Obtain reference dimensionless suspended sediment rating curve for appropriate stream type/stability rating.
FS–12	Determine ratio of wash load/suspended sediment by Q/Q_{bkf} relation.
FS–13	Construct a bed-load rating curve (enter range of Q/Q_{bkf} ratios into the reference bed-load relation from step 10 and multiply by the measured bankfull bed load from step 4).
FS–14	Construct suspended sediment rating curve in the same manner as in step 13 using reference dimensionless sediment relations (step 11) and bankfull suspended sediment (step 3).
FS–15	Construct a suspended sediment rating curve less wash load (silt/clay) for potential settleable sediment by multiplying ratio of wash load/suspended sediment for appropriate Q/Q_{bkf}.
FS–16	Convert suspended sediment less wash load from mg/L to tons/day on rating curve: tons/d = $0.0027 \times ft^3/s \times mg/L$.
FS–17	Convert suspended sediment less wash load from mg/L to tons/d as in step 16.
FS–18	Convert bed load in lb/s to tons/d, where tons/d = (lb×86,400)/2000 (if metric, convert kg/s to lb/s by multiplying by 2.205).
FS–19	Obtain dimensionless flow-duration curve from either water yield model or regionalized relation.
FS–20	Develop the dimensionless flow-duration curves using the normalization parameter of mean daily bankfull discharge, rather than momentary maximum values from flood-frequency data. Divide the mean daily discharge (the day bankfull discharge occurs) by the momentary maximum value to determine the appropriate conversion ratio.
FS–21	Convert dimensionless flow-duration curve to actual flow by multiplying bankfull discharge (step 2) times the Q/Q_{bkf} ratios from dimensionless flow-duration curve (step 19).
FS–22	Calculate total annual sediment yield for suspended sediment, suspended sediment less wash load, and bed load from sediment rating curve/flow-duration curve procedure (table 11–11). Obtain flow from the water yield model for hydraulically recovered condition to compare departure from existing/proposed condition (step 22). This represents the pre-treatment flow duration/sediment relation.
FS–23	To determine flow-related increase in sediment, multiply post-treatment flow-duration curve times appropriate sediment rating curves for suspended, bed-load and total sediment rating curves to calculate total annual sediment yield using the same procedure as step 21 (table 11–11).

Table 11–11 FLOWSED calculation of total annual sediment yield

Stream: **Notes:**

From flow-duration curve						From sediment rating curves					Calculate	Calculate daily mean sediment yield				
Flow exceedance	Daily mean discharge	Mid-ordinate streamflow	Increment	Mid-ordinate streamflow	Dimensionless streamflow	Dimensionless suspended sediment discharge	Suspended sediment discharge	Suspended sediment minus wash load	Dimensionless bed-load discharge	Bed load	Time adjusted streamflow	Suspended sediment	Suspended sediment minus wash load	Bed load	Bed load plus suspended	Bed load plus suspended minus wash load
(%)	(ft^3/s)	(%)	(%)	(ft^3/s)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/d)	(tons/d)	(b_s/b_{bkf})	(tons/d)	(ft^3/s)	(tons/d)	(tons/d)	(tons/d)	(tons/d)	(tons/d)
									Annual totals:		(acre-ft)	tons/yr)	(tons/yr)	(tons/yr)	(tons/yr)	(tons/yr)

Bankfull discharge (ft^3/s)	
Bankfull bed load (kg/s)	
Bankfull suspended (mg/L)	

Dimensionless sediment rating curve used							
Type	**Intercept**	**Coefficient**	**Exponent**	**X**	**Y**	**Form**	**Notes**
Bed load							
Suspended							

Figure 11–21 Dimensionless flow-duration curve for Weminuche Creek, CO

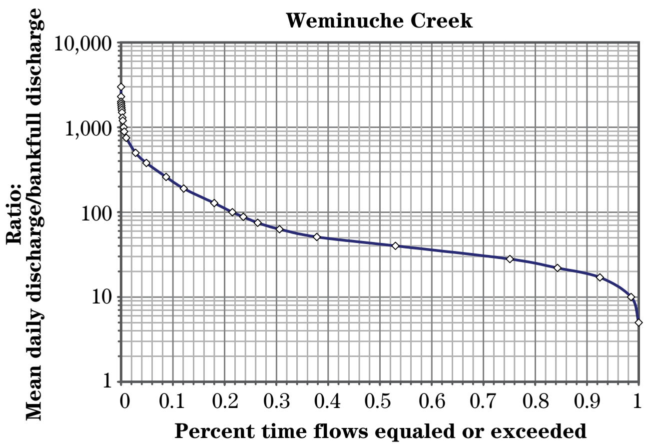


Figure 11–22 Bed-load sediment rating curve for Weminuche Creek, CO

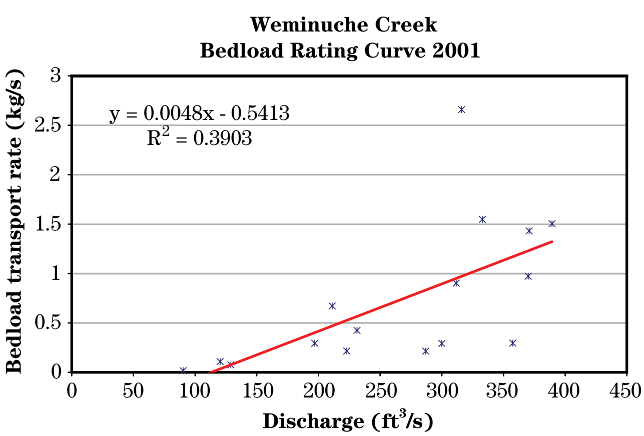


Figure 11–23 Suspended sediment rating curve for Weminuche Creek, CO

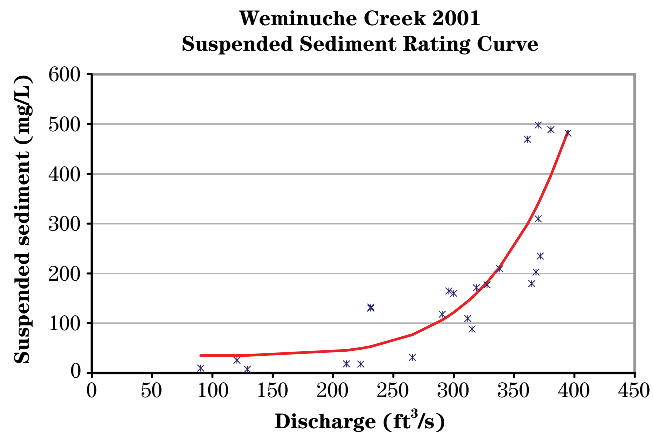
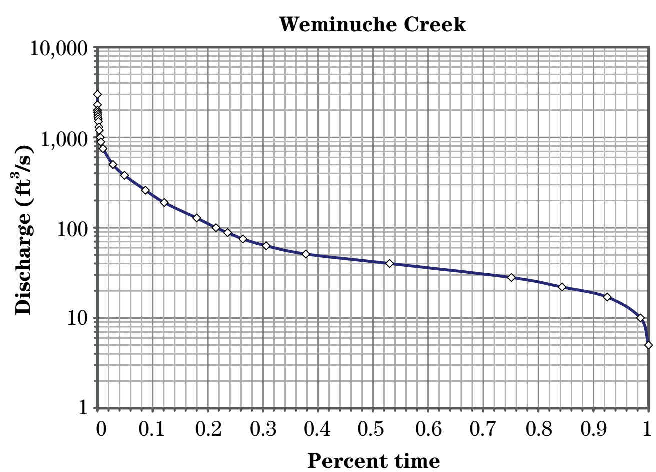


Figure 11–24 Dimensioned flow-duration curve for Weminuche Creek, CO



POWERSED

A generalized flowchart depicting the POWERSED model is shown in figure 11–25, and a graphical depiction of the model is shown in figure 11–26.

Evaluate channel characteristics that change hydraulic and morphological variables—Changes in the cross section and/or pattern (slope) for potentially impaired reaches are measured to determine width, depth, slope and calculated velocity. Comparisons are made between hydraulic characteristics of the reference versus the impaired reach. This analysis is used in the bed-load transport model (POWERSED) or in a comparable bed-load model selected by the user. Shear stress and unit stream power are calculated using equations 11–2 and 11–7:

$$\tau=\gamma dS \qquad \text{(eq. 11–2)}$$

where:
γ = specific weight of the fluid
d = mean depth
S = water surface slope

Unit stream power or power per unit of streambed area (ω_a) is defined as:

$$\omega_a=\tau u \qquad \text{(eq. 11–7)}$$

where:
τ = bankfull shear stress (lb/ft^2)
u = mean velocity

POWERSED can be used to simulate hydraulic geometry (width, depth, slope, velocity, and discharge) for a wide range of stages for reference and impaired reach hydraulic evaluations. POWERSED can also be used to compute changes in hydraulic character due to modified channel dimension, pattern, profile or materials. This information is used to determine changes in unit stream power for increased or decreased discharge. This model predicts channel stability response to imposed sediment load, change in flow, and/or change in distribution of energy due to channel change. The model determines sediment transport and predicts aggradation, stability, or degradation, depending on the nature and extent of the channel and/or flow change. The hydraulic/sediment departure is compared to the corresponding reference or stable condition. A recent comparison of predicted to observed values on an independent data set was shown in Rosgen (2006) where predicted annual sediment yield values were predicted within 3 percent of measured values for a C4 stream type and within 6 percent of measured values for a D4 stream type on Weminuche Creek, Colorado.

Calculate bed-load and suspended sand-bedmaterial load transport (stream power)—Bed load and suspended sand-bed material load transport calculations may use various equations, such as the Bagnold equation. The POWERSED model (figs. 11–25, 11–26 and tables 11–12 and 11–13) assists in the analysis of sediment transport and channel response. This model was developed to predict the effects of channel instability and sediment supply changes in sediment transport. Other bed-load and suspended sand-bed material load transport models can be employed by the user, based on familiarity with and calibration/validation of the model for application to the particular stream types being analyzed.

The POWERSED model applies the suspended sand-bed material and bed-load sediment rating curves/flow duration/revised unit stream power-transport curves or a comparable model selected by the user to predict sediment transport and channel stability. The prediction includes river stability and total annual bed-load sediment yield in tons/year. The equations or computer program generates a change in coarse bed-load transport that will be influenced by changes in channel cross section and/or slope. Changes in streamflow, velocity, unit stream power, critical dimensionless shear stress, and other variables due to land use changes predict changes

POWERSED—Continued

in river stability and total annual bed-load sediment yield. The sediment supply component is predicted using the FLOWSED model and is derived from dimensionless bed-load and suspended sediment rating curves for corresponding stream and stability types. These changes are compared to stable reference conditions for a departure comparison.

Procedural steps for computations of the POWERSED model are presented in table 11–12. Bed-load transport and suspended sand-bed material load is calculated using the POWERSED worksheet (table 11–13).

The POWERSED model is used to predict the transport rate and capacity for each reach independently. Reaches may be stable (sediment in versus sediment out), aggrading, or degrading. The model identifies reaches that may have serious instabilities due to changes in sediment supply and/or hydraulic characteristics. The analysis assists in pinpointing various river reaches for mitigation. The sediment transport changes reflect the sediment supply of the existing condition compared to the reference condition. Annual streambank erosion rates and other sources are compared to the total annual sediment yield.

Figure 11–25 POWERSED model to predict bed-load and suspended sand-bed-material load transport

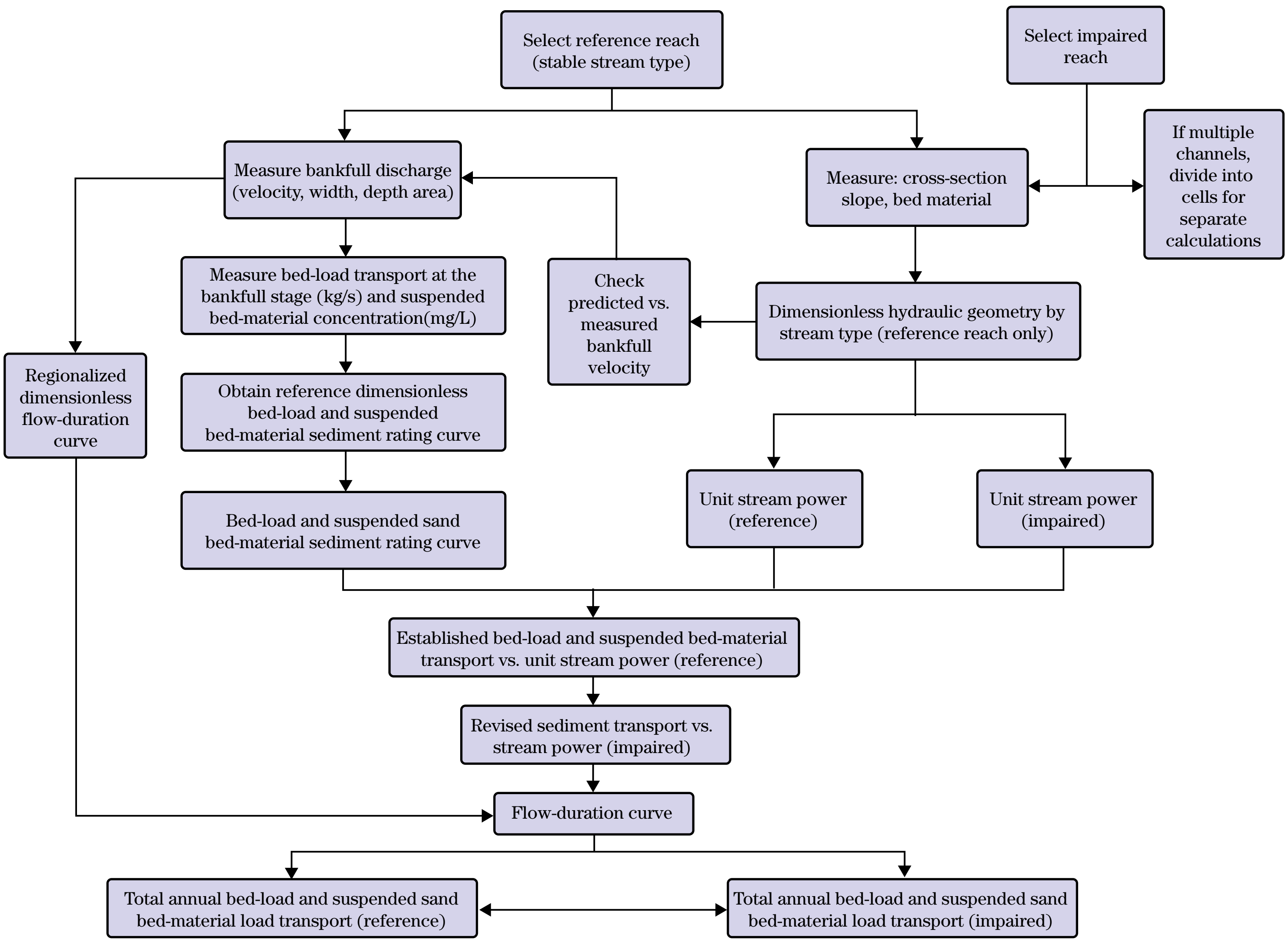


Figure 11–26 Graphical depiction of POWERSED model

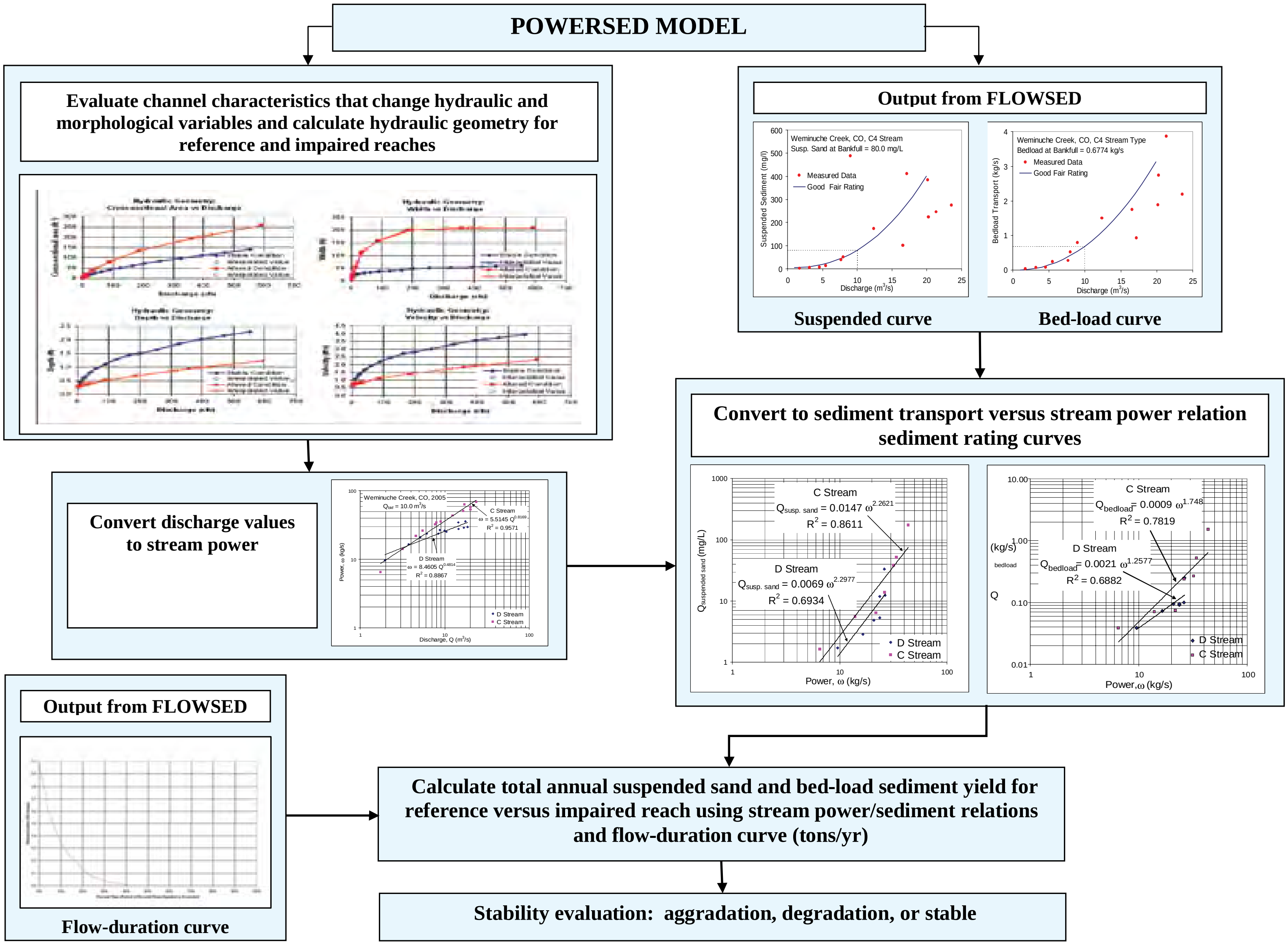


Table 11–12 POWERSED procedural steps of predicted bed-load and suspended sand-bed material transport changes due to alterations of channel dimension or slope (same stream with different bankfull discharges)

