HAY CREEK SUBWATERSHED TARGETED IMPLEMENTATION PROFILE

EXECUTIVE SUMMARY

The purpose of this report is to target conservation practices that would improve geomorphic and hydrologic conditions within the Hay Creek Subwatershed. There have been many studies completed in the watershed that indicate Hay Creek's channel is unstable and could benefit from focused implementation efforts. This report describes a study that focused on targeting conservation practices—with stakeholder input—that would help to reduce sediment, water, and total phosphorus (TP) delivered to Hay Creek. It also describes targeted strategies for managing the stability of the creek itself.

This project also sought to target potential conservation practices that would make progress towards measurable goals from previous studies, like the Roseau River Watershed Restoration and Protection Strategy (WRAPS; https://www.pca.state.mn.us/water/watersheds/roseau-river), that have been identified within the Hay Creek subwatershed. The potential conservation and best management practices (BMPs) in this report align with preferred BMPs as determined by surveys conducted within the subwatershed.

The completion of this project included several significant milestones. They are:

- An analysis with the Prioritize, Target, and Measure Application (PTMApp) data to support efforts to target conservation practices that would improve geomorphic conditions and make progress towards local water management goals (**Table ES-1**)
- Assessing the geomorphic stability of streams within the Hay Creek Subwatershed by applying a rapid geospatial assessment technique for assessing stream bank stability and guiding in-channel management recommendations
- Applying recently developed methods of attaching hydrologic calculations to PTMApp data to determine effects on the hydrologic character

The remainder of this report describes how the various milestones of this project were tied together to develop a targeted implementation profile. The Roseau River Watershed District will use the data developed in this project to provide technical support to farmers and landowners and educational outreach activities in the subwatershed. This targeted implementation profile can be used to support ongoing efforts or guide conservation implementation in the study watershed.

Specifically, **Table ES-1** ties together the multiple assessments performed for this report. It provides an investment range (i.e., bang-for-your-buck) for reducing sediment or TP delivery to Hay Creek. For example, whether implementing an in-channel stream restoration, upstream water retention, or in-field farm management practice, **Table ES-1** provides a reference for a good rate of return in terms of mass of sediment or TP reduced to Hay Creek.

Implementing the BMPs presented in this report is voluntary and requires willing landowners. The specific locations where practices are implemented will likely differ from the locations identified within this document. Nothing in this report should be construed as forcing landowner cooperation. This report is intended to guide implementation efforts and should not be considered prescriptive.

Table ES-1: Hay Creek Subwatershed targeted practice implementation summary. Cost-effectiveness is based on reductions at the watershed outlet. The cost estimates show the total cost to reach a 10% reduction goal for sediment or TP if you were to implement conservation practices that provided a rate of return at the respective cost-effectiveness rate.

Constituent	Load Reduction Goal	Lower Quartile of Cost-Effectiveness	Median of Cost-Effectiveness	Upper Quartile of Cost-Effectiveness	Lower Quartile of Total Costs	Median of Total Costs	Upper Quartile of Total Costs
Total Phosphorus	1,131 lbs/year	$524 lbs/year	$571 lbs/year	$613 lbs/year	$592,644	$645,801	$693,303
Sediment	519 tons/year	$596 tons/year	$862 tons/year	$1,323 tons/year	$309,324	$447,378	$686,637

1 INTRODUCTION

This report describes three related assessments that were conducted to targeted potential conservation practices within the Hay Creek Subwatershed. A PTMApp analysis was conducted to prioritize, target, and measure the anticipated load reduction associated with ongoing in-field conservation efforts. PTMApp practices targeted based on stakeholder input and load reductions were assessed for their impacts on the hydrology within the subwatershed. The bank erosion assessment was conducted to guide field investigations for riparian management actions that may fit within the context of a wise investment range. The results of these analyses should support more focused efforts to target conservation within the subwatershed, conduct education and outreach efforts to farms about targeted conservation, and guide investments in conservation practices for the purpose of reducing sediment and TP.

PROJECT AREA

The Hay Creek Subwatershed covers approximately 106 square miles in Roseau County (**Figure 1**). It is situated in the East Central portion of the larger Roseau River Watershed. The watershed drains, in its entirety, to the Roseau River, which eventually flows into the Red River of the North after crossing the Canadian Border. The land cover in the subwatershed is dominated by cultivated crops (40% of area). The headwaters in the south-eastern portion of the subwatershed are largely covered by wetlands (33% of total area).

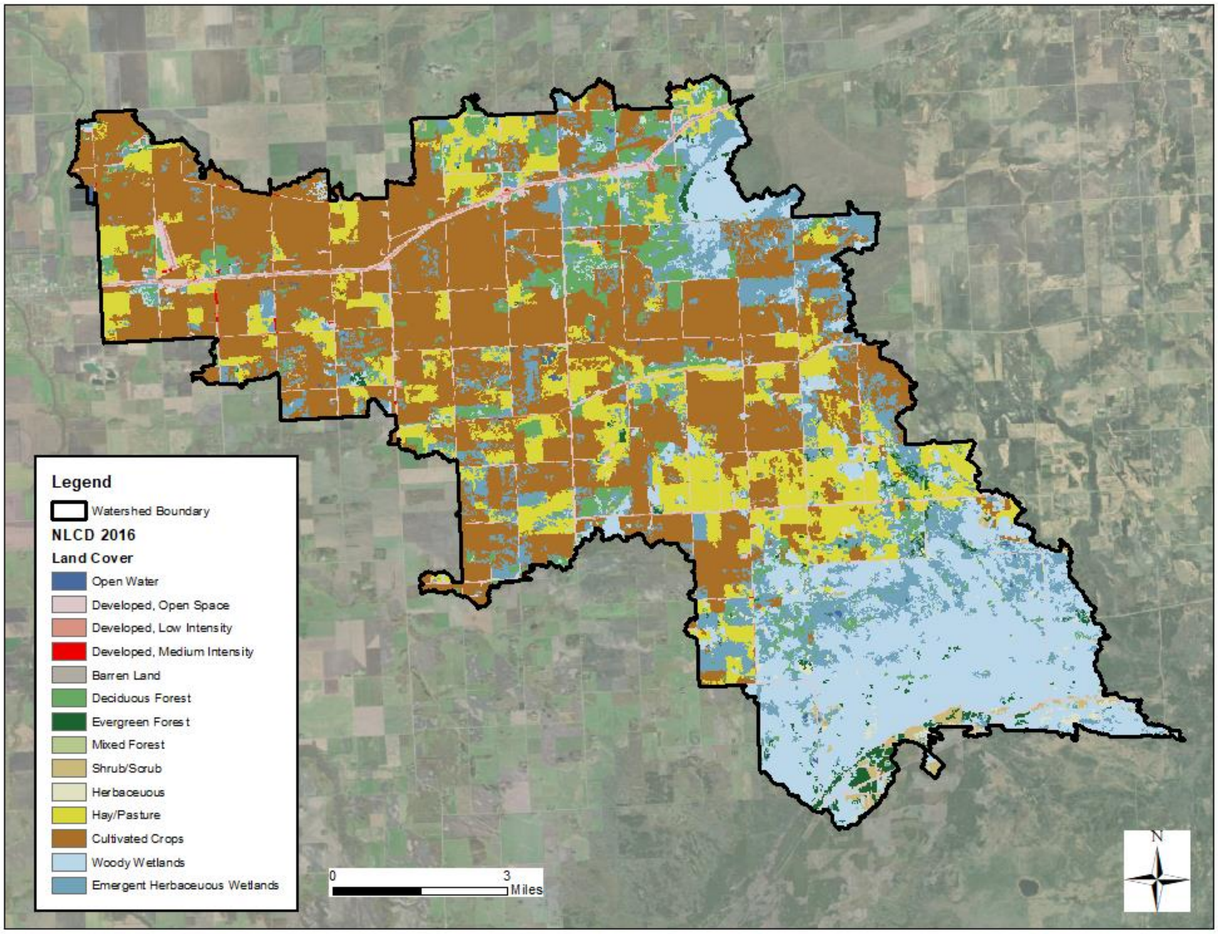


Figure 1: Land use within the Hay Creek Subwatershed

2 STAKEHOLDER SURVEY

To better understand the issues within the subwatershed and what types of BMPs the farmers and landowners within the Hay Creek Subwatershed are interested in, the Roseau River Watershed District and partners administered a survey and conducted a discussion at a stakeholder meeting. The meeting was held in Roseau on February 13, 2020. During the meeting, tabletop maps of the Hay Creek Subwatershed were provided for discussion on management opportunities. The survey contained four key topics (issues, goals, actions, interest) with selectable options within each category. A total of 16 participants responded to the survey (see **Appendix A** for more details).

Tabletop Maps of critical sediment loss within the Hay Creek Subwatershed were supplied for discussion during the meeting (see maps in **Appendix A**). The discussion was used to obtain feedback on where management opportunities are in the subwatershed. A variety of comments and concerns were noted on the maps. Key concerns revolved around hydrologic issues, including runoff, drainage, and flooding. Channel erosion was also brought up as an important concern. These comments were often area-specific but, in many cases, applied to the entire subwatershed.

From the survey responses, information on key issues, goals, and actions was collected. Bank erosion, water quantity impacts on land productivity and water quality, and flooding were the highest-ranked issues. Most respondents indicated that flooding was an issue in the subwatershed. Managing flow into the drainage system, maintaining drainage benefits, and keeping agricultural lands productive were the top-ranked goals. Grade control, drainage water management, conservation tillage, residue management, and cover crops received the highest rankings in the actions category. Respondents stated that there is a strong desire for cost-share to implement some of the conservation practices (e.g., grade control and side water inlets).

3 PTMAPP ANALYSIS

PROCESSING DATA IN PTMAPP-DESKTOP

The science and theory used to process data in PTMApp-Desktop are well documented through a series of Technical Memoranda. These documents describe the technical aspects of the processing performed to generate the output products. They are available at https://ptmapp.bwsr.state.mn.us/User/Documentation

PTMApp-Desktop generates estimates of annual loads (sediment, TP, and Total Nitrogen [TN]) leaving the landscape based on empirical methods and yield coefficients. The loads are routed to downstream locations through concentrated flowpaths and priority resource points using a sediment delivery ratio and first order decay equations for TP and TN as a function of travel time. **Figure 2** shows priority resource point locations within the Hay Creek Subwatershed.

A previous report (*Targeted Implementation Plan for the Roseau Watershed*) was completed and delivered to the Roseau River Watershed District on February 8, 2019. This report details the efforts and technical investment that was involved in generating and processing PTMApp-Desktop data for the Roseau River Watershed.

Between the completion of the initial PTMApp-Desktop analysis for the entire Roseau River Watershed and the start of PTMApp-Desktop processing for this report, several improvements and updates were incorporated into PTMApp. Modifications include minor changes to algorithms and equations for estimating sediment delivery as well as overland and in-stream travel time. An additional data product produced during the PTMApp-Desktop analysis was also incorporated into this PTMApp-Desktop analysis. This allows for a set individual BMP types (as opposed to general BMP treatment groups) to be analyzed and highlighted as part of the overall PTMApp-Desktop process.

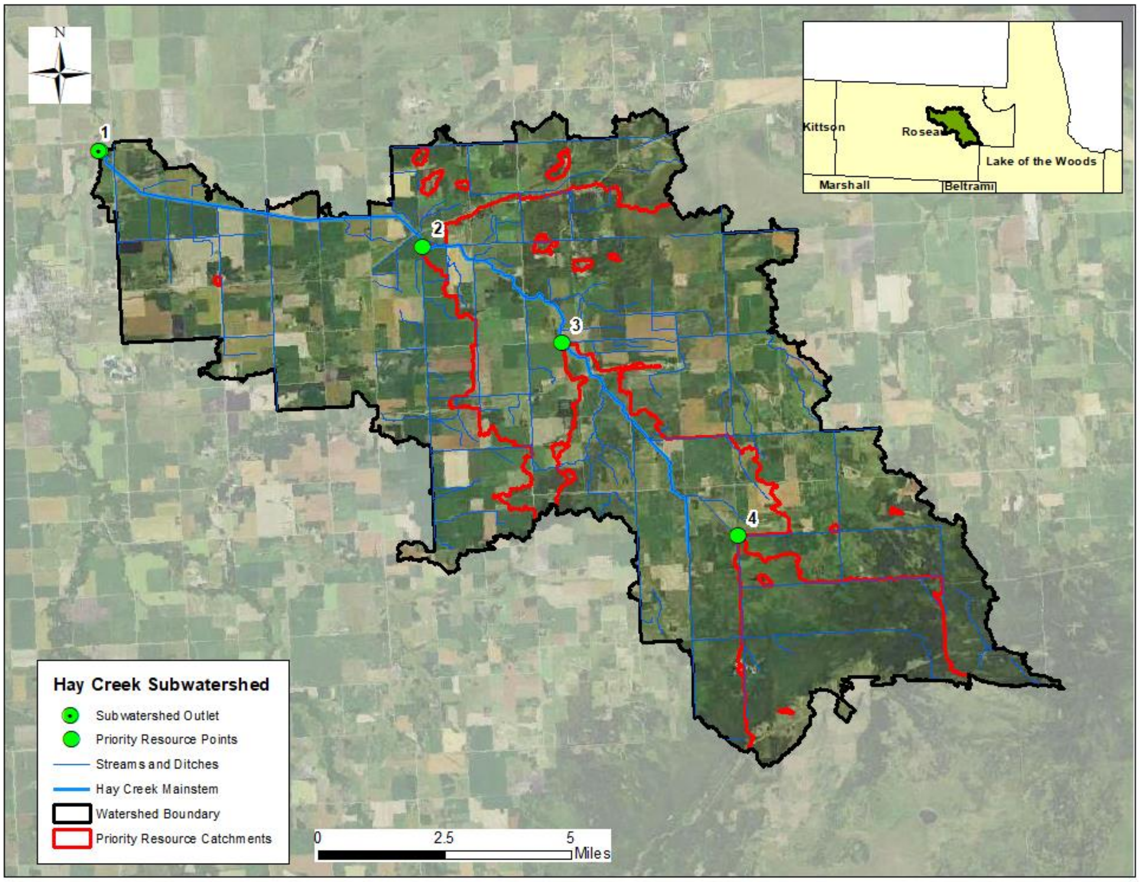


Figure 2. Hay Creek Subwatershed priority resource points and associated catchments. Hollows in some catchments represent non-contributing sub-catchments.

During geospatial product development and before this report, criteria were used to screen the BMPs considered technically feasible for implementation (**Table 1**). Feasible practice locations are identified through PTMApp-Desktop based on NRCS design standards. The screening process is intended to remove BMPs that may be technically feasible, but not practicable to implement. The resulting BMPs remaining after screening (practical BMPs) are shown in **Figure 3**.

Once the BMPs had been screened to remove the impractical options, the remaining BMPs were analyzed to find the most cost-effective. BMPs that could be used to meet the sediment and TP load reduction goals for the subwatershed. The most cost-effective BMPs were incorporated into the targeted implementation profile included in **Section 7**.

During the analysis, PTMApp determines the feasible locations for specific BMPs before combining their information into the standard output treatment groups. These intermediary data products were used for the analysis of this report. An additional processing step found where the most cost-effective, targeted BMPs overlap the intermediary BMPs output features of PTMApp-Desktop. This way specific BMPs were able to be located within the subwatershed, not just general BMP treatment groups. For example, Water And Sediment Control Basins (WASCOBs) are highlighted in the Targeted Implementation Profile in **Section 7** instead of the PTMApp Storage treatment group practice, which a WASCOB is just one type of.

Table 1. Criteria used for screening PTMApp-Desktop BMP output data.

			Remove BMPs with little runoff volume delivery or constituent removal efficiency						Remove BMPs with low removal magnitudes at the edge-of-field					
PTMApp Treatment Group Code	Treatment Group Name	Total BMPs Generated	Delivery and Efficiency Selection Criteria (value must be greater than) *			BMPs Not Meeting Criteria	BMPs Remaining After Criteria Applied	% of Original BMPs Remaining	Reduction Magnitude Selection Criteria (value must be greater than) **			BMPs Not Meeting Criteria†	BMPs Remaining After Criteria Applied	% of Original BMPs Remaining
			Sediment Reduction, %	TP Reduction, %	TN Reduction, %				Sediment Reduction @ Catchment Outlet, tons/year	TP Reduction @ Catchment Outlet, lbs./year	TN Reduction @ Catchment Outlet, lbs./year			
1	Storage	1,578	5.0%	5.0%	5.0%	666	912	57.8%	0.25	0.25	0.5	705	207	13.1%
2	Filtration	Not Considered for this Study												
3	Biofiltration	Not Considered for this Study												
4	Infiltration	Not Considered for this Study												
5	Protection	Not Considered for this Study												
6	Source reduction	697	NA	NA	NA	0	697	100%	0.25	0.25	1	104	593	85.1%

* Second quartile (Q2; 50th percentile) reduction efficiency was used for all treatment groups except filtration, where the third quartile (Q3; 75th percentile) reduction efficiency was used for TP and TN terms
** Second quartile (Q2; 50th percentile) catchment outlet reduction was used for all treatment groups except filtration, where the third quartile (Q3; 75th percentile) catchment reduction was used for TP and TN terms
† Represents BMPs failing to meet Reduction Magnitude Selection Criteria after the BMPs failing to meet Delivery and Efficiency Selection Criteria were removed

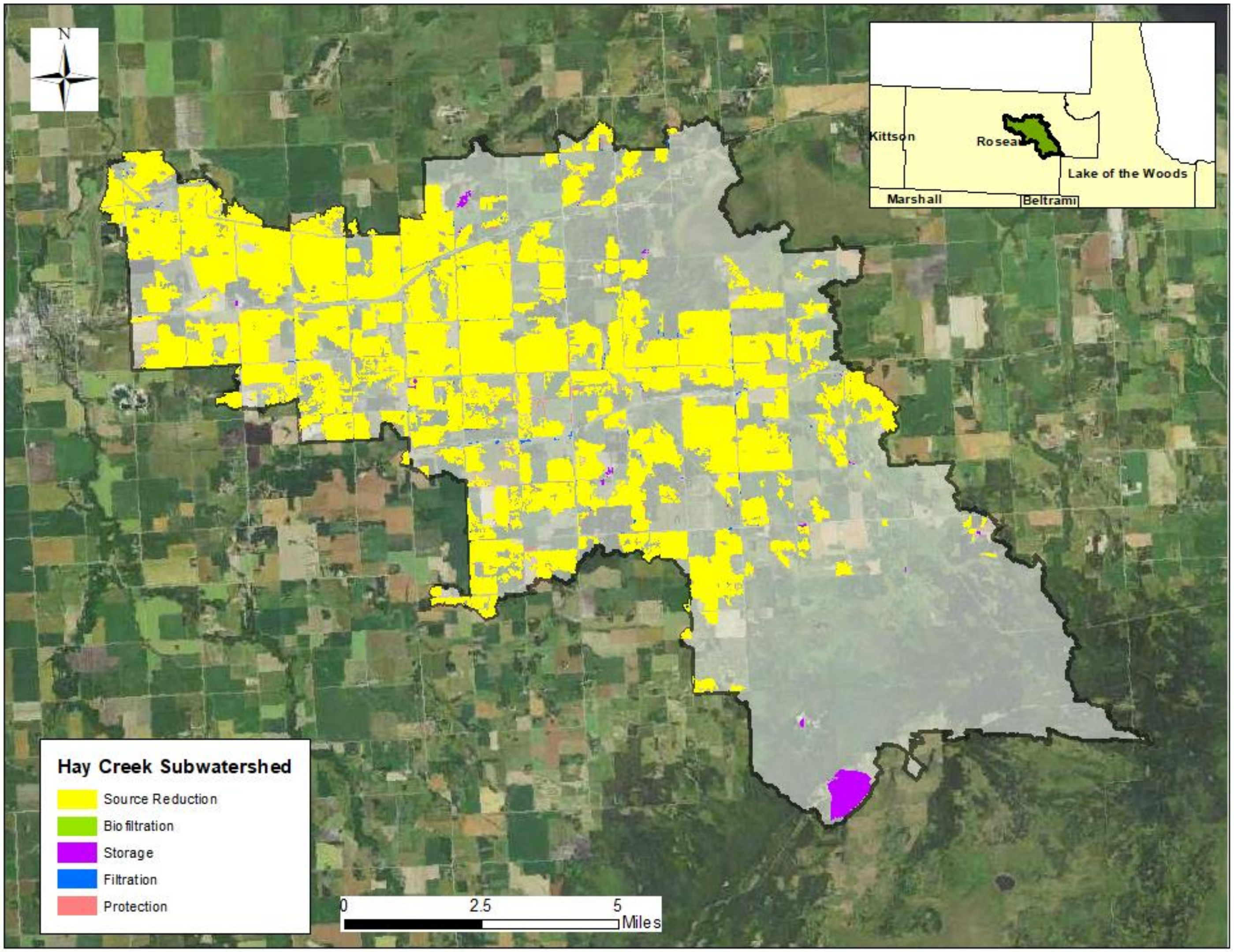


Figure 3. All practical BMPs (post-BMP screening) from the PTMApp analysis that could be implemented within the Hay Creek Subwatershed.