POWERSED procedure	
PS–1	Select a reference reach: a. Survey a stable cross section; measure the stream gradient and bed material. b. Measure bankfull discharge (ft^3/s). c. Measure bankfull bed load (kg/s).
PS–2	Obtain an appropriate dimensionless bed load and suspended sand sediment rating curve: a. Construct a dimensional bed load and suspended sand sediment rating curve for the defined range of flow using the measured bankfull discharge, bankfull bed load transport and suspended sand-bed material load.
PS–3	Obtain the drainage area of the reference reach: a. Predict bankfull discharge and cross-sectional dimensions using regional curves. b. Validate the regional curves using the measured bankfull discharge and cross-sectional dimensions.
PS–4	Use dimensionless hydraulic geometry by stream type to predict the hydraulic geometry of the stable cross section for a full range of discharge (baseflow to above bankfull): a. Construct hydraulic geometry curves. b. Check predicted versus measured bankfull velocity. c. Obtain hydraulic geometry for each discharge value within the defined range of flow. d. Calculate unit stream power for each discharge value within the defined range of flow.
PS–5	Select an impaired reach on the same stream: a. Obtain the drainage area. b. Predict bankfull discharge from the validated regional curve. c. Survey the cross section, and measure the stream gradient and bed material.
PS–6	Obtain the stable (potential) dimension, pattern, and profile for the impaired reach. If reference reach is not immediately upstream and/or is of different size or drainage area, complete the following procedure: a. Slope = valley slope/sinuosity. b. Obtain appropriate cross-sectional area from regional curve. c. Obtain width-to-depth ratio (W/d) from reference dimensionless ratios by stream type. d. Calculate appropriate width.
PS–7	Use the RIVERMorph® procedure or applicable spreadsheet calculations to predict the hydraulic geometry of the impaired and potential cross sections for a full range of discharge (baseflow to above bankfull). Follow the step below for the impaired and potential cross sections: a. Construct hydraulic geometry curves. b. Obtain hydraulic geometry for each discharge value within the defined range of flow. * If channel has multiple channels, divide the channels into thirds and treat as a separate channel c. Calculate unit stream power for each discharge value within the defined range of flow.
PS–8	Plot unit stream power vs. bed load and suspended sand-bed material transport for the stable cross section.
PS–9	Construct a unit stream power versus bed-load transport curve for the impaired and potential cross sections using the relationship constructed in step 8.
PS–10	Obtain a dimensionless flow-duration curve for the appropriate region: a. Create a dimensional flow-duration curve using the bankfull discharge for the stable reach. b. Create a dimensional flow-duration curve using the bankfull discharge for the impaired reach.

Table 11–12 POWERSED procedural steps of predicted bed-load and suspended sand-bed material transport changes due to alterations of channel dimension or slope (same stream with different bankfull discharges)—Continued

POWERSED procedure	
PS–11	Calculate total annual sediment yield (bed-load and suspended sand-bed-material load) in tons/yr for all three (stable, impaired, potential) cross sections using the appropriate flow-duration curve: a. Convert the predicted bed-load transport for each discharge value within the defined range of flow from kg/s to tons/d by multiplying kg/s by 95.24. Convert values of suspended sand-bed material load in mg/L to tons/d by multiplying (mg/L)(.0027)(ft^3/s). b. Multiply the predicted bed-load and suspended sand-bed material load transport (tons/d) by the percent time factor from flow-duration curve. c. Sum the time adjusted bed-load transport and multiply by 365 days to obtain annual bed load yield in tons/yr. d. Divide the annual yield for both bed-load and suspended sand-bed material load by the drainage area to obtain the annual unit area bed-load and suspended sand-bed material load yield (tons/yr/mi^2). e. Compare the annual unit area bed-load and suspended sand-bed material load yield predicted for all three conditions (stable, impaired and potential).
PS–12	Record data for impacted and reference condition (separately) in POWERSED worksheet (table 11–13).

Table 11–13 POWERSED model to predict bed-load and suspended sand and bed-material load transport*

Stream: **Gage station#:** **Date:**

Equation type	B0	B1	B2	Form	Equation name	Enter equation number (1 or 2)	Bankfull discharge (ft^3/s)	Bankfull bed load (lb/s)	Suspended bed-material load (mg/L)
1 Dimensional									
2 Dimensionless									
3 Bed load									
4 Suspended sand-bed concentration									

Flow-duration curve		Calculate	Hydraulic geometry				Measure	Calculate								
Exceedance probability	Daily mean discharge	Mid-ordinate streamflow	Area	Width	Depth	Velocity	Slope	Shear stress	Stream power	Unit power	Time increment	Daily mean bed-load transport	Time adjusted bed-load transport	Daily mean suspended transport	Time adjusted suspended transport	Time adjusted total transport
(%)	(ft^3/s)	(ft^3/s)	(ft^2)	(ft)	(ft)	(ft/s)	(ft/ft)	(lb/ft^2)	(lb/s)	(lb/ft/s)	(%)	(tons/d)	(tons)	(tons/d)	(tons)	(tons)
											Annual total sediment yield (tons/yr):				

*Use this model for both reference and impaired conditions separately. Calculate bed load separately from suspended bed-material load.

Step 28 Obtain maximum bankfull riffle depth (d_{max}) from ratio of maximum riffle depth divided by mean bankfull depth from dimensionless ratios of reference reach data (step 7) (table 11–3).

$$d_{mbkf} = \left[\left(\frac{d_{mbkf}}{d_{bkf}}\right)_{ref}\right] d_{bkf} \qquad \text{(eq. 11–18)}$$

Step 29 Determine entrenchment ratio of proposed channel by measuring the width of the flood-prone area at an elevation of twice the maximum bankfull depth ($d_{max\ bkf}$). Entrenchment ratio is calculated by:

$$ER = \frac{W_{fpa}}{W_{bkf}} \qquad \text{(eq. 11–19)}$$

Step 30 Calculate flood-prone area capacity. This involves estimating velocity associated with the cross-sectional area and slope of the stream channel and flood-prone area. Determine cross-sectional area of the flood-prone area. Plot the bankfull cross-section and flood-prone area elevation ($2 \times d_{max\ bkf}$) and width. Use valley slope for hydraulic calculations for the flood-prone area. Estimate roughness from Manning's equation based on vegetative cover and other roughness elements. HEC–2, HEC–RAS, or other models can be used to obtain the corresponding discharge of the flood-prone area. Calculate the 50- and 100-year flood levels based on the proposed design. Use the bankfull channel capacity from step 22.

Step 31 Calculate depth of pool (ratios from table 11–3):

$$d_{mbkfp} = \left[\left(\frac{d_{mbkfp}}{d_{bkf}}\right)_{ref}\right] d_{bkf} \qquad \text{(eq. 11–20)}$$

Step 32 Calculate depth of glide (ratios from table 11–3):

$$d_g = \left[\left(\frac{d_g}{d_{bkf}}\right)_{ref}\right] (d_{bkf}) \qquad \text{(eq. 11–21)}$$

Step 33 Calculate depth of run (ratios from table 11–3):

$$d_{run} = \left[\left(\frac{d_{run}}{d_{bkf}}\right)_{ref}\right] (d_{bkf}) \qquad \text{(eq. 11–22)}$$

Step 34 Calculate slope of pool (ratios from table 11–3):

$$S_p = \left[\left(\frac{S_p}{S}\right)_{ref}\right] S \qquad \text{(eq. 11–23)}$$

Step 35 Calculate slope of glide (ratios from table 11–3):

$$S_g = \left[\left(\frac{S_g}{S}\right)_{ref}\right] S \qquad \text{(eq. 11–24)}$$

Step 36 Calculate slope of run (ratios from table 11–3):

$$S_{run} = \left[\left(\frac{S_{run}}{S}\right)_{ref}\right] S \qquad \text{(eq. 11–25)}$$

Step 37 Calculate pool-pool spacing (from plan view and profile layout).

Step 38 Design stabilization/fish habitat enhancement measures (grade control, energy dissipation, bank stability, holding cover). See phase VI.

Step 39 Prepare revegetation plan compatible with native plants, soil, and site conditions. Make recommendations on vegetative maintenance and management for long-term solutions.

Step 40 Design a monitoring plan including effectiveness, validation, and implementation monitoring. Prepare maintenance plan to ensure long-term success.

The variables associated with existing, proposed, gage station, and reference reach data are summarized in the form as demonstrated in table 11–14 (Rosgen 1998). The variables used in table 11–14 and forms used in field data collection are in the Reference Reach Field Book (Rosgen, Leopold, and Silvey 1998; Rosgen and Silvey 2005).

Table 11–14 Morphological characteristics of the existing and proposed channel with gage station and reference reach data

Restoration site (name of stream and location):
Reference reach (name of stream and location):

Variables		Existing channel	Proposed reach	USGS station	Reference reach
1	Stream type				
2	Drainage area, mi^2				
3	Mean riffle depth, ft (d_{bkf})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
4	Riffle width, ft (W_{bkf})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
5	Width-to-depth ratio (W_{bkf}/d_{bkf})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
6	Riffle cross-sectional area, ft^2 (A_{bkf})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
7	Max riffle depth (d_{mbkf})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
8	Max riffle depth/mean riffle depth (d_{mbkf}/d_{bkf})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
9	Mean pool depth, ft (d_{bkfp})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
10	Mean pool depth/mean riffle depth	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
11	Pool width, ft (W_{bkfp})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
12	Pool width/riffle width	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
13	Pool cross-sectional area, ft^2 (A_{bkfp})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
14	Pool area/riffle area	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
15	Max pool depth (d_{mbkfp})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
16	Max pool depth/mean riffle depth (d_{mbkfp}/d_{bkf})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:

Table 11–14 Morphological characteristics of the existing and proposed channel with gage station and reference reach data—Continued

Variables		Existing channel	Proposed reach	USGS station	Reference reach
17	Low bank height (LBH)	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
18	Low bank height to max riffle depth (LBH/d_{mbkf})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
19	Width of flood-prone area, ft (W_{fpa})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
20	Entrenchment ratio (W_{fpa}/W_{bkf})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
21	Point bar slope	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
22	Bankfull mean velocity, ft/s (u_{bkf})				
23	Bankfull discharge, ft^3/s (Q_{bkf})				
24	Meander length, ft (Lm)	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
25	Meander length ratio (Lm/W_{bkf})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
26	Radius of curvature, ft (Rc)	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
27	Ratio of radius of curvature to bankfull width (Rc/W_{bkf})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
28	Belt width, ft (W_{blt})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
29	Meander width ratio ($W_{b/t}/W_{bkf}$)	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
30	Individual pool length, ft	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
31	Pool length/riffle width	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
32	Pool to pool spacing (based on pattern), ft (p-p)	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:

Table 11–14 Morphological characteristics of the existing and proposed channel with gage station and reference reach data—Continued

Variables		Existing channel	Proposed reach	USGS station	Reference reach
33	Ratio of p-p spacing to bankfull width (p-p/W_{bkf})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
34	Stream length (SL)				
35	Valley length (VL)				
36	Valley slope (VS)				
37	Average water surface slope (S)		S = VS/k		
38	Sinuosity (k)	SL/VL:	SL/VL:	SL/VL:	SL/VL:
		VS/S:		VS/S:	VS/S:
39	Riffle slope (water surface facet slope) (S_{rif})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
40	Ratio riffle slope to average water surface slope (S_{rif}/S)	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
41	Run slope (water surface facet slope) (S_{run})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
42	Ratio run slope/average water surface slope (S_{run}/S)	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
43	Pool slope (water surface facet slope) (S_p)	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
44	Ratio of pool slope/average water surface slope (S_p/S)	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
45	Glide slope (water surface facet slope) (S_g)	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
46	Ratio glide slope/average water surface slope (S_g/S)	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
47	Max run depth, ft (d_{run})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
48	Ratio max run depth/ bankfull mean depth (d_{run}/d_{bkf})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:
49	Max glide depth, ft (d_g)	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:

Table 11–14 Morphological characteristics of the existing and proposed channel with gage station and reference reach data—Continued

Variables		Existing channel	Proposed reach	USGS station	Reference reach
50	Ratio max glide depth/ bankfull mean depth (d_g/d_{bkf})	Mean:	Mean:	Mean:	Mean:
		Range:	Range:	Range:	Range:

Materials					
51	Particle size distribution of channel material (active bed)				
	D_{16} (mm)				
	D_{35} (mm)				
	D_{50} (mm)				
	D_{84} (mm)				
	D_{95} (mm)				
52	Particle size distribution of bar material				
	D_{16} (mm)				
	D_{35} (mm)				
	D_{50} (mm)				
	D_{84} (mm)				
	D_{95} (mm)				
	Largest size particle at the toe (lower third) of bar (mm)				

Sediment transport validation (Based on Bankfull Shear Stress)		**Existing**	**Proposed**
Calculated shear stress value (lb/ft^2) from curve			
Size from Shields diagram - Original data (mm)			
Size from Shields diagram - Colorado data (mm)			
Largest size (mm) to be moved (D_{max})			
Dimensionless shear stress (τ^*)			
Mean d_{bkf} (ft) calculated using dimensionless shear stress equations for given slope			

Remarks:

(f) Phase VI—Selection and design of stabilization and enhancement structures/methodologies

The objectives of river structures are often primarily designed to:

- buy time to protect the new channel from excess erosion until significant riparian vegetation can become established
- reduce accelerated streambank erosion
- provide grade control
- provide recreational boating
- obtain stable flow diversions
- enhance fish habitat including instream cover, holding cover, spawning habitat, and habitat diversity
- reintroduce and stabilize large wood for fishery, stability, and aesthetic purposes
- protect infrastructure adjacent to streams
- protect bridges, culverts, and drainageway crossings
- reduce flood levels
- transport sediment
- provide energy dissipation

River stabilization and enhancement structures are numerous and continue to be improved and developed. The effort here will not be to make a complete listing, but rather present methods used in the Rosgen geomorphic channel design methodology consistent with the objectives. The structures and methods primarily utilize native materials such as natural boulders, logs, rootwads, and vegetative transplants.

Design objectives will be presented to provide the user with alternatives to standard or traditional structures.