4 RIPARIAN ANALYSIS

Local governments in Minnesota continue to work on reducing sediment and TP from bank and near-channel erosion (referred to as riparian areas hereafter). A geospatial analysis was conducted to identify and target banks that are susceptible to erosion, along with recommending management actions to improve the geomorphic stability within the riparian areas along Hay Creek's mainstem. Two reaches were defined and assessed: the downstream portion of the mainstem (State Hwy 11 to the watershed outlet at the confluence of the Roseau River) and the upstream portion of the mainstem (near the intersection of CR-132 and CR126 to State Hwy 11). Priority banks for stabilization were given either a high or medium risk rating (**Table 2**). Riparian management actions include channel restoration, runoff reduction, protection from overland flow and bank stabilization, or a combination of these (**Table 3**). This type of approach can focus prioritization efforts on reaches with known stability and/or erosion issues as well as to help understand reaches that may not have prior data or studies. Although the framework for the results is qualitative, it is driven by quantitative calculations. This enables the data to be easily queried or manipulated as more insight is gained on reaches.

Section 8 of this report pairs these results with concept plans for practices that could be used to improve near-channel riparian conditions.

Table 2. Number of banks with each erosion priority level in the upstream and downstream mainstem portions of Hay Creek.

Priority Level	Upstream	Downstream
High	8	24
Medium	14	38

Table 3. Number of each type of management action (and the associated percentage of that action amongst all riparian blocks) corresponding to the riparian blocks in the upstream and downstream mainstem portions of Hay Creek. Note that the sum of the percentages is a value less than 100% due to blocks not in need of any action per the results of this assessment.

Management Action*	Upstream	Downstream
Protect Overland Flow	95 (20%)	42 (7%)
Protect Overland Flow and/or Restore Channel	83 (17%)	42 (7%)
Reduce Runoff	43 (9%)	130 (23%)
Protect Overland Flow and/or Restore Channel and/or Runoff Reduction	17 (4%)	39 (7%)
Protect Overland Flow and/or Runoff Reduction	22 (5%)	39 (7%)
Restore Channel	182 (38%)	134 (24%)
Runoff Reduction and/or Restore Channel	30 (6%)	130 (23%)

*Riparian blocks around road intersections should be evaluated with greater scrutiny as they will inherently be assigned as needing more mitigation within the tool.

5 ALTERED HYDROLOGY ANALYSIS

"Altered hydrology" has become a buzzword used to describe watersheds in Minnesota that contain unstable streams and rivers that are impacted by climate and land use changes. These impacts can result in increased surface and subsurface flow and alter the quantity and timing of water in ditches, streams, and rivers. An altered hydrology analysis was performed to determine the hydrologic effects of targeted BMPs within the watershed. The intent of this process is to estimate the progress of specific conservation efforts towards "altered hydrology" goals. BMPs used to store, slow, or infiltrate water into the soil have the effect of reducing or lagging surface runoff. This has an impact on peak flow and maximum volume (**Table 4**). This type of approach can focus prioritization efforts on catchments with known flooding issues as well develop or validate an understanding of the hydrologic processes with the watershed.

Table 4. Percent reduction in peak flow, maximum volume, and the change in runoff depth as measurable at each priority resource outlet resulting from targeted BMP implementation.

Priority Resource Point	Priority Catchment Reduction	2-yr, 24-hr	10-yr, 24-hr	100-hr, 24-hr
1 (Planning Region Outlet)	Peak flow (%)	28%	22%	15%
	Max Volume (%)	20%	15%	11%
	Change in RO Depth (in)	0.12	0.20	0.36
2	Peak flow (%)	15%	14%	12%
	Max Volume (%)	14%	11%	8%
	Change in RO Depth (in)	0.08	0.14	0.25
3	Peak flow (%)	13%	10%	7%
	Max Volume (%)	13%	10%	8%
	Change in RO Depth (in)	0.08	0.13	0.25
4	Peak flow (%)	0%	0%	0%
	Max Volume (%)	0%	0%	0%
	Change in RO Depth (in)	0	0	0

*No BMPs upstream of priority resource points

As part of this methodology, results from running the altered hydrology analysis were compared to the USGS Stream Stats Report generated for the Hay Creek Subwatershed. The 2-, 10-, and 100-year peak flows were compared to determine the accuracy of this study relative to available information. The average difference in peak flows between the USGS data and this analysis was 5%. Source reduction practices had the largest impact on peak flow and maximum volume reduction within the watershed. The final set of targeted practices included 401 source reduction practices covering 16,791 acres, or 25% of the watershed area. However, no practices were selected that fall within the most upstream priority resource catchment (#4 in **Table 4**). The average curve number for the catchments over which these BMPs were applied changed from 77 to 66.

6 TARGETED PLAN COMPONENTS

The Targeted Implementation Profile (**Section 7**) is divided into several components. The following section describes the Targeted Implementation Profile that was developed for this report and how it can be used to support efforts to make progress towards local water management goals. BMPs that are part of the Targeted Implementation Profile represent the most cost-effective BMPs that can be implemented to achieve the water quality goals of the watershed.

MEASURABLE GOALS

The Measurable Goals portion of the Targeted Implementation Profile summarizes the current PTMApp estimated annual sediment and TP loads as measurable at the watershed outlet. It also includes the load reduction goals for sediment and TP, along with the estimated annual cost of practices needed to meet these goals. The strategies contained within the Targeted Implementation Profile are meant to identify the level of effort to restore or protect waterbodies within the subwatershed.

TARGETING APPROACH

The Targeting Approach portion of Targeted Implementation Profile briefly describes the criteria that were used to screen, select, and target BMPs throughout the subwatershed. These targeting criteria identify a range of practices that provide cost-effective treatment within the watershed. However, the targeted practices exceed the number of practices needed to achieve the sediment and TP reduction goals set for the subwatershed. The sediment and TP reduction goals can be achieved with fewer practices than are contained within this Targeted Implementation Profile.

The following criteria are used at the catchment outlet to select targeted practices from the larger population of feasible BMPs:

1. > 1 acre-foot of storage
2. > 1 lb. of TP removal at the catchment outlet per year for the 2-year, 24-hour event
3. > 2 tons of sediment removed per year at the catchment outlet for the 2-year, 24-hour event
4. < $6,000 per acre-foot of storage
5. < $2,000 per ton of sediment removed
6. < $2,000 per pound of TP removed

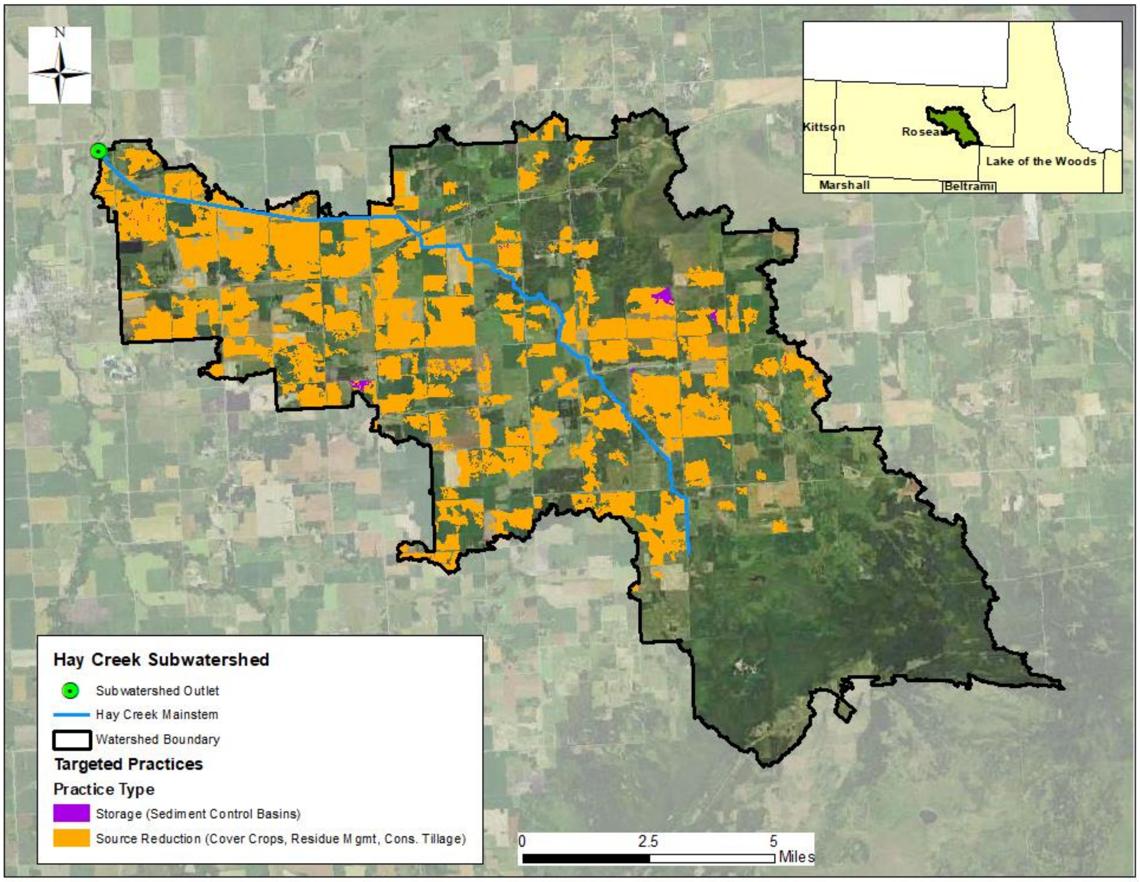


Figure 4. Targeted BMPs that could be implemented to reach water quality goals throughout the watershed.

OVERALL FINDINGS

The overall findings section of the Targeted Implementation Profile provides an overview of:

- the estimated cost to reach each water quality goal,
- the average load reduction efficiency of structural and management BMPs, and
- the most effective type of structural or management BMPs to implement within the Hay Creek Subwatershed.

PRACTICE SUMMARY

The Practice Summary breaks down the most cost-effective practices that could be implemented within the Hay Creek Subwatershed along with the estimated investment in each PTMApp treatment group (i.e., type of structural or management BMP) necessary to reach the load reduction goals at the subwatershed outlet. It also provides the number of practices necessary from each treatment group, the total investment necessary, and the load reduction estimated as a result of implementing all the BMPs within each treatment group. The practice summary table in the lower right hand corner provides PTMApp treatment groups along with examples of specific BMPs that correspond to each treatment group. These BMPs are based on results from surveys conducted by the Roseau River Watershed District to determine the types of practices individuals within the subwatershed are interested in and willing to implement. Survey results and a map of the targeted BMPs are presented in **Appendix A.**

ALTERED HYDROLOGY

The Altered Hydrology portion of the Targeted Implementation Profile shows an estimated catchment level reduction in peak flow for the 10-year rainfall event as a result of the targeted selection of source reduction and storage of BMPs. A detailed description of the methods used for altered hydrology is provided in **Appendix B.**

7 TARGETED IMPLEMENTATION PROFILE AND CONCLUSIONS

TARGETED IMPLEMENTATION PROFILE

The information contained in the Targeted Implementation Profile for the Hay Creek Subwatershed is intended to be a stand-alone source of data for guiding implementation efforts within the subwatershed. By adapting and using this information, conservation professionals will be able to target conservation opportunities that provide multiple benefits toward issues associated with water quality.

While the targeted BMPs from this assessment should provide sufficient progress toward reaching sediment and TP management goals, there is no guarantee that all BMPs can be implemented. Many factors will affect the ability to install or implement BMPs such as funding, landowner willingness, or the presence of existing practices. As such, flexibility is required when choosing which targeted BMPs to invest in.

FUTURE USE OF DATA PRODUCTS

The data products provided in this report should not be taken as a prescriptive plan, but a guide that can be used to inform decisions. A factor in implementing a BMP is farmer or landowner involvement as well as their understanding the BMP and the potential benefits or drawbacks of implementation. A series of template concept designs were created that could be used to address in-channel issues within Hay Creek Subwatershed. The designs are presented in **Section 8** and can be presented to farmers and landowners who are interested in installing or learning about certain BMPs.

Opportunities for BMPs outside of the PTMApp practices will also be available for implementation within the subwatershed. For example, if there is an opportunity to implement a conservation BMP that is not included in the Targeted Implementation Profile, but the dollar per mass load reduction falls within the range of viable cost-effectiveness (**Figure ES-2**). It is likely that the BMP would provide a reasonable option for making progress towards local water management goals.

It is important to note that more BMPs were included in the Targeted Implementation Profile than are required to meet the 10% load reduction goals set for the Hay Creek Subwatershed. Therefore, the total cost listed in the Targeted Implementation Profile exceeds the total cost needed to achieve the 10% load reduction goal. Additional practices were included in the Targeted Implementation Profile to illustrate the potential for hydrology management within Hay Creek Subwatershed through the implementation of cost-effective on farm (e.g., cover crops) and edge-of-field management practices (e.g., side water inlets and WASCOBs).

Table ES-1 can be used to evaluate the range of investment that would be required to meet the 10% load reduction goals for Hay Creek if cost-effective BMPs are implemented.

TARGETED IMPLEMENTATION PROFILE: HAY CREEK SUBWATERSHED

MEASURABLE GOALS

Existing Load at Watershed Outlet:

-Sediment 5,187 tons/year, TP 11,312 lbs./year

Targeted Load Reduction at Outlet (10%):

-Sediment 519 tons/year, TP 1,131 lbs./year

Estimated Cost of Targeted Practices:

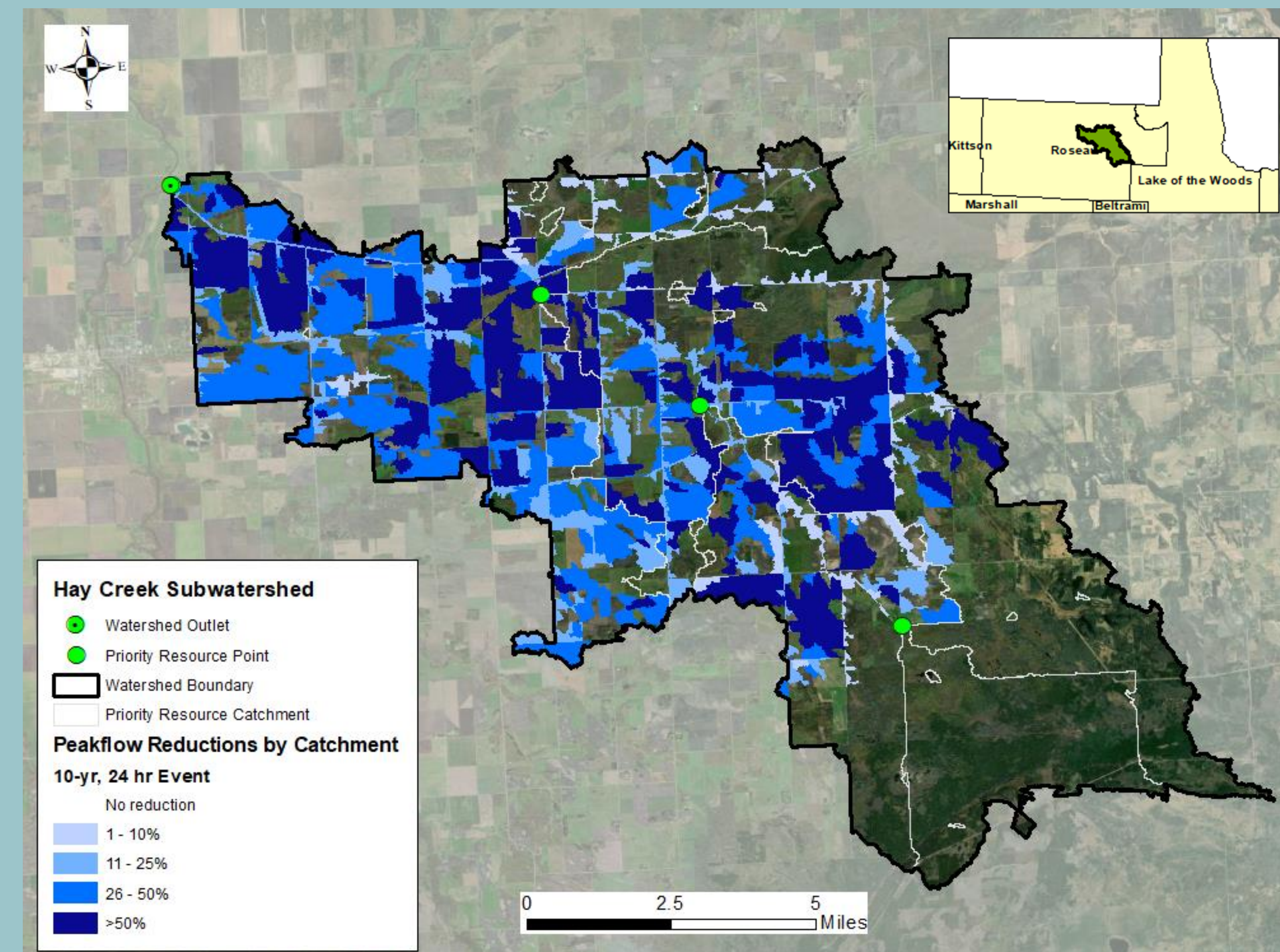
-$1,305,689

TARGETING APPROACH

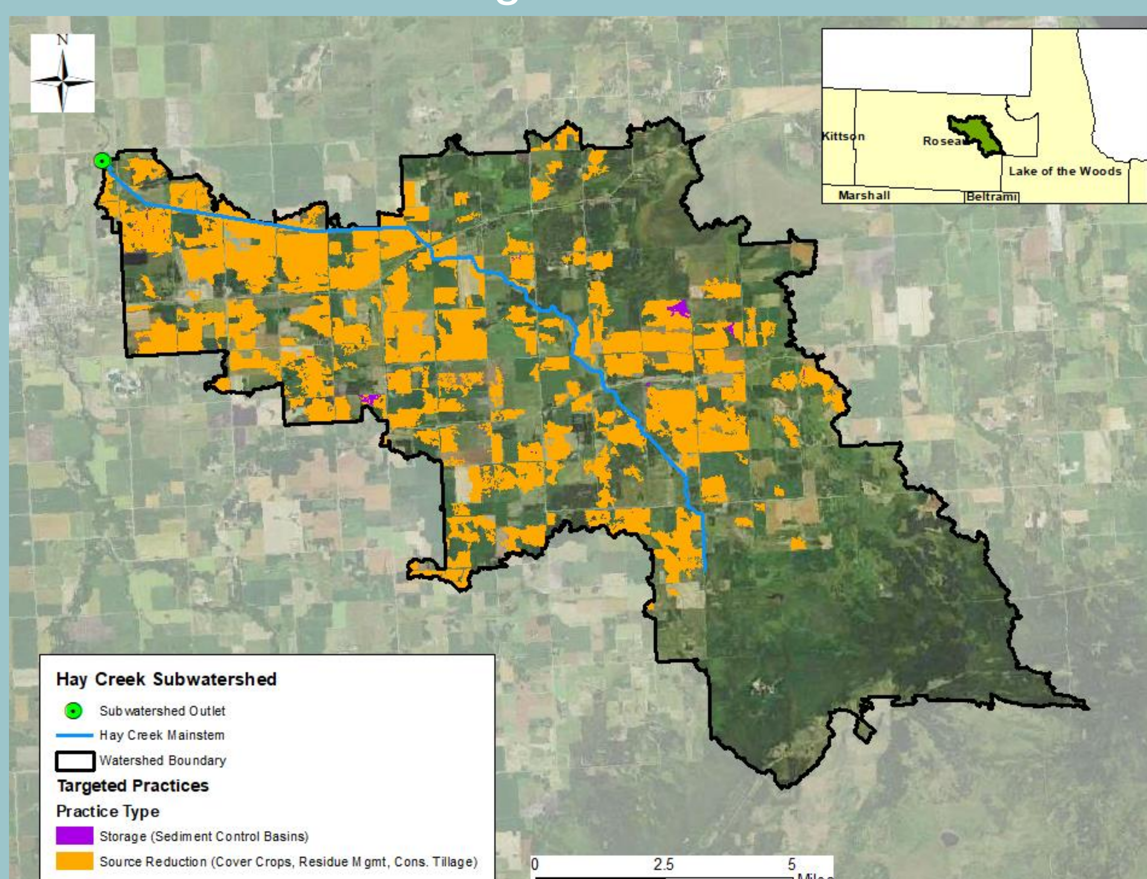
PTMApp output BMPs were screened to remove practices with low sediment and TP delivered to the practice as well as practices with small annual sediment and TP reduction.