Grade control

Often cross-channel check dams are used for grade control. NRCS has successfully used many types of channel grade control structures, but streams with high sediment loads have experienced some adverse channel adjustment in some case. The adjustments are associated with aggradation, lateral erosion, flood stage increase, migration barriers for fish, increased recreational boating risk, land loss, channel incision through lateral migration and channel avulsion. To prevent these stability problems, the cross vane was developed (fig.11–27 (Rosgen 2001e)).

Application of this design is also very effective for bridge pier scour reduction (Johnson, Hey, et al. 2002). A photograph depicting the structure as constructed on the lower Blanco River, Colorado, is shown in figure 11–28. The structure also decreases near-bank shear stress, minimizing streambank erosion.

The photographs in figures 11–29 and 11–30 demonstrate the use of cross vanes in river restoration. In this example, a reconstructed river project on the East Fork Piedra River, Colorado, in a valley type V (glacial trough), converted a braided (D4) stream type to a meandering (C4) stream type. The use of the cross vane structure was effective at maintaining grade control, transporting excessive coarse bed load, reducing bank erosion, buying time for riparian vegetation colonization, and providing trout habitat. The structures located along 3 miles of this project withstood floods at twice the bankfull discharge magnitude in 2004. Logs and rootwads can also be utilized in this structure as designed in Rosgen (2001e) and as shown in figure 11–31. The use of large wood in this structure assists in the visual, as well as biological enhancement objectives. The step in the upper third of the structure dissipates energy, reduces footer scour, and minimizes risk for recreational boating and fish passage.

A structure designed for larger rivers for grade control and streambank protection is the W-weir. This structure can also be effectively used for irrigation diversions, protection of central piers and approach sections on bridges, bed-load transport, recreational boating, and fish habitat. Visually, it is improved over a line of rock often used in grade control. It resembles natural bedrock features in stream channels. Figure 11–32 depicts the design (Rosgen 2001e), and figure 11–33 shows a typical W-weir structure as installed on the Uncompahgre River in Colorado.

Streambank stabilization

Most stream restoration projects require some degree of streambank stabilization. Often the stabilization involves riparian vegetation reestablishment or change in management. Regardless, there is a time element that is needed to establish rooting depth, density, and

Figure 11–27 Cross section, profile, and plan view of a cross vane

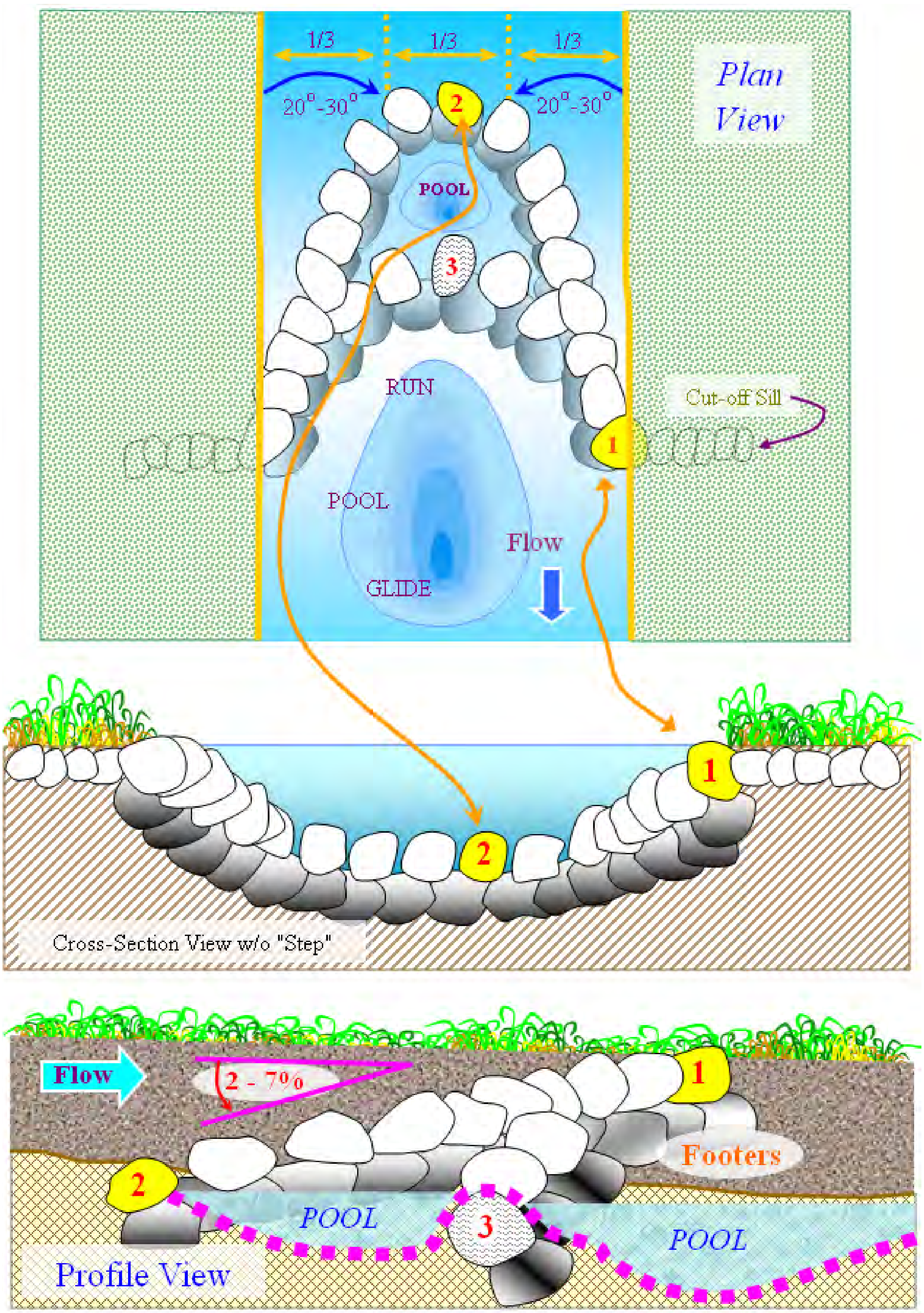


Figure 11–28 Cross vane installed on the lower Blanco River, CO

Figure 11–30 Cross vane/step-pool on the East Fork Piedra River, CO

Figure 11–29 Cross vane structure with step on the East Fork Piedra River, CO

Figure 11–31 Cross vane/rootwad/log vane step-pool, converting a braided D4→C4 stream type on the East Fork Piedra River, CO