Sediment and TP load reduction goals were set to 10%. Once load reduction goals were set, all the possible BMPs targeted by PTMApp (see **Figure 5**) within the subwatershed were evaluated to establish criteria for targeting a range of cost-effective BMPs. Additional BMPs were selected than needed to achieve the 10% load reduction goals to illustrate the potential hydrology management impacts of implementing cost-effective, on-farm (e.g., cover crops) and edge-of-field management practices (e.g., side water inlets and WASCOBs).

Altered Hydrology



Targeted Practices



OVERALL FINDINGS

The overall estimated cost to implement all targeted practices is $1,305,689. This reduces the sediment loading by 31% and the TP loading by 19%. The analysis suggests that the 10% load reduction goals could be met by investing around $309,324 for sediment and $592,644 for TP, if cost-effective practices are implemented (see **Table ES-1**).

Peak flow reductions by catchment averaged 16% across the watershed for the 10-year, 24-hour event.

PRACTICE SUMMARY

Hay Creek Subwatershed - Watershed Outlet

Goals: 10% Sediment Reduction = 519 tons/yr., 10% TP Reduction = 1,131 lbs./yr.

BMP Practice	Cost	Sediment Reduction (tons/yr.)	Total Phosphorus Reduction (lbs./yr.)	Number of Practices
Storage	$208,630	180	138	19
Source Reduction	$1,097,059	1,402	1,963	401
Overall Total	**$1,305,689**	**1,582**	**2,101**	**420**

PTMApp Treatment Group	BMPs of interest to the farmers and landowners in the Hay Creek Subwatershed
Storage	Water and sediment control basin (WASCOB), Drainage water management
Source Reduction	Cover Crops, Conservation Tillage and Residue Management

Underlined practices represent specific BMPs that were analyzed using PTMApp.

8 RIPARIAN MANAGEMENT

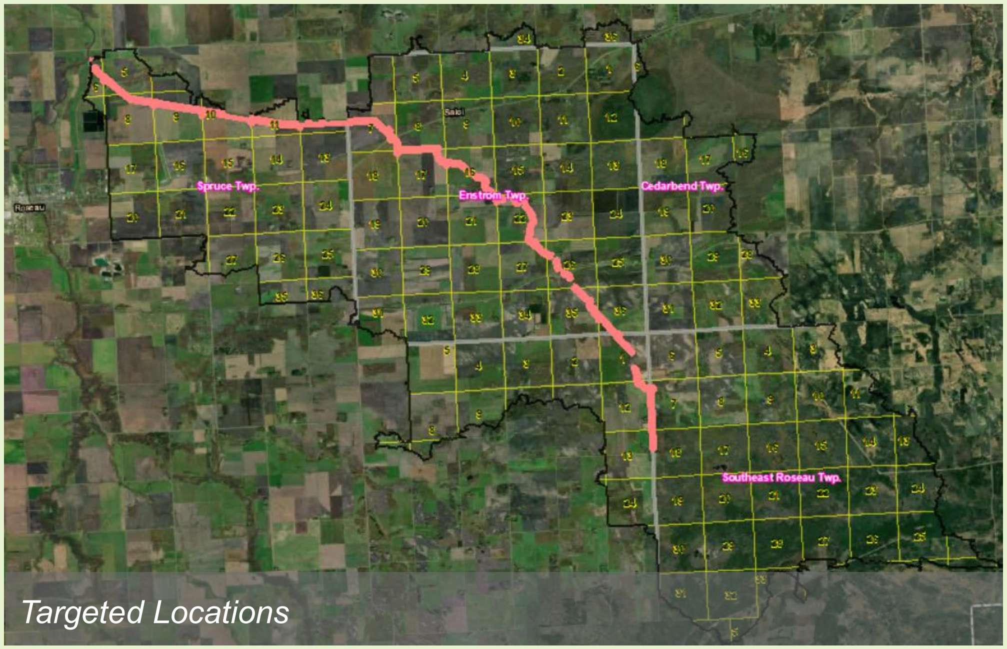
INTRODUCTION

The following information provides a range of implementation practices that can be implemented to help improve the near-channel riparian area of Hay Creek. Riparian Management is broken into the following categories:

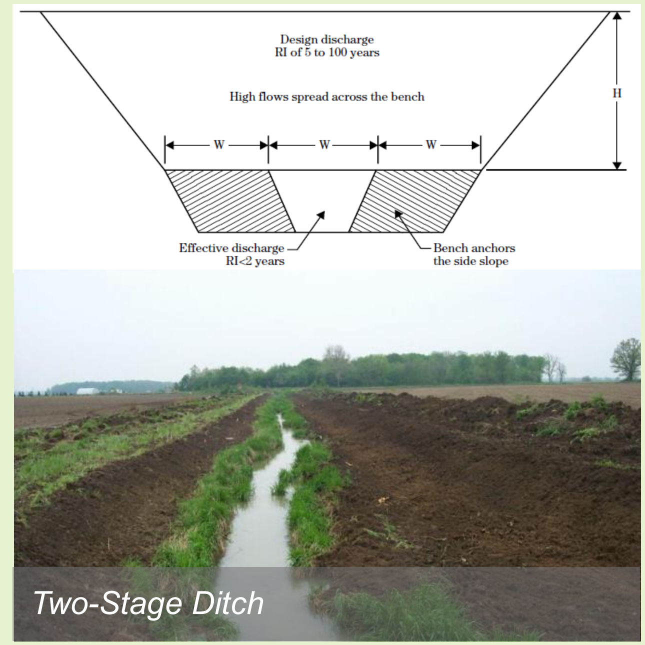
- **Restore Channel** – actions that can be taken to restore biological and geomorphic functions of the Hay Creek Channel, while maintaining proper flow conveyance.
- **Bank Erosion** – actions that directly stabilize an individual stream bank.
- **Protect Overland Flow** – actions that can be taken to treat flow being delivered into Hay Creek.
- **Reduce Runoff** – actions that can be taken to reduce the volume or peak flow delivered to Hay Creek.

Targeted locations where each form of riparian management is needed to improve Hay Creek are presented in this section. Concept plans are presented for management actions that could be implemented within the targeted areas for **Restore Channel** and **Bank Erosion**. For **Protect Overland Flow** and **Reduce Runoff**, HEI provided several flyers that provide overviews of the practices described in the targeted riparian management recommendations. The full technical descriptions of the methods used to target riparian management locations is provided in **Appendix C**.

RESTORE CHANNEL



Targeted Locations



Two-Stage Ditch

General Criteria

Max Sheer Stress (lbs./feet^2)	Max Slope	Max Substrate	Zone[1]	Vegetation Density	Cost[2]	Strength[3]	Advantages	Disadvantages
2-4	N/A	Boulder	T, B, C	76-100%	$$$	M	Brings creek to a more natural flow	Loss of farming land

TWO-STAGE DITCH CONCEPT PLANS

Two-stage ditches incorporate benches that function as floodplains and attempt to restore or create a natural flow in the main channel. However, these two-stage channels are not exact copies of natural systems, as the width of the benches is often small due to the confining geometry of the constructed channel. Two-stage ditches are applicable to low gradient ditches and channels that are not undergoing incision. The two stages of a two-stage ditch are a dominant discharge or channel-forming channel and a floodplain bench channel.

Fluvial processes at work in agricultural ditches often try to develop a floodplain with low benches. While this deposition reduces flood capacity, these ditches show improved stability and habitat quality. This two-stage approach provides improved physical and ecological performance. The channel-forming discharge channel provides the necessary sediment conveyance, while the floodplain channel provides flood conveyance. By nesting the channel-forming discharge channel within the larger channel, the entire waterway is more stable. **Figure 5** provides a cross-section of a two-stage ditch design.

Advantages

- Improved drainage and ecological function.
- Increased ditch stability and reduced maintenance.
- Reduction in the erosive potential of larger flows, as they are spread across the bench.

Disadvantages

- Permanent loss of farming land.
- Increased construction cost.
- Future maintenance difficulties.
- Possible excess excavated soils.

Maintenance

- Should be monitored, especially following high flow events.
- Repairs to vegetation should be made as needed and, if damaged, additional vegetation should be planted to prevent future erosion.
- Ditch system clean out should be much less than typical ditch system.

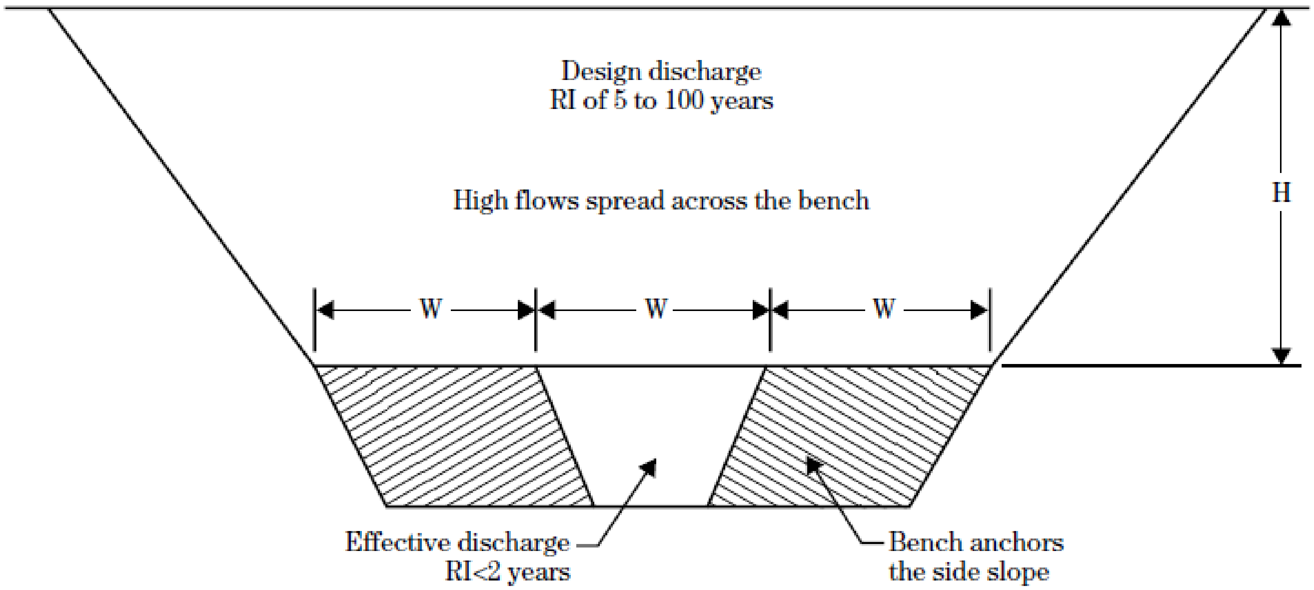


Figure 5. Cross section schematic of a two-stage ditch (NRCS, 2007).

Cost

- Management costs vary based on the existing ditch's size, topography, engineering design, existing infrastructure, and spoil material.
- Costs are site-specific, but they typically range from $10–$50 per linear foot to construct.
- Additional costs may be necessary for adjacent land to expand the ditch channel and can increase costs substantially.
- Planning to use spoil material on-site or nearby reduces costs significantly.
- Two-stage ditches might impact existing grass buffer contracts.
- Channel width will vary by site. Land taken out of production should be considered in the cost analysis.

Table 6 provides some basic design criteria for the Two-Stage ditch concept.

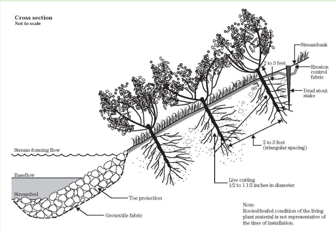
Table 6: General design criteria for Two-stage Ditches.

Allowable Shear Stress	Maximum Slope	Zone of Impact	Level of Construction
3 - 4 lbs/ft^3	NA	Channel	Heavy Machinery

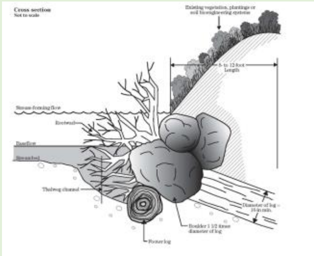
BANK EROSION

Practices

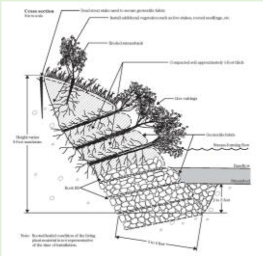
Minimal Impact Design/Maintenance



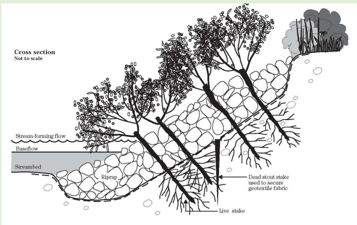
Natural Restoration and Protection



"Soft" Protection – Soft Armor



"Hard" Protection-Hard Armor



General Criteria

Practice	Max Shear Stress (lbs/ft²)	Max Slope	Max Substrate	Zone[1]	Veg Density	Cost [2]	Strength[3]	Advantages
Vegetative Restoration	4	2:1	Gravel	U	76-100%	$	L	Inexpensive and easy to install
Tree/Boulder Revetment	3.9	N/A	Boulder	T, B	10-25%	$$	M	Reduces velocity along bank
Soft Armor Walls	3.8	1:1	Bedrock	T, B	76-100%	$$$	M	Permanent armor solution w/o rocks
Riprap with Live Stakes	2.5 - 10.1	2:1	Bedrock	T, B	26-50%	$$	H	Structural flexibility

1 - T = Toe/Splash Zone, B= Bank, C = Channel, and U = Upland Area.

2 - Cost is relative cost for the conceptual designs; $ is lowest cost option(s) to $$$ is the highest cost option(s).

3 - Strength is the relative strength of the practice to resist erosive flows (L= relatively low resistance, M = medium resistance, and H = high resistance).

Minimal Impact Design/Maintenance

The Minimal Impact Design alternative encompasses bank re-sloping, cutting back any existing canopy to increase the sunlight reaching the ground vegetation to promote ground cover growth, and re-establishing vegetation along the channel. The Minimal Impact Design practice uses a combination of erosion control blankets to temporarily stabilize the soil to aid the re-established vegetation, cutting back the existing canopy where the trees were not removed to re-slope the grade, and live stakes to quickly and easily establish woody vegetation. **Figure 6** provides a cross-section of a conceptual vegetative repair.

Advantages

- Relatively inexpensive and quick to install.
- Can be used in areas with limited access, if project doesn't require heavy machinery to re-grade the slope.
- Can be used in conjunction with other practices.
- Allows streambank to revegetate.

Disadvantages

- May dislodge under high-water levels prior to vegetation establishment.
- May fail under extreme events where shear stress exceeds the allowed stresses of the vegetation.
- If live stakes used, should be completed when stakes are dormant, such as spring or fall.

Maintenance

- Should be monitored, especially following high flow events.
- Repairs should be made as needed and additional vegetation should be planted if damaged to prevent future erosion.

Costs

- Costs dependent on level of earth work;
- Costs site dependent and range from $10-$100 per linear foot of streambank

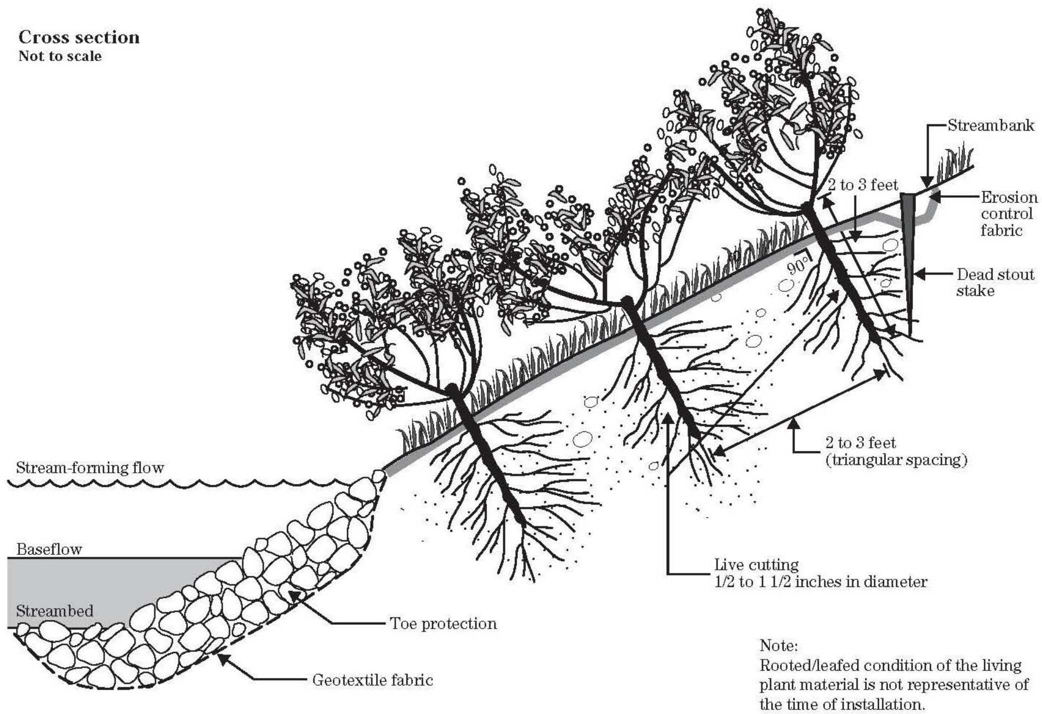


Figure 6. Cross section schematic of vegetative restoration with live stakes (NRCS, 2007).

Table 5 provides some basic design criteria for the vegetative restoration concept. This option is relatively robust and can be placed by location. It is a relatively low-cost option but also provides the least protection among the five design concepts because it could be damaged during high flow events.

Table 5. General design criteria for vegetative restoration.

Allowable Shear Stress	Maximum Slope	Zone of Impact	Level of Construction
3-4 lbs/ft^2	2:1	Bank, Upland	Manual labor to Heavy Machinery

*Values primarily from Mississippi Watershed Management Organization 2010.

Natural Restoration and Protection

The Natural Restoration and Protection group consists primarily of log, tree, and/or boulder revetments and remeandering the altered channel. Revetments are a system of logs, trees, and/or boulders selectively placed in and around the streambanks. They provide protection by disrupting the high erosive power of the stream near the streambank and reducing the erosive stream velocities near the eroding bank. They also allow sediment to deposit, rebuilding the bank. In addition, they provide habitat and substrate for aquatic organisms. Revetments are effective on meandering stream bends outside bank flow conditions by pushing the fastest moving water away from the eroding streambank. **Figure 7** provides a conceptual cross-section of a revetment repair.

Advantages

- Can be easy and inexpensive to install.
- Reduces velocities along streambank.
- Collects sediment and debris to rebuild streambank.
- Can be used in conjunction with other practices.
- Allows Streambank to revegetate.

Disadvantages

- Not appropriate for sites with loose, distributed soil.
- Can appear messy in highly visible areas.
- Should not be installed close to structures where dislodged revetments from high flows could cause damage or block river.
- Tree will not root into soil.

Maintenance

- Should be monitored, especially following high flow events.
- Repairs should be made as needed and additional vegetation should be planted if damaged to prevent future erosion.

Costs

- Costs are site specific.
- Sourcing materials (rocks and trees) in the area can reduce costs.
- Costs approximately $300 - $400 per linear foot, depending on scale of project.

Table 7 provides some basic design criteria for the revetment repair concept design. This option is more site-specific than the Minimal Impact Design option, but relatively robust. It is a more expensive option but also provides a more natural and restorative look compared to the more engineered conceptual designs. This option also provides some habitat benefits for wildlife.