Figure 11–32 Plan, cross section, and profile views of a W-weir structure

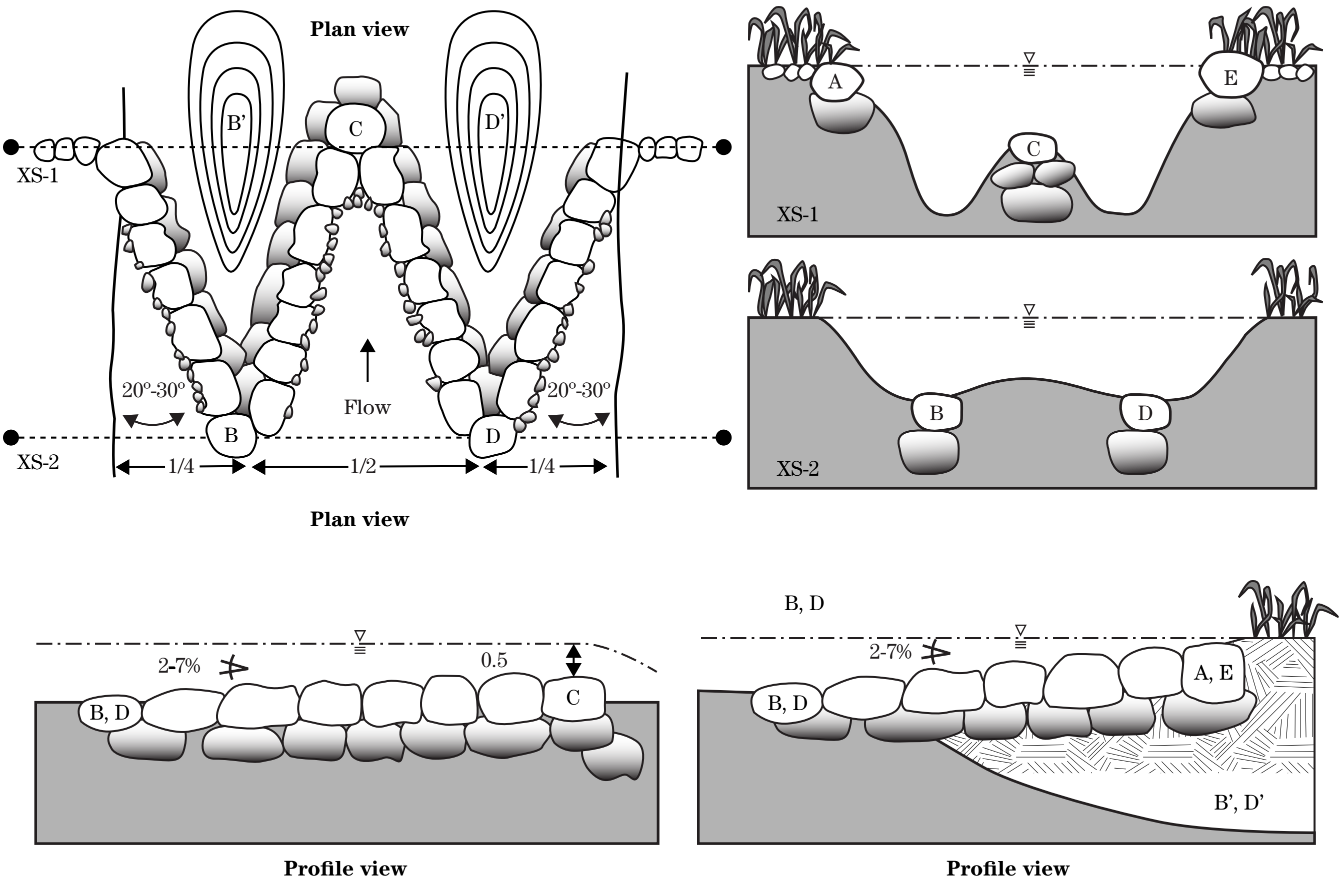


Figure 11–33 W-weir installed on the Uncompahgre River, CO

Figure 11–34 Plan, profile, and section views of the J-hook vane structure

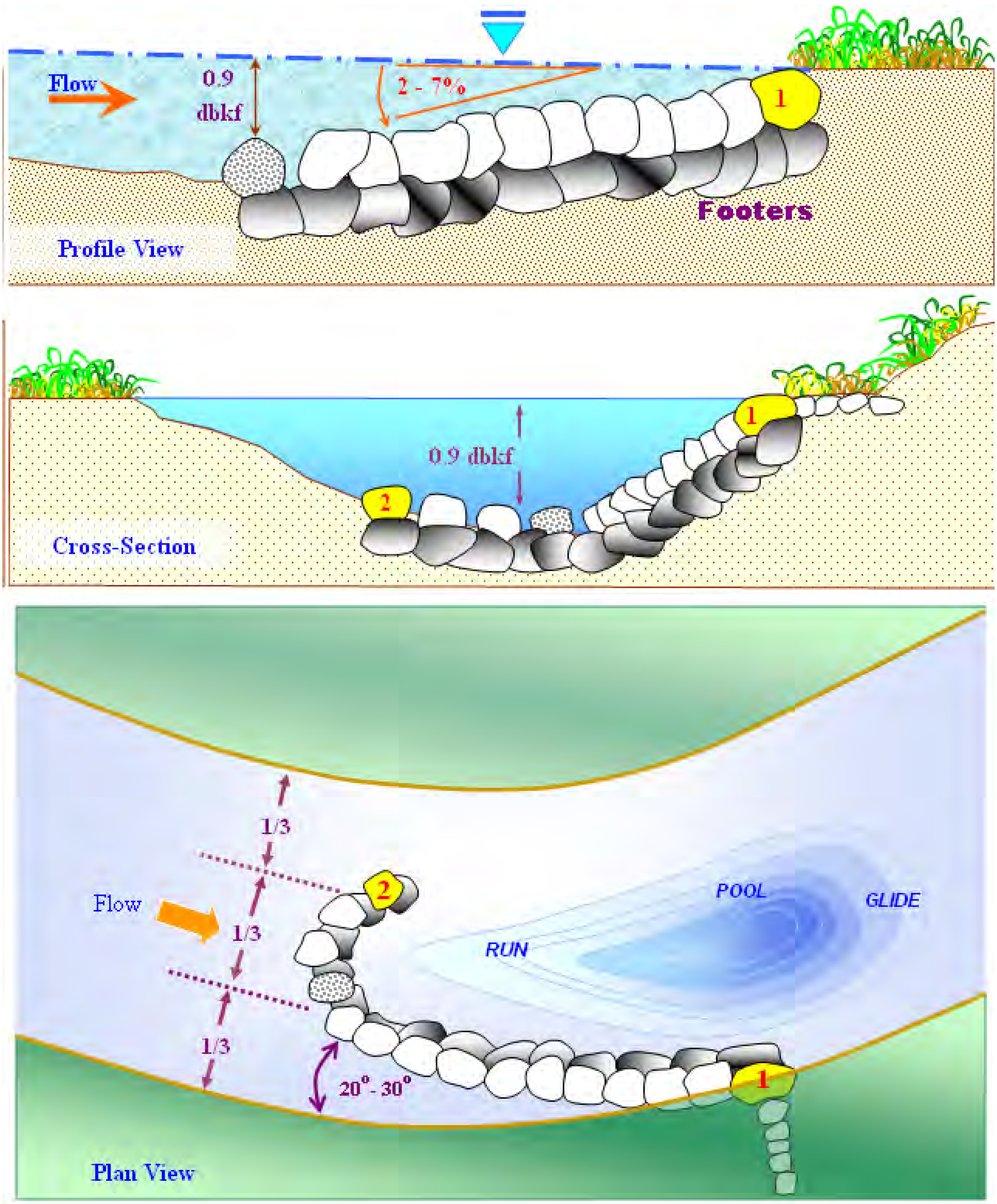


Figure 11–35 Log vane/J-hook combo with rootwad structure

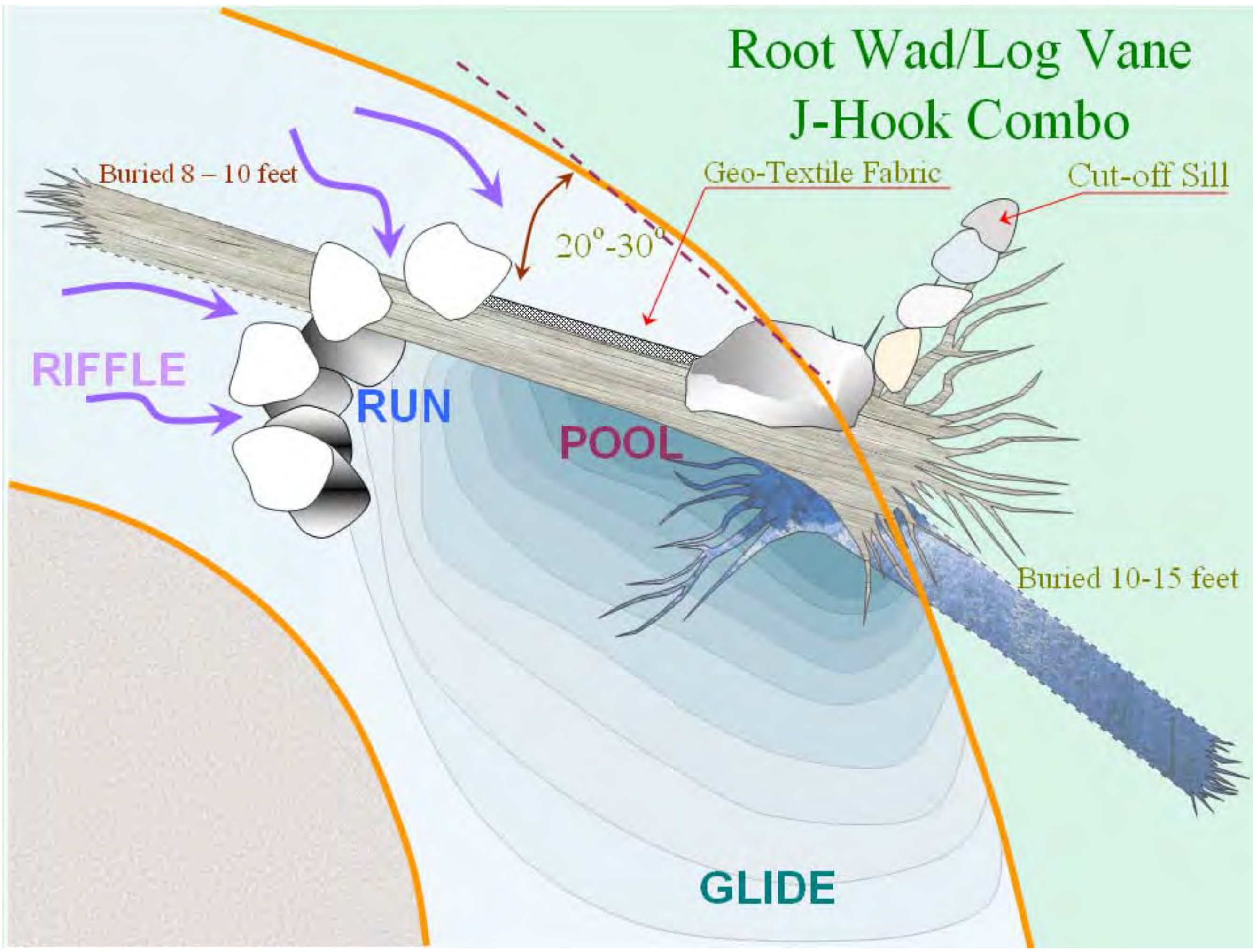


Figure 11–36 Rock vane/J-hook combo with rootwad and log vane footer

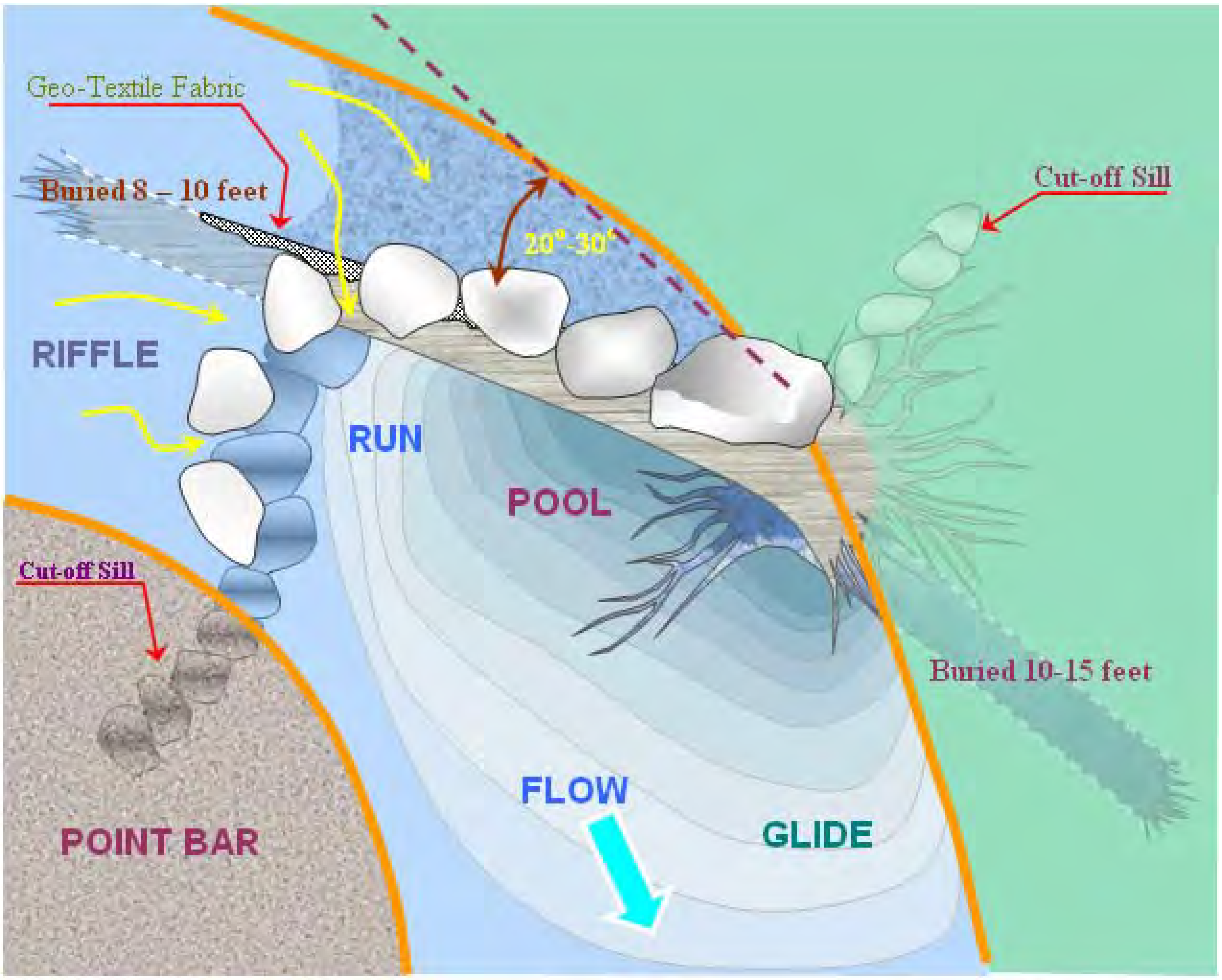
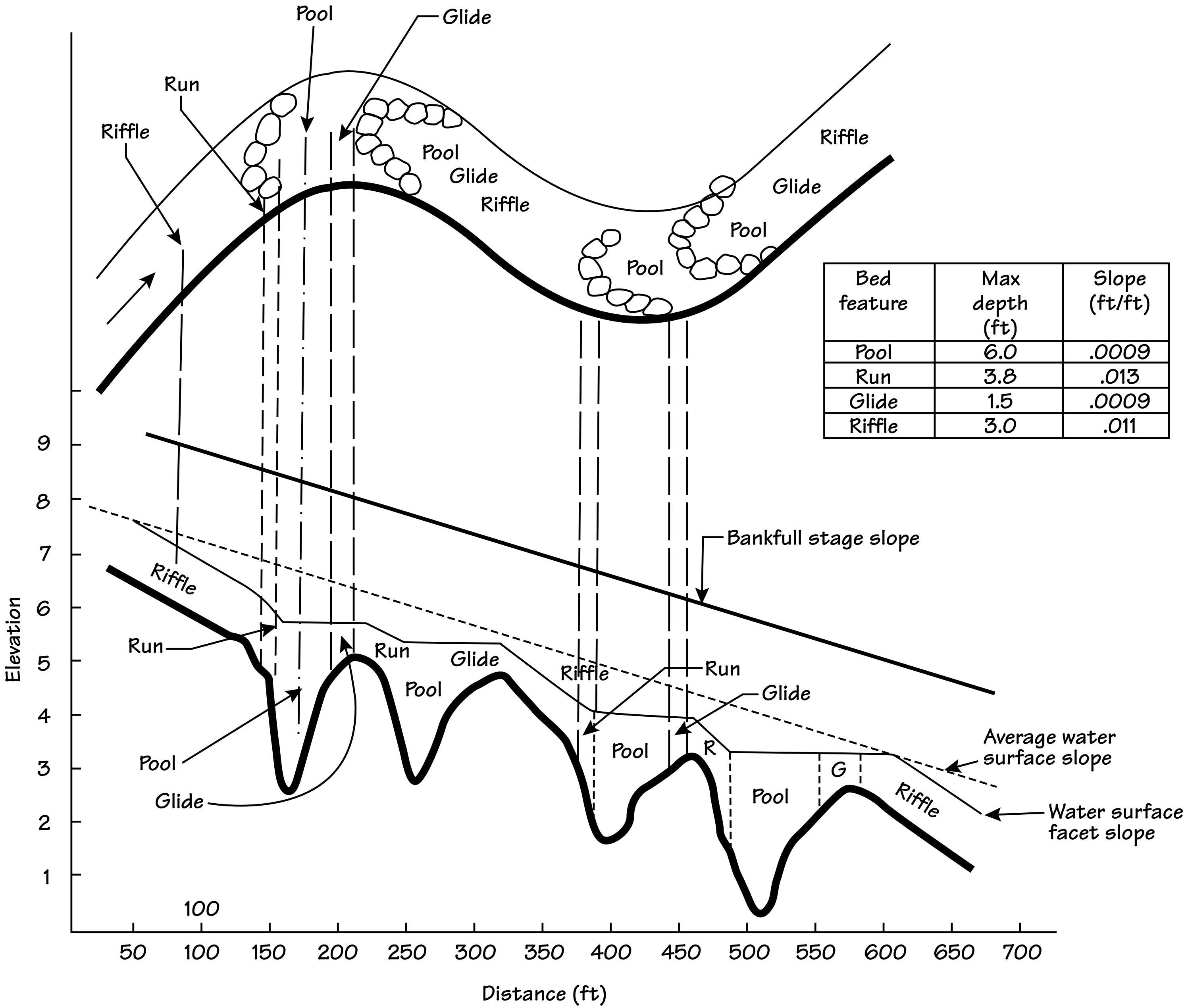


Figure 11–37 Native boulder J-hook with cut-off sill, East Fork Piedra River, CO

Figure 11–38 Rootwad/log vane/J-hook structure, East Fork Piedra River, CO

Figure 11–39 J-hook/log vane/log step with cut-off sill, East Fork Piedra River, CO

Figure 11–40 Longitudinal profile of proposed C4 stream type showing bed features in relation to structure location



Bed feature	Max depth (ft)	Slope (ft/ft)
Pool	6.0	.0009
Run	3.8	.013
Glide	1.5	.0009
Riffle	3.0	.011

Figure 11–41 Boulder cross vane and constructed bankfull bench

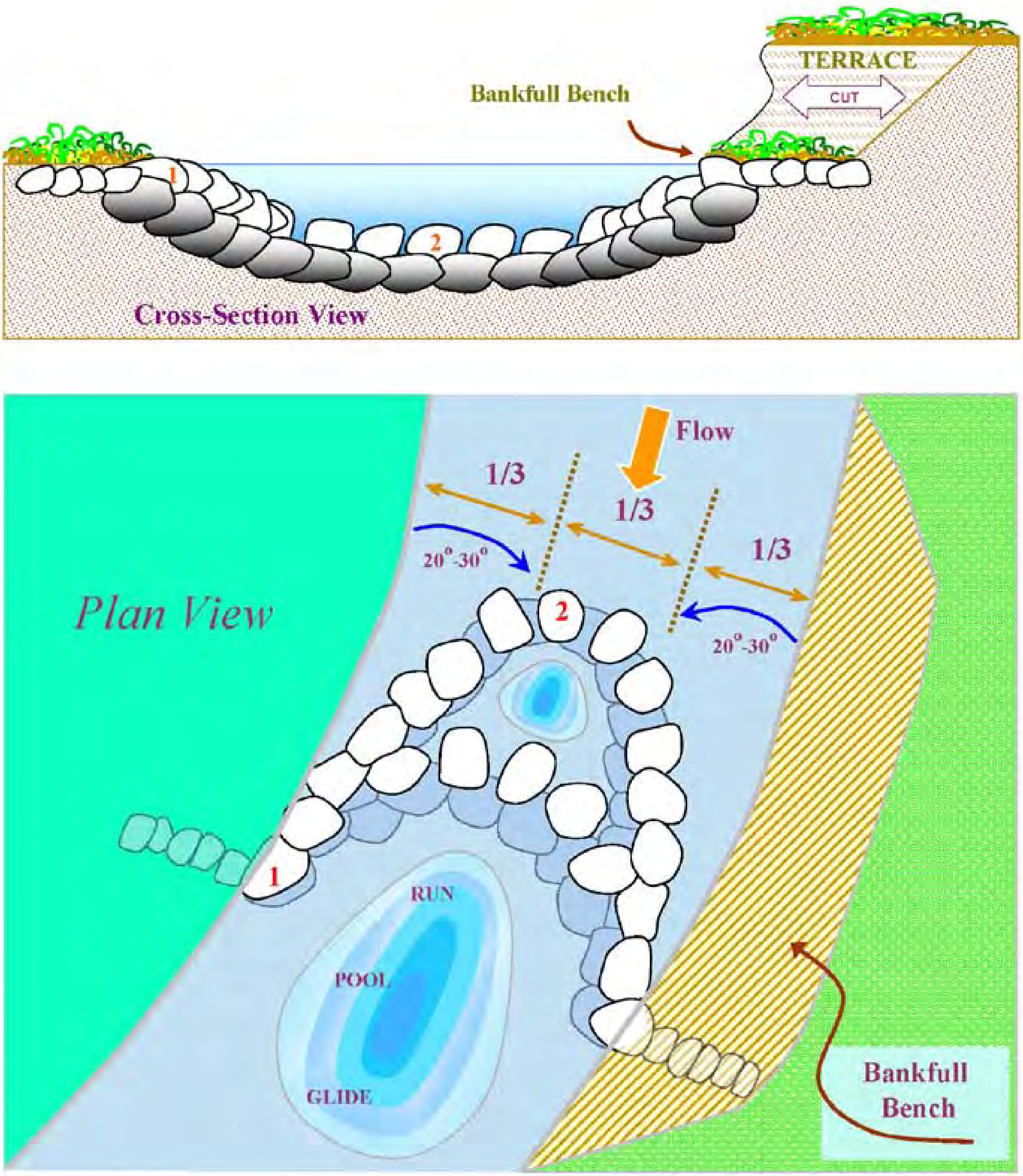
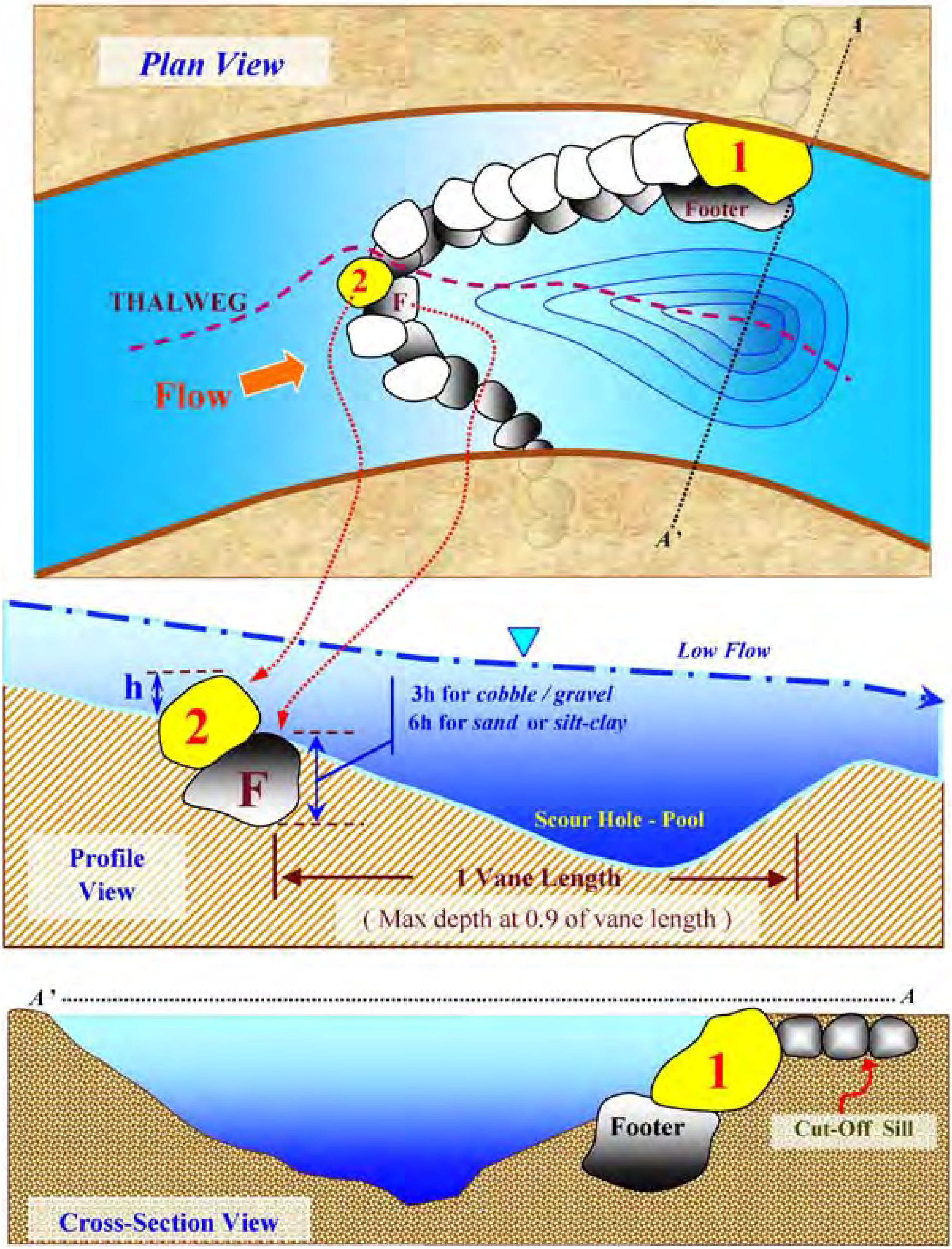


Figure 11–42 Locations/positions of rocks and footers in relation to channel shape and depths



strength to help maintain bank stability. The use of the J–hook (or fish hook) vane was developed to reduce near-bank stress to buy time for root development. The design is shown in figure 11–34 (Rosgen 2001e). Materials other than boulder are used in the J–hook vane. Logs and rootwads can be effectively used for multiple objectives (fig. 11–35 (Rosgen 2001e)). Variations in the use of materials are shown in figure 11–36 (Rosgen 2001e). An example of a J–hook vane is shown in figure 11–37, as constructed out of native boulders located in a reconstructed East Fork Piedra River. The structure also provides fish habitat, energy dissipation, bed-load transport, and provides protection of developments along streambanks. The use of a J–hook vane reduces the need for toe rock stabilization or a surfacing or hardening of the bank with riprap or other resistant structure. The length of bank protected is approximately two and a half to three times the length of the vane. The J–hook vane also is used to protect bridges and structures (Johnson, Hey, et al. 2001). Figures 11–38 and 11–39 provide examples of a J–hook vane using logs, rootwads, and log steps, as well as native boulders.

An example of the use of structure location forming compound pools consistent with meander curvature and bed features is shown in figure 11–40. The accompanying data indicate the slope and depth of the corresponding bed features. Regardless of structures, riparian vegetation establishment and management must be an active part of Rosgen geomorphic channel design.

Vane design specifications

The use of structures must be compatible with curvature and bed features of natural rivers. Figures 11–41 and 11–42 illustrate the use of rock for cross vanes, as well as for footers. Figure 11–43 provides guidance on rock sizing.

Vane slope—The slope of the vane extending from the bankfull stage bank should vary between 2 to 7 percent. Vane slope is defined by the ratio of bank height/vane length. For installation in meander bends, ratios of J-hook vane length/bankfull width is calculated as a function of the ratio of radius of curvature/bankfull width and departure angle (table 11–15). Equations for predicting ratios of J-hook vane spacing/bankfull width on meander bends based on ratio of radius of curvature/bankfull width and departure angle are shown in table 11–16. Vane length is the distance measured from the bankfull bank to the intercept with

Figure 11–43 Rock size

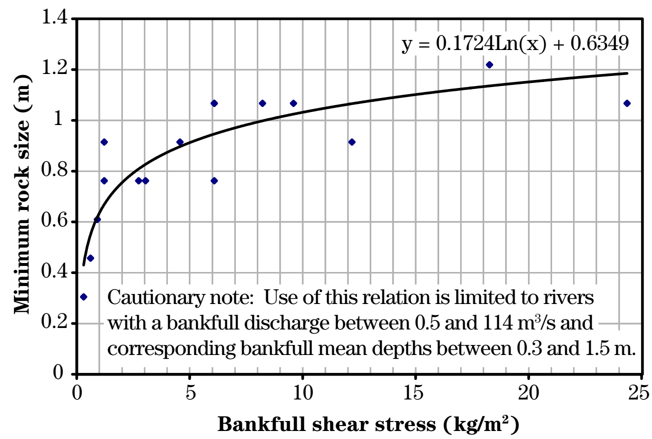


Table 11–15 Equations for predicting ratio of vane length/bankfull width (V_L) as a function of ratio of radius of curvature/width and departure angle, where W = bankfull width (SI units)

Rc/W	Departure angle (degrees)	Equation
3	20	V_L = 0.0057 W+0.9462
3	30	V_L = 0.0089 W+0.5933
5	20	V_L = 0.0057 W+1.0462
5	30	V_L = 0.0057 W+0.8462

Table 11–16 Equations for predicting ratio of vane spacing/width (V_s) as a function of ratio of radius of curvature/width and departure angle, where W = bankfull width (SI units)

Rc/W	Departure angle (degrees)	Equation
3	20	V_s = –0.006 W+2.4781
3	30	V_s = –0.0114 W+1.9077
5	20	V_s = –0.0057 W+2.5538
5	30	V_s = –0.0089 W+2.2067

the invert elevation of the streambed at a third of the bankfull channel width for either cross vanes or J-hook vanes. For very large rivers, where it is impractical to extend the vane length to a third of the bankfull width, vane slope is calculated based on the specified angle of departure and the ratio of bank height/vane length where the vane arm intercepts the proposed invert of the structure.

The spacing of J-hook vanes can be increased by 0.40W for a low BEHI of less than 30 (Rosgen 1996, 2001b).

Bank height—The structure should only extend to the bankfull stage elevation. If the bank is higher, a bankfull bench is constructed adjacent to the higher bank, and the structure is integrated into the bench. The use of a cross vane is shown in figure 11–41 where a bankfull bench is created adjacent to a terrace bank.

Footers—The minimum footer depth at the invert for cobble and gravel-bed streams is associated with a ratio of three times the protrusion height of the invert rock. This is applicable to all three structures and is shown in figure 11–41 for a J-hook vane. For sand-bed streams, the minimum depth is doubled due to the deeper scour depths that occur. All rocks for all three structures require footers. If spaces are left between the invert rocks for cross vane and W-weirs, the top of the footer rocks becomes the invert elevation for grade control. If no gaps are left, the top of the surface rock becomes the base level of the stream.

Rock size—The relationship of bankfull shear stress to minimum rock size used for all three structures is shown in figure 11–43. The application of this empirical relation is limited to size of rivers whose bankfull discharge varies from 0.56 cubic meters per second (20 ft^3/s) to 113.3 cubic meters per second (4,000 ft^3/s). For example, appropriate minimum rock sizes for values of bankfull shear stress less than 1.7 kilograms per square meter (0.35 lb/ft^2) are associated only with stream channel bankfull depths from 0.26 to 1.5 meters (2–5 ft). This relation would not be appropriate for applications outside the limits of the data for a river slope of 0.0003 and a mean depth of 6.1 meters, even though a similar shear stress results, as in the example presented.

(g) Phase VII—Design implementation

A key requirement at this phase is to correctly implement the proposed design. This involves the layout, construction supervision, and water quality controls during construction.

Layout

It is necessary to pre-stake the alignment of the channel and to provide for protection of existing vegetation outside of the construction alignment. The layout involves making necessary onsite adjustments to the design based on constraints that may have been previously overlooked. Terrain irregularities, vegetation, property boundaries, and channel changes since the field data were collected can all require local modifications to placement. Staging areas for materials must be located for both the collection and temporary storage of materials. Stockpile areas, vegetative donor sites, and boundary references/facilities requiring special identification must be flagged. Locations of structure placement and type must be flagged.

Construction supervision (oversight)

Without exception, it is critical to have daily onsite inspection and construction coordination. It is essential to check grades, dimensions, structure placement, slopes, angles, and footers as an on-going requirement. It is most effective to coordinate this work during construction, rather than wait and provide a postconstruction inspection and find problems after the work is completed. The daily field review and documentation at this phase is very helpful to properly implement the design.

Water quality controls

As part of the layout, sediment detention basins, diversions, silt fences, and pump sites must be located to prevent onsite and downstream sediment problems and as required by Federal, state, and local ordinances. Staging of construction should also be conducted in such a manner to minimize sedimentation problems. Monitoring of water quality during construction may be required; thus, preventative measures will reduce future potential problems.

(h) Phase VIII—Monitoring and maintenance

Monitoring

The key to a successful monitoring program is the focus on the question or the specific objectives of monitoring. Monitoring is generally recommended to:

- measure the response of a system from combined process interaction due to imposed change
- document or observe the response of a specific process and compare to predicted response for a prescribed treatment
- define short-term versus long-term changes
- document spatial variability of process and system response
- ease the anxiety of uncertainty of prediction
- provide confidence in specific management practice modifications or mitigation recommendations to offset adverse water resource impacts
- evaluate effectiveness of stabilization or restoration approaches
- reduce risk once predictions and/or practices are assessed
- build a data base to extrapolate for similar applications
- determine specific maintenance requirements

Watershed and river assessments leading to restoration involve complex process interactions, making accurate predictions somewhat precarious. Measured data reflecting specific processes will continually improve understanding and prediction of sedimentological, hydrological, morphological, and biological process relations. Another great benefit resulting from monitoring is the demonstration of the effectiveness of reduced sediment problems and improved river stability due to management/mitigation—the central purpose of watershed and sediment assessments and restoration.

The state of the science cannot be advanced, nor can the understanding of complex processes be improved without monitoring. This phase is divided into three major categories:

- implementation monitoring to ensure restoration designs were laid out and constructed correctly
- validation monitoring (matching predicted to observed response, including model calibration and model validation)
- effectiveness monitoring (response of a process or system to imposed change)

Field methods/procedures are also addressed.

Implementation monitoring—Often the best-laid design plans are not implemented correctly due to various reasons. Response of a process and/or system must first address the question or possible variable of potential problem in instituting the design and stabilization/enhancement structures correctly. Riparian vegetation response may be ineffective if heavy grazing of livestock occurred. Exclusion fence maintenance can also be a key in vegetative recovery. If restoration designs were correct, but the contractor installed structures at the wrong angle, slope, or position on the bank, then near-bank stress reduction or erosion rate would not be a correct design implementation related to the effectiveness of the mitigation structure.

As-built measurements of dimension, pattern, and profile are essential to compare to design plans. Documentation of exact locations and types of stabilization and/or enhancement structures is also required. Many failures observed in monitoring are due to poor structure placement locations, construction problems, as well as inability to implement correct design specifications.

Vegetation establishment problems are often traced to establishing the wrong plant associations (species), planting at the wrong time of year and at the wrong elevations on the bank (water table), using the wrong techniques in transplanting and/or cutting plantings, and lacking an irrigation plan, if needed. This monitoring leads the designer to be very thorough in the vegetative planning and implementation phase of restoration.

Validation monitoring—For every prediction methodology, there is a procedure to validate the model. Some methods are more difficult and time consuming to validate than others, while some results can be determined on a short-term, rather than a long-term basis.

The monitoring will improve predictive capability for the future and potentially reduce mitigation measures that would not be effective for continued implementation. Conversely, if management practices indicate that sediment and/or stability conditions create obvious impairment, revised practices or specific process-based mitigation such as restoration may be recommended. The restoration specialist will gain the most confidence in the procedure only by field measurements, which not only validate a prediction, but determine if the initial assessment objectives were met. The various categories of validation monitoring include calibration and validation.

- **Validation**—Model validation involves testing of a model with a data set representing local field data. This data set represents an independent source (different from the data used to develop the relation). Often these data are used to extend the range of conditions for which the model was developed. Due to the uncertainty of prediction, this step is very important prior to widespread application of model output. Models can be extremely helpful in comparative analysis, even if observed values depart from measured. It is important, however, to be aware of the variability in the prediction. Often this monitoring outcome develops tighter relations or subsets of the initial relation, improving the understanding of the processes being predicted. An example of this type of monitoring would be similar to the effectiveness monitoring of streambank erosion rates presented previously. However, beyond measuring bank erosion rate, the observer is additionally required to measure the same parameters used to predict streambank erosion. The streambank prediction involves calculating a bank erosion hazard index (BEHI) and near-bank stress (NBS) (Rosgen 1996, 2001b). The analysis involves plotting the observed values with the predicted values for the same prediction variables. In many cases (with sufficient numbers of observations), this monitoring can lead to improved local or regional models, adapted for unique soil types and vegetation. Validation modeling provides documentation not only on how well the mitigation performed but also on the performance of the model.

  Validation modeling is designed to answer specific questions at specific sites/reaches. Design must be matched with a strong understanding of the prediction model. Validation modeling for the dimensionless ratio sediment rating curves would involve sampling sediment over the full range of streamflows to compare predicted to observed values. The measurements would need to be stratified by the same stream type and stability rating used for the prediction.

- **Calibration**—Models are often used to predict potential impairment. Model calibration is the initial testing of a model and tuning it to a set of field data. Field data are necessary to guide the modeler in choosing the empirical coefficients used to predict the effect of management techniques. An example of this is the data set of measured suspended sediment and bed-load sediment by stream type and stability to establish dimensionless ratio sediment rating curves used for design. These data were not collected in all areas where the model would potentially be applied; thus, another type of monitoring (validation) is helpful to determine if the model is appropriate for extrapolation to a particular region.

Effectiveness monitoring—The specific restoration design and implementation needs to be monitored. Monitoring will determine the appropriateness or effectiveness of specific designs and is implemented to reduce potential adverse sediment and/or river stability effects. Since monitoring requires site-specific measurements, temporal, spatial, scale, streamflow variation, and site/reach, monitoring is required to properly represent such variability and extrapolate findings of a process and/or system response to imposed change. Such variability factors are summarized as:

- **Temporal**—To isolate the variability of season and/or annual change, designs of monitoring should include monitoring over time scales. For example, measuring annual lateral erosion rates should include measurements once per year at the same time of year. If the objectives are to identify seasons where disproportionate erosion occurs, measurements may be obtained during snowmelt runoff, later post stormflow runoff, ice-off, and other periods of time associated with a given erosional process. Annual replicate surveys of particle size gradation of bed material under a permanent glide cross section will provide valuable information of magnitude, direction, and consequence of annual shifts. Temporal measurements must also cover a range of time during bed-load sampling as surges occur or slugs of bed load often appear as discontinuities of time. Sampling over recommended time periods for a given flow (generally 20 minutes) helps the probability of observing this variability (as opposed to an instantaneous point sample). Short-term versus long-term monitoring must also be considered based on the probability of change, the severity and consequence of effects, and the likelihood of variation. Sampling over many years, although costly, may be warranted to cover changes in wet/dry periods.

- **Spatial**—Variability of change/response involving spatial considerations can be identified by measurements of the same process at more than one site (cross section) or even more intense on the same site. For example, a longitudinal profile measured over a couple of meander wavelengths will indicate changes in the maximum depth and/or slope of pools, rather than just monitoring one pool at one location. Identifying more than one reach of the same morphological type can also be used to understand response trends. Sampling the spatial variability (both vertically and laterally) within a cross section of velocity and sediment helps identify or at least integrate such variability into a documented observation.
- **Scale**—Monitoring streams of various sizes and/or stream orders, but of the same morphological type and condition, will help identify variability in system response for proper extrapolation of results. For example, vertical stability measurements should be made on river reaches of the same condition and the same type, but at locations that reflect various stream widths (size) and stream order.
- **Streamflow variation**—Measurements of channel process relations need to be stratified over a range of seasonal and annual flows. For example, both suspended and bed-load sediment should be measured over a wide range of flows during the freshet, low-elevation snowmelt, high-elevation snowmelt, rising versus recession stages, stormflow runoff, and baseflow. This stratification for streamflow allows the field observer to plot a sediment rating curve that represents the widest range of seasonal flows where changes in sediment supply can vary.
- **Site or reach variation**—Monitoring a site for soil loss should include a soil type designation for potential extrapolation for similar conditions on similar soil types. The same is true for stream types. Sediment, hydraulic, and stability monitoring need to be stratified by stream type since such data will naturally vary for the reference (stable) reach between stream types. This information is helpful to be able to readily detect departure from a reference stream type, rather than differences between stream types.
- **Design concepts for effectiveness monitoring**—The key information summary from the assessments used to identify impairment and resultant restoration designs are as follows:
  - Summarize the causes of land use impacts responsible for the impairment.
  - Understand the processes affected.
  - Identify specific locations and reaches associated with adverse impacts.
  - Determine the time trends of impacts (potential recovery periods).
  - Identify the specific nature of impairment (direction, magnitude, and trend of change).
  - Evaluate the consequence of change.
  - Determine the nature, location, extent and quality of mitigation (implementation).

The information supplied in the following list leads the observer to identify the locations, nature of processes affected, the extent of the impact, and quality of the mitigation implementation. For example, if the dominant process impacted by a land use is causing disproportionate sediment supply, land loss and river instability, and is determined to be accelerated streambank erosion, then the lateral stability monitoring would emulate the following design:

- Locate reaches of the same stream type that represent an unstable bank.
- Locate reaches of the same stream type that represent a stable bank.

- Install permanent cross sections on each set of reaches.
- Install bank pins (if conditions warrant) and/or toe pins (see monitoring methods).
- Inventory vegetation, bank material, and slope for each site (see monitoring methods).
- Resurvey both streambanks at least once per year to measure soil loss (lateral erosion) and total volume (in cubic feet and tons/year).
- Compare annual lateral erosion rates over time to the stable reach and document rate of recovery based on the nature of the mitigation.

Vertical stability and enlargement rates and direction can also be monitored using permanent cross sections in a similar stratification procedure (comparison to reference reach, above versus below, before versus after).