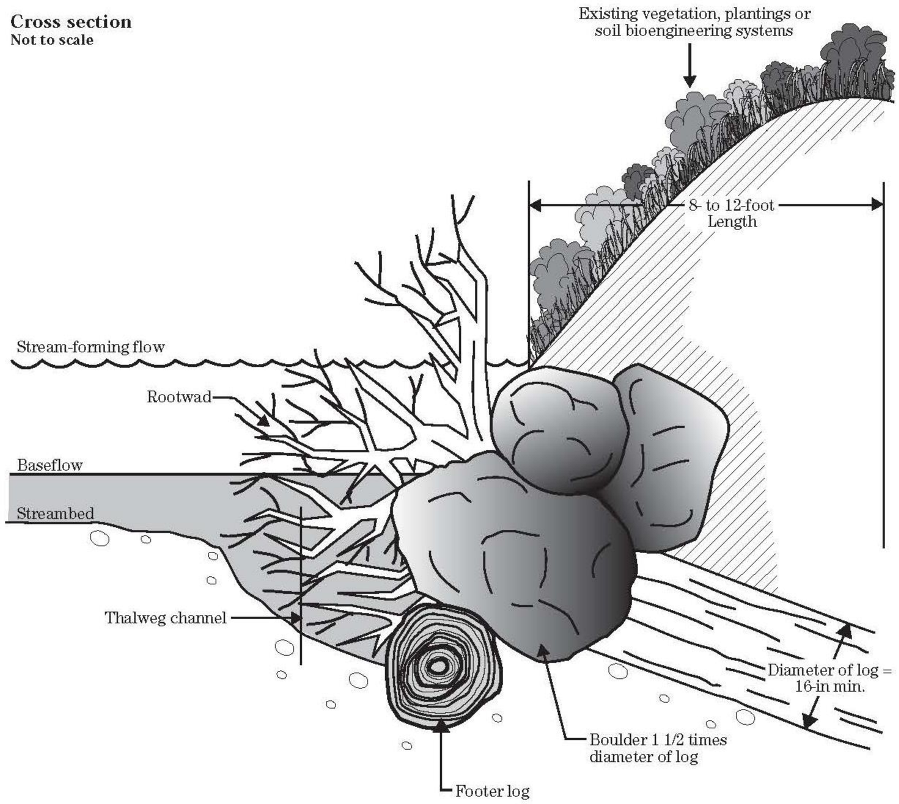


Figure 7. Cross section schematic of log, rootwad, and boulder revetment detail (from NRCS, 1996).

Table 7. General design criteria for tree/boulder revetments.

Allowable Shear Stress	Maximum Slope	Zone of Impact	Level of Construction
3.9 lbs/ft^3	N/A	Toe/Splash, Bank	Heavy Machinery

*Values primarily from MWMO 2010.

ENGINEERED "SOFT" PROTECTION-SOFT ARMOR

Engineered "Soft" Armor Protection include soft armor and geotextile grids. Soft armor walls are a soft, engineered, permanent structure designed to be fully vegetated for bank stabilization and erosion control applications using interlocking geotextile bags. "Soft" refers to the use of geotextiles and soil instead of "hard" riprap. Vegetative geogrids are layers of soil wrapped inside erosion blankets or fabric. Both are more natural engineered solutions that provide bank stability without the use of rocks or concrete. The difference between the two are the design. Vegetative geogrids are layers of soil and soft armor are bag of soil. These systems provides structure strength before vegetation exists and is water permeable. The soft armor practice will be applied to the example erosion site to estimate the cost. **Figure 8** shows a cross-section of a conceptual design of soft armor.

Advantages

- Creates a permanent soft armor solution without the use of rocks or concrete.
- Provides immediate erosion control and slope stabilization.
- Can accommodate steep slopes with no limitation on height.
- Water permeable to minimize hydrostatic pressure.

Disadvantages

- Requires a considerable amount of fill material.
- Needs to be reinforced for walls over 3 feet tall.

Maintenance

- Should be monitored, especially following high flow events.
- Repairs to vegetation should be made as needed and additional vegetation should be planted if damaged to prevent future erosion.

Costs

- May need to import soil to construct if a source cannot be found on-site.
- Costs for "soft" protection is about $200 per linear foot of streambank.

Table 8 provides some basic design criteria for the soft armor concept. This option is more site-specific and can be used in areas with steep gradient banks. It is more labor intensive and more expensive option but also provides a natural looking repair not possible by some of the other practices.

Table 8. General criteria for soft armor/vegetative geogrids.

Allowable Shear Stress	Maximum Slope	Zone of Impact	Level of Construction
3.8 lbs/ft^3	1:1	Toe/Splash, Bank, Upland	High

*Values primarily from MWMO 2010.

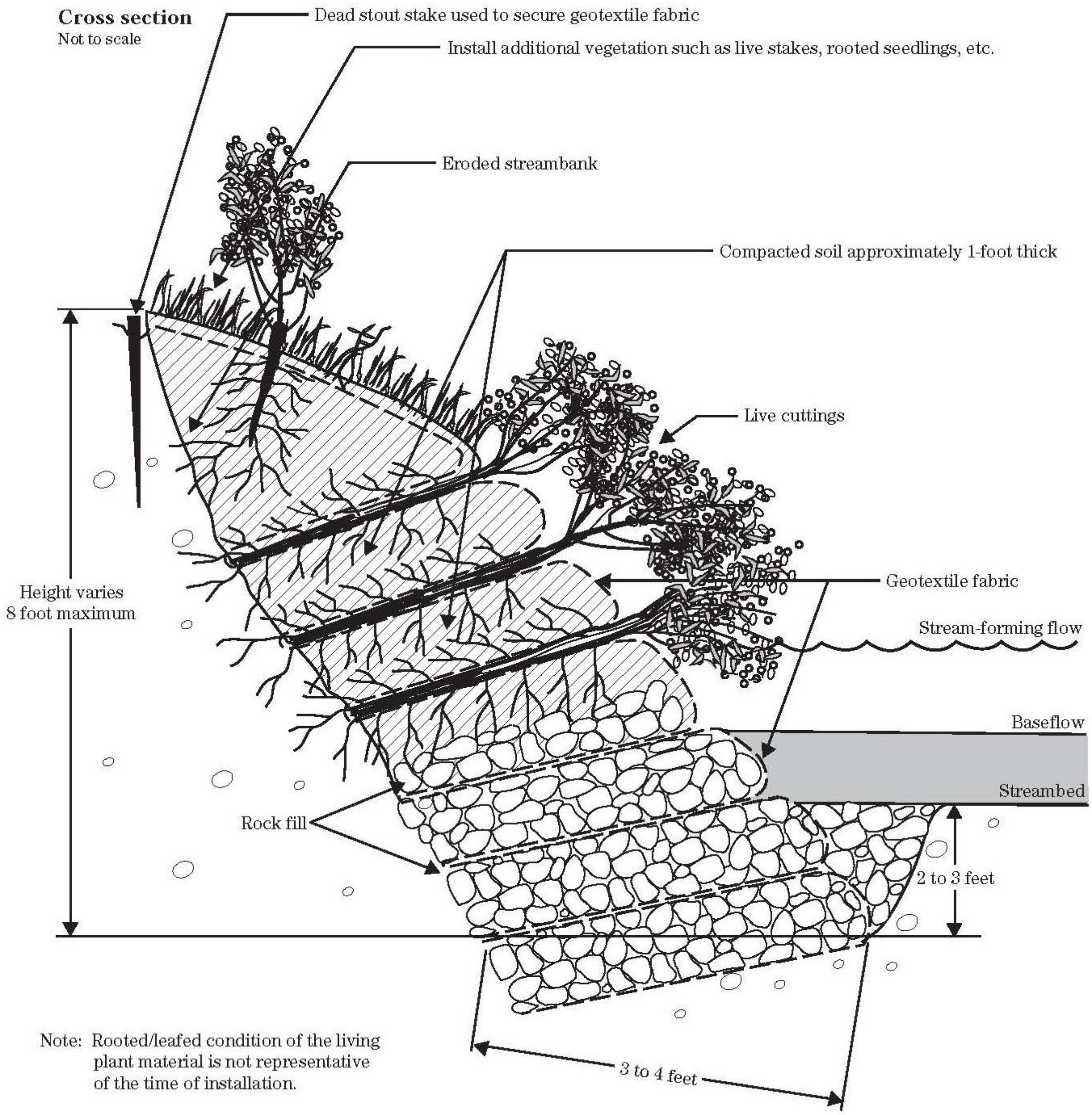


Figure 8. Cross section schematic of soft armor (NRCS, 2007).

Engineered “Hard” Protection-Hard Armor

Engineered “Hard” Protection is engineered streambank protection that uses riprap or “hard” armor to protection the streambanks from the erosive forces of the creek. It represents a more traditional, engineered, bank stabilization technique. Hard armor (i.e., riprap) is a slope stabilization technique used in instances where flow velocities require more stability than bioengineered techniques can provide. This includes hard armor riprap, a vegetative riprap where vegetation is incorporated to provide a more aesthetic look, gabions where riprap is held in place with wire baskets and form a wall of protection, and interlocking blocks used to create a strong interlock surface to protect streambanks. Vegetative riprap was selected as the conceptual design practice from this group. Riprap uses free set stones over a slope to prevent erosion. Vegetation is added to soften the appearance of the riprap and achieve a more natural aesthetic to camouflage the rock. A cross-section of a conceptual vegetative hard armor design is given in **Figure 9**.

Advantages

- Has structural flexibility, which allows it to react to changes in slope.
- If properly sized and engineered, traditionally long-term solution to protect against large events.

Disadvantages

- Requires heavy/large machinery to install.
- May not be cost effective is limited access areas.

Maintenance

- Riprap may settle in first few years and should be monitored and corrected.
- Rock should be added or adjusted to prevent weak points from forming.
- Additional vegetation should be added to areas with little to no vegetation.

Costs

- Site and scale cost dependent.
- Costs range from $200-$350 depending on access and transportation of material costs.