Physical and biological monitoring—The sediment and river stability changes associated with assessment and design are primarily related to physical changes. However, the consequences of such physical changes are directly related to potential impairment of the biological function. Changes in river stability, such as aggradation, degradation, enlargement, and stream type changes, are also related to habitat and food chains. Limiting factor analyses assesses habitat loss due to river instability and/or excess sediment such as relations of holding cover, instream/overhead cover, water temperature, dissolved oxygen, and benthics. A range of information associated with stream condition can be stratified by stream type by stream stability including diversity index, population dynamics, age class distribution, spawning, rearing habitat, and many more attributes related to stream health. Biological monitoring should follow similar rules of inventory stratification based on the diverse nature of streams and their natural variability.

If a biologist is studying only the biological parameters within a specific ecoregion, the natural stable differences between reference reach stream types cannot be identified if the stratification of the inventory does not include stream types. In other words, a stable C4 stream type will not have the attributes of a stable E4 or B4 stream type, even though they are all gravel-bed streams. If the biological inventory is not stratified by stream type or stream stability, departure of habitat conditions between a stable C4 and an unstable C4 cannot be easily identified. Reference conditions that reflect biological potential must be stratified as a minimum by stream type and stream stability for adequate departure analysis to identify degree, direction, and magnitude of impairment. Companion biological inventories of assessment and monitoring can be very compatible with the monitoring methods of the physical system described.

Once this information is analyzed, the monitoring design can proceed. The next step is to identify a strategy of monitoring. Effectiveness monitoring should always be conducted near the activity responsible for the initial impairment. Four primary design strategies often utilized are as follows:

- Measurements obtained before versus after the initiation of a management change in the land use activity, mitigation, restoration, and enhancement. This can be very effective as it establishes a precalibration period that identifies premitigation variability of the measured parameters. Following mitigation, departure can be readily determined, assuming measurements take into consideration the aforementioned variability factors.
- Measurements or observations taken above versus below impact areas related to specific land uses and specific mitigation. For example, if two different grazing strategies are implemented, measurements of effectiveness can be observed above versus below fence line contrasts. This can also be implemented where a mitigation may only influence the lower reach of a river compared to the upper reach (assuming the same stream type).
- Measurements obtained determining departure from a paired watershed are often helpful as similar climatic events similarly impact both watersheds. The pairing would contrast a watershed that had extensive mitigation or land management change with one that had not been changed. This also assumes variability of scale, temporal, and spatial variability and comparisons of similar landscapes and stream types have been identified.

- Measurements obtained of a disturbed reach or site, receiving mitigation compared to a reference condition. This type of monitoring can occur at locations far removed from the reference reach. The reference condition, however, must be of the same soil type, stream type, valley type, lithology, and vegetative type.

Maintenance plan

To ensure that the implemented design is successful, it is key to have a maintenance plan. The maintenance plan must ensure the following:

- Survival of the riparian vegetation reestablishment—This could involve an irrigation supply or replanting/interplanting.
- Structure stability—Post-runoff inspections must be conducted of structures for grade control, bank stabilization and/or fish habitat enhancement. Maintenance needs are assessed and implemented to prevent future failures and to secure proper function.
- The dimension, pattern, and profile must stay within the natural variability or range as depicted in table 11–5 for each variable. Maintenance of these variables is recommended only if the values exceed the design channel ranges.
- The biological maintenance may involve reestablishment of described populations of various age classes and/or species of fish and/or food sources.

654.1103 Conclusion

The individual(s) responsible for the project should also become experienced by being involved in all phases of this methodology. If the same individual conducts the assessment and also completes the design, implementation, and monitoring, the desired objectives of restoration are the most likely to be accomplished. The complexity of this method requires great attention to detail, training, and an understanding of processes. The monitoring of the project, including the implementation, validation and effectiveness procedures, is the best approach to become experienced and knowledgeable about the Rosgen geomorphic channel design methodology.

Mathematical definitions

Variables	
Riffle cross-sectional area at bankfull	A_{bkf}
Pool cross-sectional area at bankfull	A_{bkfp}
Mean riffle depth at bankfull	d_{bkf}
Mean pool depth at bankfull	d_{bkfp}
Maximum glide depth at bankfull	d_g
Maximum riffle depth at bankfull	d_{mbkf}
Maximum pool depth at bankfull	d_{mbkfp}
Maximum run depth at bankfull	d_{run}
Diameter of riffle particle at 50% finer than size	D_{50}
Diameter of bar sample particle at 50% finer than size	$\hat{D}_{50}$
Diameter of riffle particle at 84% finer than size	D_{84}
Maximum size of particle on bar	D_{max}
Gravitational acceleration	g
Weight density of water	γ
Sinuosity	k
Low bank height	LBH
Meander length	Lm
Meander-length ratio	(Lm/W_{bkf})
Manning's *n*	*n*
Pool-to-pool spacing (based on pattern)	(p-p)
Bankfull discharge	Q_{bkf}
Hydraulic radius	R
Radius of curvature of meander	Rc
Average water surface slope (bankfull slope)	S
Slope of glide (water surface facet slope)	S_g
Stream length	SL
Slope of pool (water surface facet slope)	S_p
Slope of riffle (water surface facet slope)	S_{rif}
Slope of run (water surface facet slope)	S_{run}
Bankfull shear stress	τ
Dimensionless bankfull shear stress	τ^*
Bankfull mean velocity	u_{bkf}
Shear velocity	u^*

Variables	
Valley length	V_L
Valley slope	V_S
Riffle width at bankfull	W_{bkf}
Width-to-depth ratio at bankfull	(W_{bkf}/d_{bkf})
Width-to-depth ratio at bankfull of reference reach	$(W_{bkf}/d_{bkf})_{ref}$
Pool width at bankfull	W_{bkfp}
Belt width	W_{blt}
Meander-width ratio	(W_{blt}/W_{bkf})
Width of flood-prone area	W_{fpa}
Entrenchment ratio	(W_{fpa}/W_{bkf})
Stream power	ω

Subscripts	
Bankfull	bkf
Meander belt	blt
Flood-prone area	fpa
Glide	g
Maximum at bankfull	mbkf
Maximum at bankfull in pool	mbkfp
Pool	p
Reference reach	ref
Riffle	rif
Run	run

Appendix F: Chapter 14 of National Engineering Handbook 654 (Natural Resources Conservation Service)

United States
Department of
Agriculture

**Natural
Resources
Conservation
Service**

**Part 654 Stream Restoration Design
National Engineering Handbook**

Chapter 14 Treatment Technique Design

Issued August 2007

Cover photos: *Top*—Treatment techniques for streambank stabilization and stream restoration require specific design tools. Management and removal of disturbance factors should be balanced with structural approaches.

Bottom—Treatments range from simple to complex. Design tools assist the user in properly installing a treatment.

Advisory Note

Techniques and approaches contained in this handbook are not all-inclusive, nor universally applicable. Designing stream restorations requires appropriate training and experience, especially to identify conditions where various approaches, tools, and techniques are most applicable, as well as their limitations for design. Note also that product names are included only to show type and availability and do not constitute endorsement for their specific use.

Chapter 14 Treatment Technique Design

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Chapter 14 Treatment Technique Design

654.1400 Purpose

Stream design and restoration often include specific treatments in the riparian area, on the bank, and in the bed of a stream. Treatments can include techniques that provide ecological enhancement, as well as protection of these areas. This chapter provides an overview of some of the frequently used treatment techniques for bank protection, grade protection, and habitat enhancement using a wide range of plant materials, earth materials, and other inert materials. In addition, analysis techniques that are needed for successful designs are provided. This chapter contains a brief overview of each analysis approach or treatment technique. Refer to the section in the listing of technical supplements for performance criteria, specific analysis, and design guidelines for each technique. Where information is available, the benefits, flexibility, risk, and cost of each technique are presented from a physical, as well as an ecological perspective.

The reader should not interpret the listed techniques as an endorsement of any particular product mentioned and should not infer that one treatment or approach is superior to another. The list of approaches is not exhaustive. There are other techniques, as well as variants of each of those described, that may be appropriate and applicable. Finally, while this chapter provides techniques that focus on the treatment of local problems, the use of several of these techniques, as well as other design elements, often can provide a more holistic approach to complex restoration projects.

654.1401 Introduction

A wide variety of analysis techniques can be applied to channel design and stream restoration. The selection and design of the different techniques depends upon the project goals, watershed conditions, and consequences of failure. All techniques contain some inherent flexibility and inherent risk. The tolerance for risk by the landowner and the public must be considered as the designer selects not only the technique to use but also the level of design analysis to apply. Finally, a selection of an appropriate treatment technique and level of analysis must consider cost. Cost effectiveness includes both the initial project costs, as well as operation, maintenance, and replacement costs. Much of the information presented in NEH654.02 and NEH654.04 should be reviewed and be included in these important decisions.

The design and restoration of a stream often requires the application of a combination of technologies. Techniques that are part of a traditional engineering approach can be altered or enhanced to provide habitat benefits. Many of the treatment techniques described herein are used in conjunction with other techniques to achieve project goals. For example, systems composed of living plant materials are often used in association with inert materials such as wood or rock, as well as manufactured products. In addition, the use of several design analysis techniques may be required for the successful application of a single treatment technique. Information on the reach and watershed that was assessed and calculated, as described in earlier chapters, may provide the required input for the designs and assessments.

Many of the treatment techniques described have been implemented by themselves to address small, local issues. This approach has sometimes been unjustly referred to as applying a band-aid solution. However, the band-aid approach may be completely justifiable in a scenario where there is only localized instability. It only becomes a band-aid when there is an attempt to address systemwide instability with a localized solution.

Some of the techniques described are sequential. For example, the installation of habitat features on an unstable stream must be done after the stream has been stabilized. Techniques such as the channel evolution model, addressed in NEH654.03 and NEH654.13, may be useful in making this assessment.

Some of the treatments described in this chapter should be implemented concurrently. For example, while it is often simpler to plant vegetation into a conventional bank protection project after construction, better results are achieved if the vegetation is incorporated directly into the treatment during construction. To adequately do so, provisions for vegetating should be addressed during the planning and design stages of the project.

654.1402 Design analysis

Design analysis, using sound physical principles and well-established engineering formulae, are used in the implementation of both soft and hard treatments. This section contains some of the techniques that have broad applicability to many treatment approaches described in this chapter.

The level of design analysis needed to employ these treatment techniques depends on both the treatment technique employed, as well as site conditions. The level of analysis should also match the cost of the project under consideration and level of risk associated with the project.

(a) Do Nothing option

The Do Nothing option is also sometimes referred to as the No Action alternative. This option is placed as the first entry under the design analysis section of this chapter to emphasize the importance of this consideration. It is covered briefly, but it is an important analysis. While it may seem self-evident that the planners and designers have discarded the Do Nothing approach if treatment options are being investigated, it is strongly suggested that this decision be continually revisited. This is also known as the Future, Without-action alternative, since the primary objective is to describe not only the problems as they exist today but also to predict a direction or magnitude of change in conditions. Natural stabilization may be occurring, but not quick enough to satisfy goals and objectives. Conversely, problems may be accelerating or affecting more area in the future, which brings the need for development of other restoration alternatives into focus.

Any treatment approach carries with it some level of both known and potential impact. These impacts can be both ecological and physical. Impacts that should be considered include:

- how the treatment interacts with the local environment
- how the treatment may alter, accelerate, or limit natural processes on a reach or watershed scale

- how the treatment may affect the social dynamics on a local or watershed scale
- alteration to the natural environment that is required for the construction of the treatment
- aesthetics—how the treatment interacts with the visual scene
- scale of impact on a temporal basis—is the cost of treatment justified based on sustainability of impact over time

These potential impacts should be weighed against the intended benefits of the treatment. These assessments often require a strong and well-coordinated interdisciplinary approach.

The Do Nothing option should constantly remain as a possibility. The resources, both physical and ecological, that may be lost by not implementing the project must be weighed against the impacts and costs of the project. By continually assessing this option, the designer can gain confidence that the selected design is appropriate and needed.

(b) Soil properties and special geotechnical problems related to stream stabilization projects

Many channel bank stability problems have a sizable geotechnical component. Although streambanks may be protected from erosive forces of flowing water, forces acting on soils in the bank can induce slope failures. Problems that are geotechnical in nature require a solution that is geotechnically based.

Analyzing bank slopes for geotechnical stability requires an understanding of a complex system of forces. The forces involved in bank instability problems include:

- gravity acting on the soils in the slope
- internal resistance of soils in the slope
- seepage forces in the soils in the slope
- tractive stresses imposed on the soils by flowing water

Knowledge of the site-specific soil characteristics and strength properties is required to understand, predict performance, and design stream restorations and stabilization. Soil characteristics and shear strength parameters are required for various stream stabilization techniques such as bank sloping, retaining wall design, sheet pile design, and pile foundation design.

NEH654 TS14A contains a descriptions of soil characteristics and special geotechnical problems, with a particular focus on bank protection. Guidance on recognizing these problems in the field is presented, along with a description of typical measures for solving them. A particular focus of NEH654 TS14A includes:

- stabilizing very steep slopes caused by erosion at the toe of the slope
- piping/sapping of streambanks, together with sloughing of saturated zones of sands and silts with low clay content
- shallow slope failures in blocky-structured, highly plastic clays
- severe erosion on dispersive clays

(c) Scour calculation

Scour is one of the major causes of failure for stream and river projects. It is important to adequately assess and predict scour in the course of any stream or river design. Designers of treatments such as barbs, revetments, or weirs that are placed on or adjacent to streambeds must estimate the probable maximum scour during the design life of the structure to ensure that the structure will either adjust to or account for this potential change. NEH654 TS14B provides guidance useful in performing scour depth computations.

Although the term scour includes both bed and bank erosion, the emphasis in NEH654 TS14B is on erosion that acts mainly downward or vertically such as bed erosion at the toe of a revetment or adjacent to a bank barb. Scour can be classified as one of three types, as shown in table 14–1.

A treatment may experience one or combinations of these scour types.

Many Federal and state agencies, as well as academic institutions, have developed methods and approaches for estimating these types of scour, and several of those techniques are briefly described in

NEH654 TS14B. Each of these techniques is developed for different types of conditions. The successful use of these techniques requires an understanding of both their inherent limitations, as well as their advantages.

(d) Stone sizing criteria

Many channel protection techniques involve rock or stone as a stand-alone treatment or as a component of an integrated system. Rock is often used where long-term durability is needed, velocities are high, periods of inundation are long, and there is a significant threat to life and property. NEH654 TS14C contains information useful in determining the required particle size to resist fluvial forces, regardless of the application of the stone.

The design of stone or riprap requires engineering analysis. Stone sizing should be approached with care because rock treatments can be expensive and can give a false sense of security if not applied appropriately. Since stone sizing methods are normally developed for a specific application, care should be exercised matching the selected method with the intended use. For example, a design technique developed for conventional riprap revetment may contain inherent assumptions that limit its applicability to a stone barb. The forces that are acting on the barb may be outside the range that were considered for the revetment and may lead to the barb being damaged during less than design flows.

Table 14–1 Scour types

Type of scour	Definition
General	Commonly affects the entire channel cross section, but general scour may affect one side or reach more than another
Bedform	Usually found in sand-bed streams, this is the troughs between crests of bedforms
Local	Commonly affects the streambed immediately adjacent to some obstruction to flow

Many Federal and state agencies have developed methods and approaches for sizing riprap, and several of those techniques are briefly described in NEH654 TS14C. NEH654 TS14C also describes some of the typical applications of both integrated systems and stand alone riprap treatments.

(e) Use of geosynthetics in stream restoration and stabilization projects

A variety of geosynthetic materials may be used for various function and applications in stream restoration and stabilization projects. A geosynthetic is defined as a planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering-related material as part of a manmade project structure or system (American Society for Testing and Materials International (ASTM D4439). Geosynthetics used in stream restoration and stabilization include geotextiles, geogrids, geonets, geocells, and rolled erosion control products. NEH654 TS14D addresses the design of these products.

(f) Use and design of soil anchors

Many treatments do not rely solely on their weight or positioning for their stability. Some external anchoring is needed to resist the fluvial forces of the stream or river. If the treatment relies on an anchor for stability, proper design and installation is essential for project success. NEH654 TS14E covers three of the more common anchoring methods that are in use.

- driven soil anchors
- screw-in soil anchors
- cabling to boulders

These approaches have been used on structures such as rootwads, large woody debris structures, and brush barbs. Depending on the site conditions and design of the treatment, these methods may provide either temporary or permanent anchoring.

The focus of NEH654 TS14E is primarily on driven soil anchors. It provides guidance for estimating the pullout capacity required of the anchor, given expected streamflows, soil characteristics, and the nature of the object that is to be anchored. Installation guidance is also provided.

(g) Pile foundations

Piles are also used to transfer foundation forces through relatively weak soil to stronger strata to minimize settlement and provide strength. The most likely applications for pile foundations in stream restoration and stabilization projects are as support for bank stabilization (retaining wall) structures and as anchors for large woody material. Piles may be used to support ancillary structures such as culverts, structural channels, bridges, and pumping station structures. NEH654 TS14F addresses the design and analysis required for pile foundation design. Installation issues are also addressed.

654.1403 Treatment techniques

Treatment techniques address a variety of stream stabilization and habitat enhancement techniques. While these treatments are addressed in separate sections, environmentally sensitive stream design will often require combining techniques. There are well-established techniques that are not listed here, including variants of some of the ones that are addressed. Depending on site conditions and project goals, these other treatments may be appropriate, as well.

(a) Grade stabilization

One of the most challenging problems facing river engineers today is the stabilization of degrading channels. Channel degradation leads to damage of both riparian infrastructure, as well as the environment. Bank protection is generally ineffective over the long term if the channel continues to degrade. When systemwide channel degradation exists, a comprehensive treatment plan is usually required. This usually involves the implementation of one or more grade control structures to arrest the degradation process. Another more involved approach would be to change the channel gradient through a reconstruction of the channel, incorporating suitable meander bend geometry.

While grade control can be applied to any alteration in the watershed that provides stability to the streambed, the most common method for establishing grade control is the construction of inchannel structures. A wide variety of structures have been employed to provide grade control in channel systems. These range from simple loose rock structures to reinforced concrete weirs and vary in scale from small streams to large rivers. NEH654 TS14G provides a description of some of the more common types of grade control structures and describes the various design factors that should be considered when selecting and siting grade control structures.

(b) Flow changing techniques

Flow changing devices are a broad category of treatments that can be used to divert flows away from eroding banks. These include devices known as deflectors, bendway weirs, vanes, spurs, kickers, and barbs. While there are variants in their design and behavior and names, they are basically structures that:

- project from a streambank
- are oriented upstream
- redirect streamflow away from an eroding bank
- alter secondary currents
- promote deposition at the toe of the bank

These treatments are typically constructed of large boulders and stone, but timber and brush have also been successfully used as part of stream design and restoration. NEH654 TS14H describes the attributes and design criteria for many flow-changing techniques. However, the primary focus of NEH654 TS14H is on the analysis, design, and installation of stream barbs. NEH654 TS14H draws on recent field evaluations that focus on areas where these structures have performed well, as well as areas where their performance has been less than satisfactory. A design description includes cautions and warnings related to specific design features. A step-by-step design procedure is also provided.

(c) Soil bioengineering

Stabilizing streambanks with natural vegetation has many advantages over hard armor linings. Compared to streams without vegetated banks, streams with well-stabilized vegetation on their banks have better water quality and fish and wildlife habitats. Vegetation is an extremely important component of biological and chemical health, as well as the stability of the system.

Streambank soil bioengineering is defined as the use of live and dead plant materials in combination with natural and synthetic support materials for slope stabilization, erosion reduction, and vegetative establishment (Allen and Leech 1997). Streambank soil bioengineering uses plants as primary structural components to stabilize and reduce erosion on streambanks, rather than just for aesthetics. As a result of increased public appreciation of the environment, many Federal, state, and local governments, as well as grass roots organizations, are actively engaged in implementing soil bioengineering treatments to stabilize streambanks.

NEH654 TS14I provides guidance for the analysis, design, and installation of many commonly used soil bioengineering techniques. Integrated approaches are addressed, as well as techniques that solely use plants to provide stabilization. Installation guidelines and materials requirements are described in detail. NEH654 TS14I addresses many of the regional concerns and issues that should be considered for the successful application of these techniques.

(d) Large woody material for habitat and bank protection

Large woody materials (LWM) structures are intended to provide habitat and stabilization, until woody riparian vegetation and stable bank slopes can be established. LWM normally decays within a few years, unless it is continuously submerged, but this decay depends on climatic conditions, wood type, and density. Therefore, structures made entirely or partially of woody materials are not suited for long-term stabilization, unless wood is preserved by continuous wetting or chemicals. Woody structures are best applied to channels that are at least moderately stable, have gravel or finer bed material, and that have a deficit of habitats created by wood. NEH654 TS14J addresses the analysis, design and installation of LWM structures.

(e) Streambank armor protection with riprap structures

Structural measures for streambank protection, particularly rock riprap, have been used extensively and with great success for many years. Many situations still require rock riprap to some degree. It is one of the most effective protection measures at the toe of an eroding or unstable slope. Rock is a fairly common commodity in most areas of the country and readily available to most sites. Rock riprap measures have a great attraction as a material of choice for emergency type programs, where quick response and immediate effectiveness are critical.

NEH654 TS14K describes some of the basic principles and techniques used to treat streambank erosion with the more traditional structural measures such as rock riprap and rock-filled gabions. These design basics are applicable to any structure that involves the use of stone. This section also describes the challenges inherent in integrating more vegetatively oriented solutions into these techniques without materially increasing the exposure time and risks involved with failures. This combined approach is desirable to produce a better long-term solution that will be complementary to the natural environment and more self-sustaining. NEH654 TS14K also addresses where stone can be used to provide habitat enhancement, either as part of a traditional bank stabilization structure or as instream habitat boulders.

(f) Articulating concrete block revetment systems for stream restoration and stabilization projects

A variety of natural and constructed materials are available to provide erosion protection in stream restoration and stabilization projects. One of these products is an articulating concrete block (ACB) revetment system. An ACB revetment system is a matrix of interconnected concrete block units installed to provide an erosion resistant revetment with specific hydraulic characteristics. The individual units are connected by geometric interlock, cables, ropes, geotextiles, geogrids, or a combination thereof and typically overlay a geotextile for subsoil retention. An ACB revetment system may be used to provide permanent erosion protection where vegetation and other soil bioengineering practices are not stable for the design event. Typical applications may include entire channel cross-sectional protection, toe and lower side slope protection, stream crossings, grade stabilization structures, and other high energy environments.

NEH654 TS14L describes the ACBs currently available and some of the benefits of their use. A summary of hydraulic performance testing is presented along with design procedure for open channel flow. Critical features are described for typical installations, including subgrade preparation, ancillary components (such as drainage layers), filter placement, ACB placement, system termination, and anchors and penetrations.

(g) Vegetated rock walls

A vegetated rock wall is a mixed-construction biotechnical slope protection. They are primarily used in urban and suburban applications where limited area is available and where there is a need for static bank stabilization. They may be considered to be an alternative to a conventional concrete channel. While vegetated rock walls are expensive, they provide more habitat benefits and are generally considered to be more aesthetically pleasing.

NEH654 TS14M describes the analysis, design, and installation requirements for these structures. Both structural, mechanical and vegetative elements work together to prevent surface erosion and shallow mass movement by stabilizing and protecting the toe of steep slopes. These walls differ from conventional retaining structures because they are placed against relatively undisturbed earth and are not designed to resist large earth pressures.

(h) Fish passage and screening design

Fish passage and screen design is often an important component in stream restoration and water resource management. A wide variety of design issues depend on the project region and species of interest. NEH654 TS14N provides an overview of fish passage and screen design including biological considerations. This section includes a generalized assessment and design approach. Additional references for more information regarding design of fish passage and screen structures are provided.

(i) Stream habitat enhancement using LUNKERS

Little Underwater Neighborhood Keepers Encompassing Rheotactic Salmonids (LUNKERS) are structures that are designed to provide both stability and edge cover for aquatic habitat. While their use has primarily focused on providing trout habitat, they are applicable to other species, as well. LUNKERS have also been used in many projects to enhance the integrity of stream channel geomorphology and bank stability. Where flood volumes and velocities are to be mitigated, LUNKERS can contribute to bank stability and establishment of a secure riparian corridor.

NEH654 TS14O provides step-by-step guidance for the analysis, design, and installation of these structures. A particular focus is on the placement, anchoring, and finished grading for LUNKER structures to result in stream channels that function efficiently without lateral scour.

(j) Gully stabilization

Gullies develop in response to concentrated flow. Basically, the forces created by flowing water exceed the resisting soil forces. Unchecked, the gullies erode and deliver sediment through a variety of processes that cause loss in soil productivity, channel entrenchment and headward advance, and expansion into the landscape. The processes increase the channel network, bank slope, bank height, and streambank instability resulting from the headward migration of nickpoints. NEH654 TS14P describes the major elements involved with gully formation processes and problem assessment. Alternate approaches to treatment may be considered, depending on gully specifics and landowner desire for effectiveness, cost, and reliability. The information and examples provided in NEH654 TS14P should help in the determination of the approach that may be most suitable for the circumstances.

(k) Abutment design for small bridges

Bridges are installed in a variety of NRCS applications including farm and rural access roads, livestock crossings, emergency watershed protection work, and recreation facilities. They may also be used to replace existing culverts that act as barriers to fish passage. NEH654 TS14Q presents a procedure for determining the ultimate and allowable bearing capacity for shallow strip footings adjacent to slopes. The procedure is appropriate for the design of abutments for the relatively small bridges typically involved in NRCS work.

(l) Design and use of sheet pile walls in stream restoration and stabilization

Sheet pile may be used in a variety of applications for stream restoration and stabilization. It is typically used to provide stability to a stream, stream slopes, or other manmade structures in high-risk situations. Typical applications of sheet pile include toe walls, flanking and undermining protection, grade stabilization, slope stabilization, and earth retaining walls. While sheet pile can be combined with soil bioengineering techniques, it does have some ecologic and geomorphic disadvantages.

NEH654 TS14R describes typical applications for cantilever sheet pile walls in stream restoration and stabilization projects. It also describes the types of sheet pile material, loads applied to the sheet pile, failure modes, design for cantilever wall stability, structural design of the piles, and some construction considerations.

(m) Sizing stream setbacks to help maintain stream stability

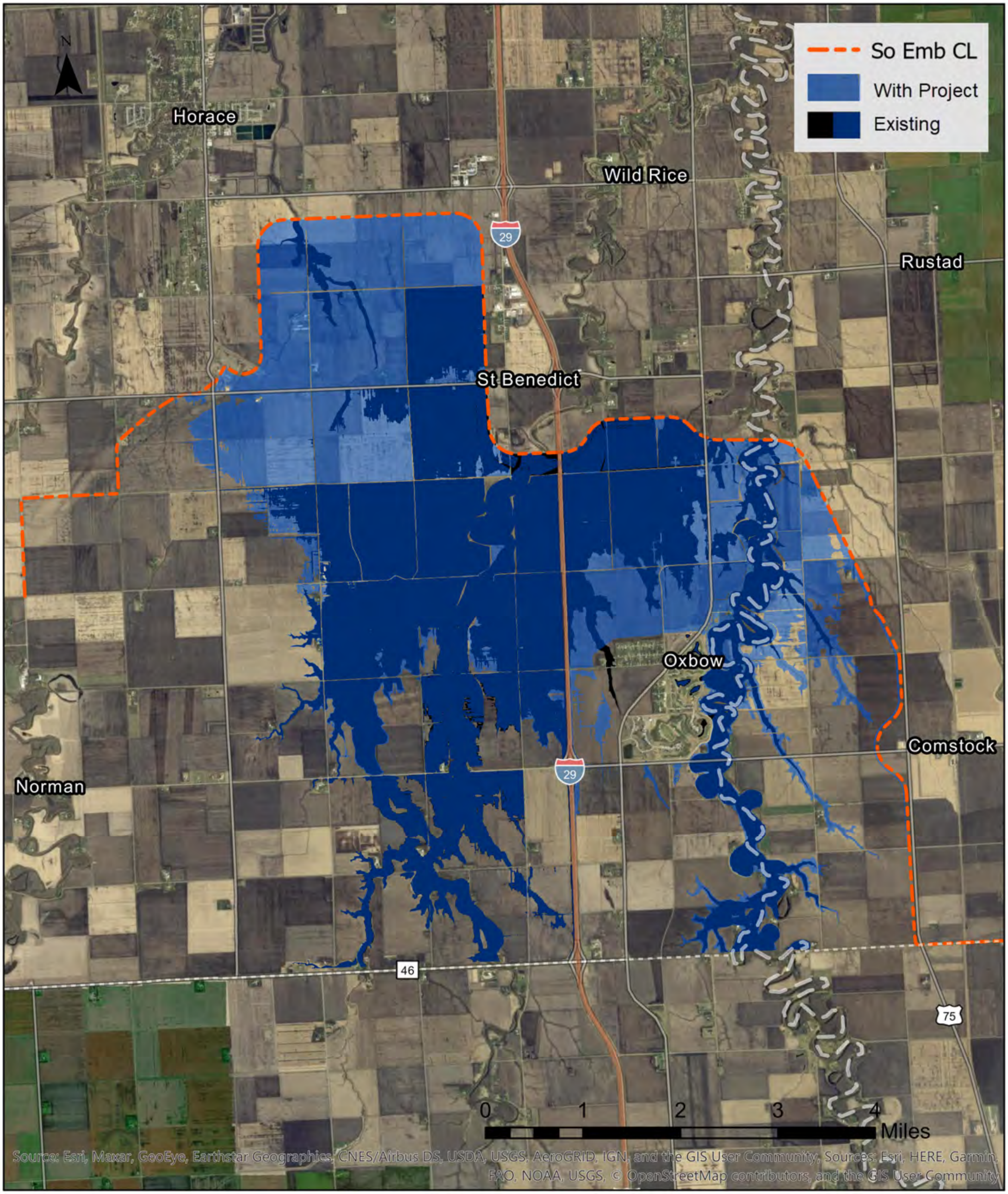
Many local communities, watershed groups, counties, and states are developing setback ordinances to help protect stream systems. NEH654 TS14S briefly outlines several guidelines and presents an empirically based equation that predicts the streamway width required to allow a stream to self-adjust its meander pattern. NEH654 TS14S does not cover stream setbacks that are required due to local or state laws or cost-sharing program rules.

654.1404 Conclusion

Treatment technique design contains an overview of some of the frequently used treatment techniques for bank protection, grade protection, and habitat enhancement, as well as analysis techniques for their design. Specifics related to each of the presented treatment and analysis approaches are included in the technical supplements of this handbook.

Many of these treatment techniques have been used and are applicable for small, local issues. While they have been considered to be band-aid solutions, in many cases, a band-aid is all that is needed or justified. In addition, many of the techniques described in this chapter have been used as components of larger, more extensive restoration and design projects.

The reader should not interpret descriptions herein as an endorsement of any product that is mentioned, nor should one treatment or approach be inferred as superior to another. The choice of a particular treatment or combination of treatments should be based on the stakeholders' goals and objectives, watershed conditions, and site condition.



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4% AEP Existing vs. With Project Conditions
Staging Area Inundation Extents

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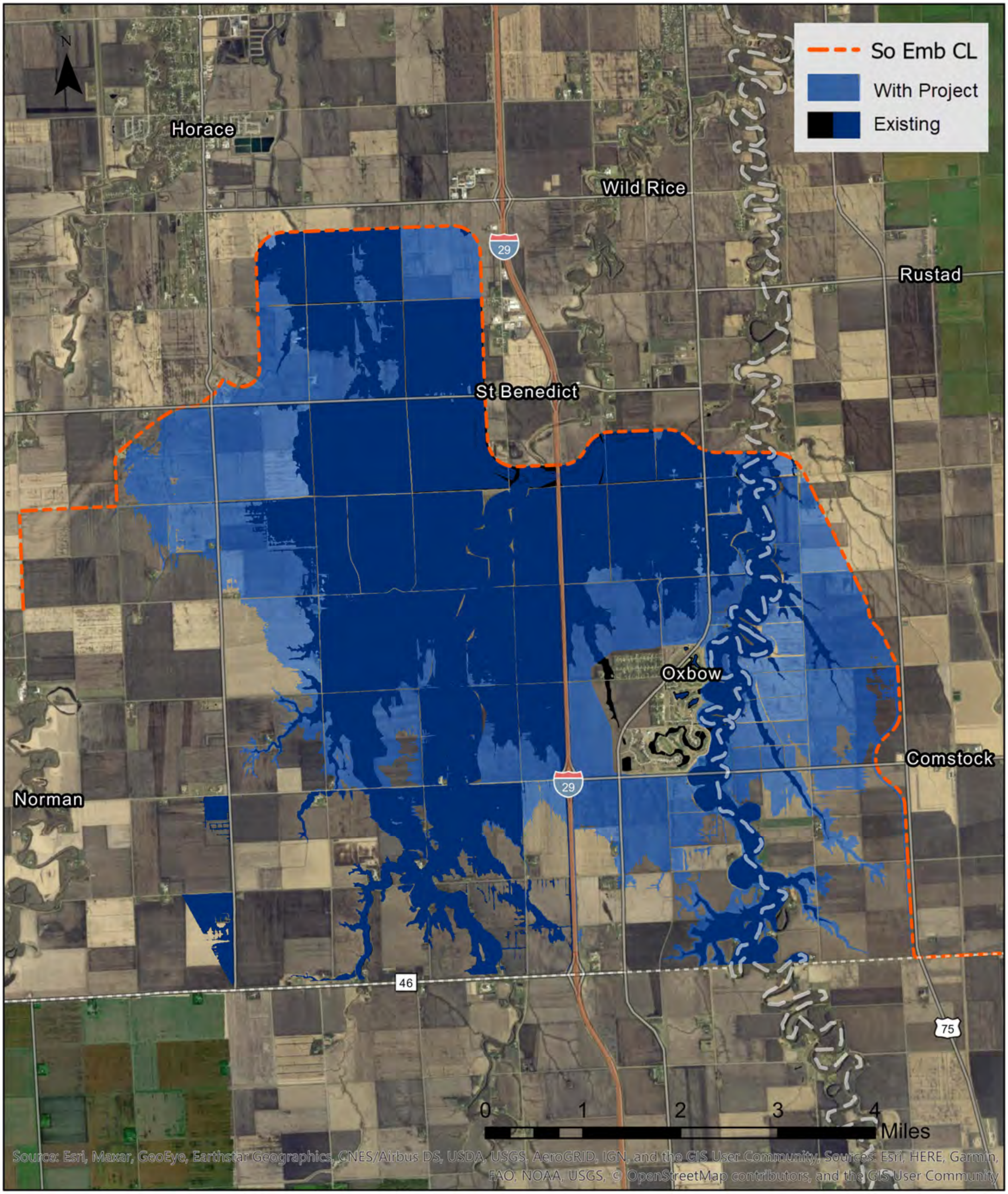

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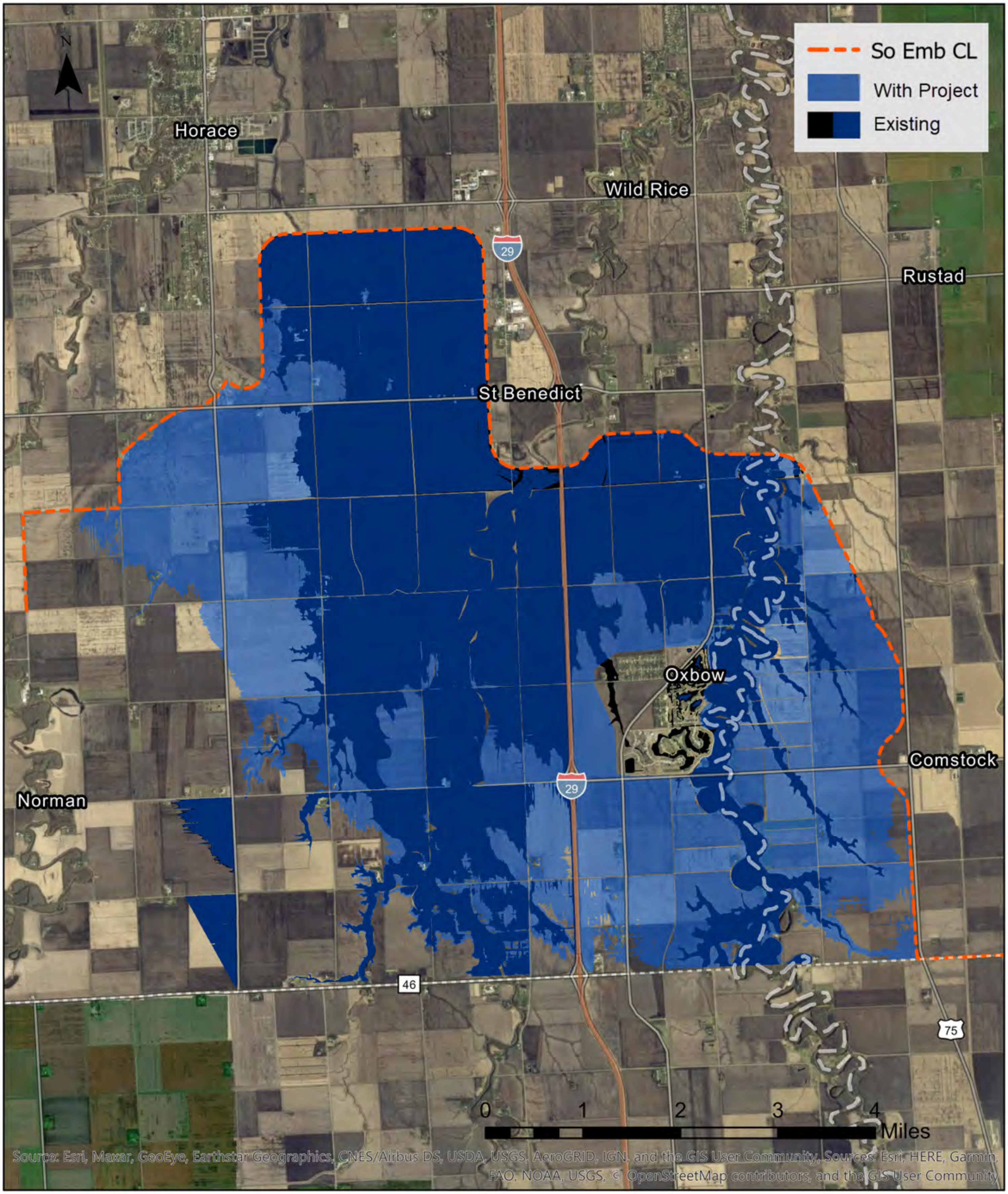

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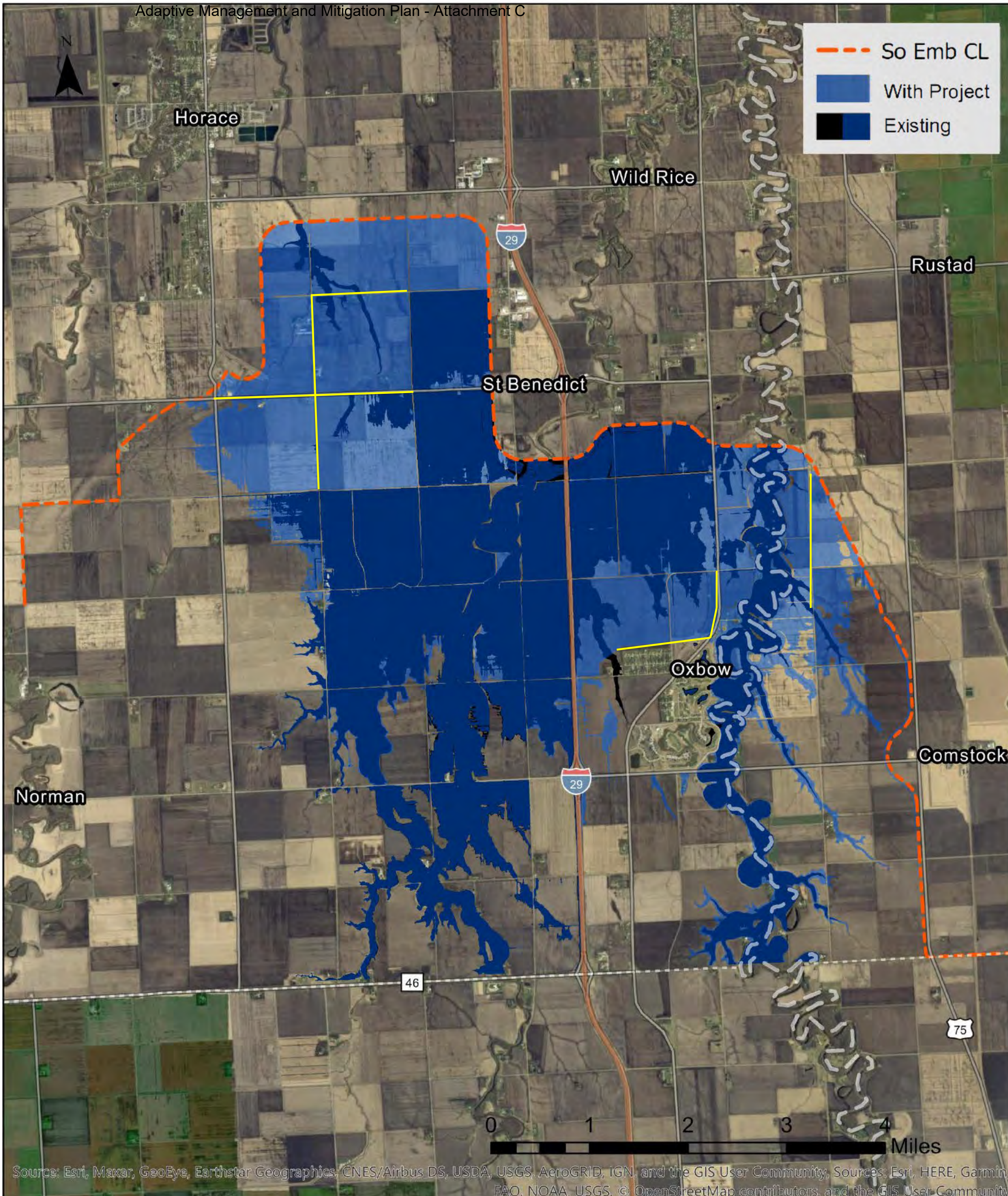

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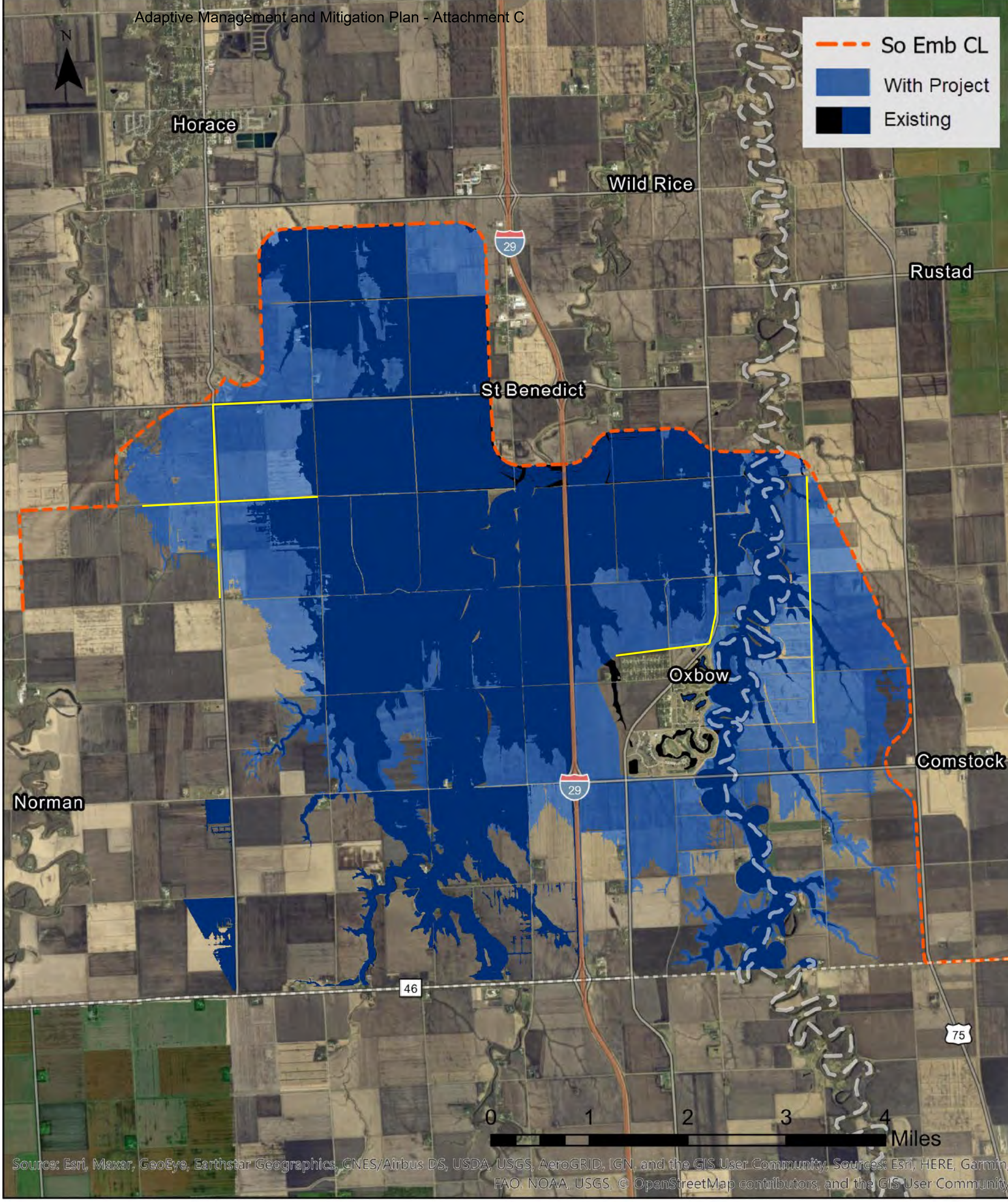

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Staging Area Inundation Extents

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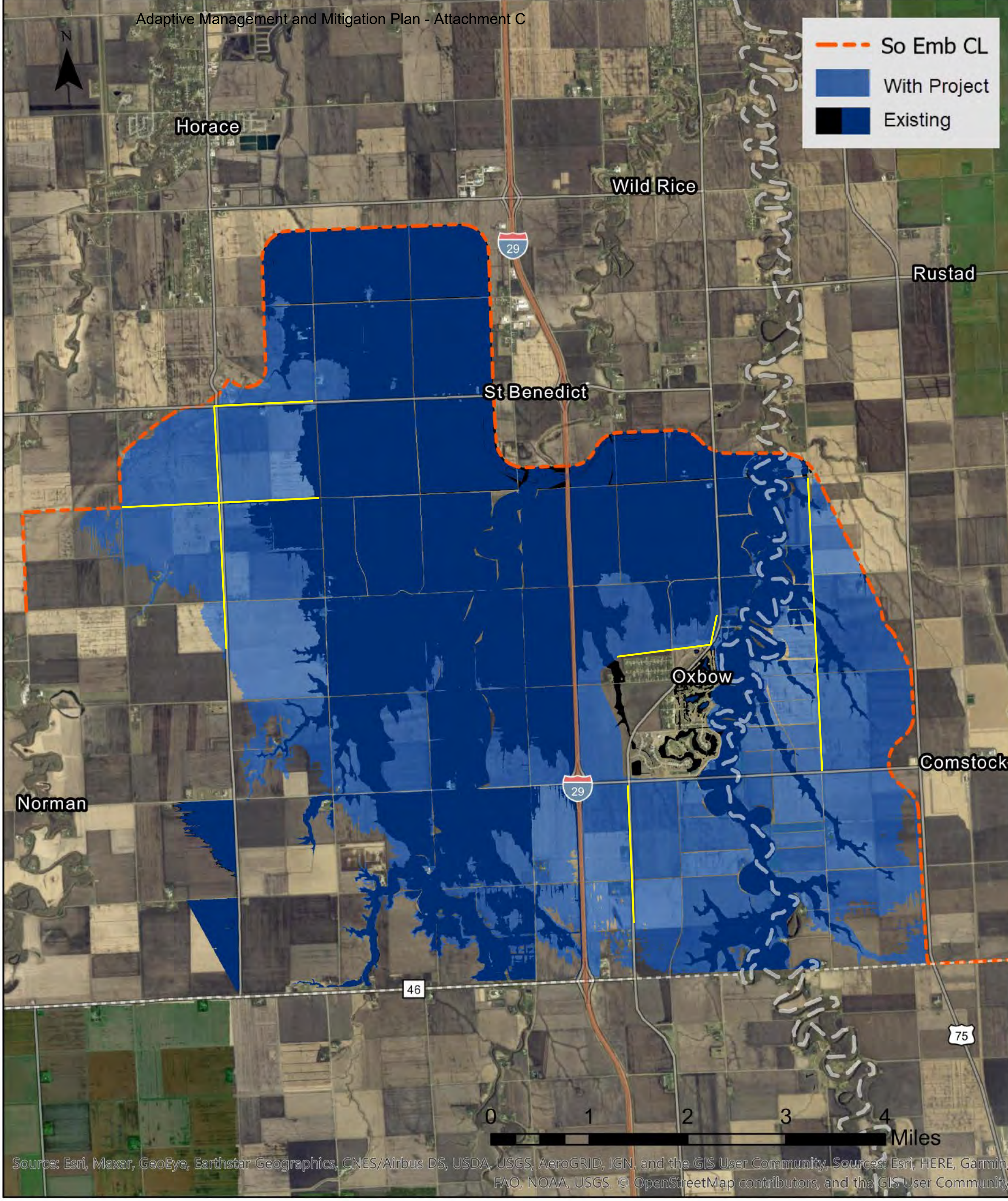

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