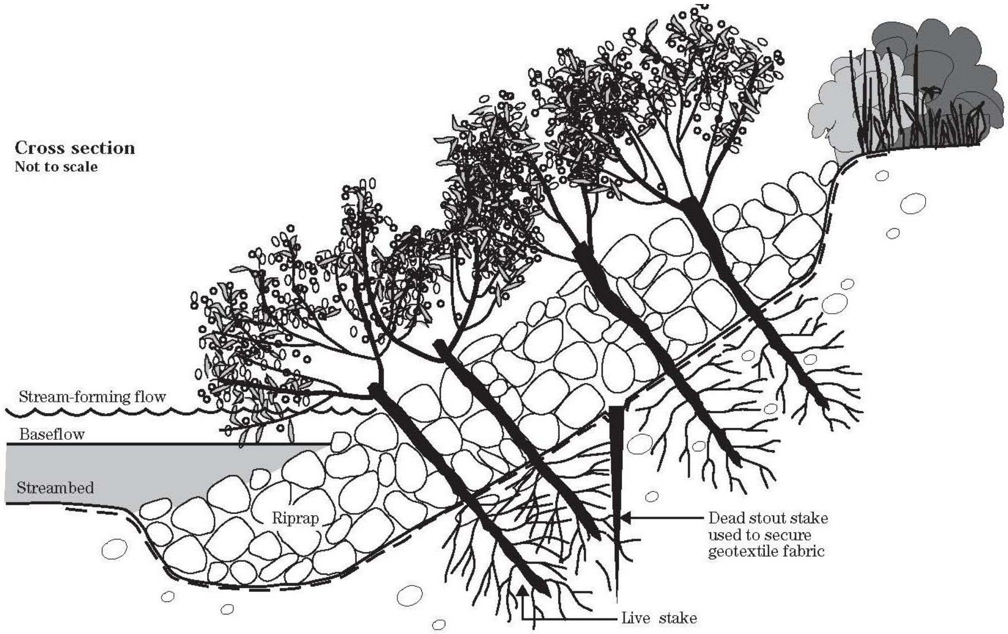


Figure 9. Cross section schematic of vegetative hard armor (from NRCS, 1996).

Table 9 provides some basic design criteria for the vegetated riprap concept design. This option is a widely used engineered option. The vegetation softens the engineered look of the rock and it provides a durable and permanent bank repair solution.

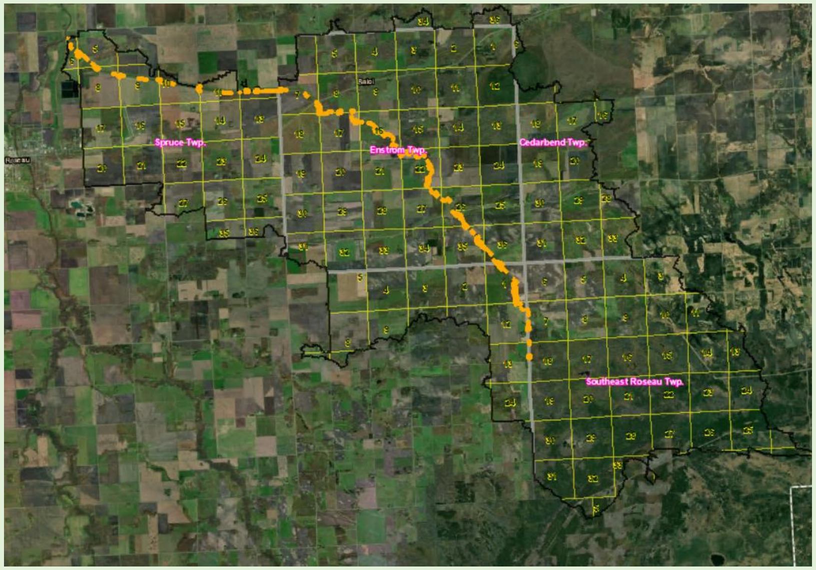
Table 9. General criteria for vegetated riprap.

Allowable Shear Stress*	Maximum Slope	Zone of Impact	Level of Construction
2.5-10.1 lbs/ft3	2.1	Toe/Splash, bank	Machinery

*Shear stress is dependent on size of riprap

Protect Overland Flow

Targeted Locations



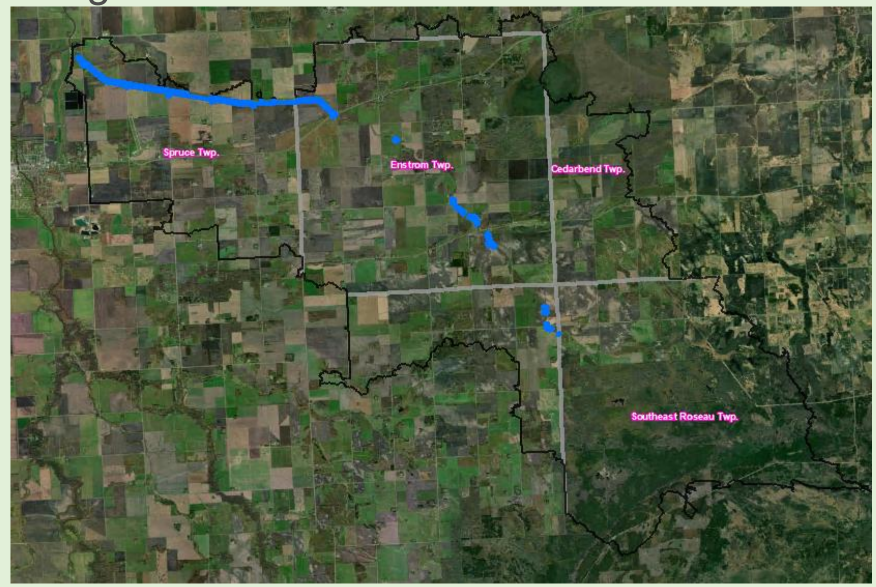
Types of Upstream Practices

Structural

- Grade Control Structure
- Side Water Inlets
- Cattle Exclusion Fencing
- Riparian Corridor Establishment

Reduce Runoff

Targeted Locations



Types of Upstream Practices

Field Management

- Cover Crops
- Conservation Tillage
- Residue Management

Structural

- WASCOBs
- Drainage Water Management
- Culvert resizing
- Impoundments
- Retention ponds

DESIGN CRITERIA MATRIX

Table 10 provides a matrix summary of the design criteria for the five conceptual designs. Included in the matric are maximum allowable shear stress, maximum bank slope, the maximum allowed substrate needed to build the practice, what streambank zone the concept is located (Toe, Bank, Channel, and/or Upland), the vegetation density needed, the relative cost and strength of the concepts, and any advantages and disadvantages of the conceptual designs.

Table 10. Summary of Design Criteria for Conceptual Streambank Stabilization Practice.

Practice	Max Shear Stress (lbs/ft^2)	Max Slope	Max Substrate	Zone[1]	Veg Density	Cost [2]	Strength[3]	Advantages	Disadvantages
Vegetative Restoration	4	2:1	Gravel	U	76-100%	$	L	Inexpensive and easy to install	Susceptible to flooding during establishment phase
Two-stage Ditch	2-4	N/A	Boulder	T, B, C	76-100%	$$$	M	Brings creek to more natural flow channel	Loss of farming land
Tree/Boulder Revetment	3.9	N/A	Boulder	T, B	10-25%	$$	M	Reduces velocity along bank	Bad with loose soils, maybe visually unappealing (looks like debris
Soft Armor Walls	3.8	1:1	Bedrock	T, B	76-100%	$$$	M	Permanent armor solution w/o rocks	Requires large amount of soil/fill
Riprap with Live Stakes	2.5 - 10.1	2:1	Bedrock	T, B	26-50%	$$	H	structural flexibility	Requires large machinery

[1]T = Toe/Splash Zone, B= Bank, C = Channel, and U = Upland Area.

[2]Cost is relative cost for the conceptual designs; $ is lowest cost option(s) to $$$ is the highest cost option(s).

[3]Strength is the relative strength of the practice to resist erosive flows (L= relatively low resistance, M = medium resistance, and H = high resistance).

APPENDIX A: STAKEHOLDER WORKSHOP TECHNICAL MEMORANDUM

TECHNICAL MEMORANDUM

To: Tracy Halstensgard, Administrator
Roseau River Watershed District

From: Drew Kessler, PhD. and Lori Han, PhD.
Houston Engineering, Inc.

CC: Jerry Bents, PE
Houston Engineering, Inc.

Subject: Hay Creek Stakeholder Meeting Summary February 13, 2020

Date: 02-28-20

Project: 5468-0008

PURPOSE OF EVENT

As part of an ongoing assessment of Hay Creek subwatershed, the Roseau River Watershed District asked Houston Engineering, Inc. and the Minnesota Agricultural Water Resource Center to support a stakeholder meeting with landowners in the Hay Creek subwatershed of the Roseau River Watershed. The goal of the meeting was to get insights on stakeholder's perspectives of:

- Issues affecting resources in the subwatershed
- Goals for managing the watershed
- Actions that could be taken to achieve goals
- Interest in staying engaged

Feedback was gathered through tabletop maps (**Exhibit A**) of the subwatershed where attendees could provide feedback and a survey (**Exhibit B**).

STAKEHOLDER RESULTS

This section summarizes the feedback from the stakeholder meeting. The first section provides a summary of key points from the tabletop map exercise where attendees could provide feedback on locations for management opportunities. The full maps are provided in **Exhibit A.**

MAP

During the meeting, we provided tabletop maps of Hay Creek subwatershed where stakeholders could provide feedback on areas where there were opportunities for management. Scanned copies of the maps are provided in the appendices. A broad array of comments and concerns were noted on the maps, however the follow themes reoccurred during the discussions.

- Storage water and reduce runoff volume, peak, and flashiness from state land on the upper end of the subwatershed

- Inadequate drainage system performance and maintenance.
- Norland impoundment operation, drawdown, and outlet channel adequacy.
- Increased flooding near outlet confluence of Hay Creek, Roseau River, and east side diversion.
- Channel and bridge erosion
- Verify watershed boundary to account for additional breakout flows that come into the Hay Creek subwatershed

SURVEY RESPONSES

We present the survey responses for each question. The tables document the number of stakeholders who responded with that answer. We highlighted responses anytime five or more responses showed agreement.

ISSUES

The stakeholder feedback on Issues within Hay Creek subwatershed is presented in **Table 1**. Bank erosion, water quantity impacts on land productivity and water quality, and flooding ranked the highest. Most of respondents indicated that flooding was an issue in the subwatershed.

Table 1. Stakeholder feedback on issues in the Hay Creek subwatershed.

Issues	Very Low	Low	Medium	High	Very High
Bank erosion impacts on drainage	0	2	2	**5**	**6**
Poor water quality	0	5	2	**6**	2
Diminished wildlife and aquatic habitat	2	3	**6**	3	1
Water quantity impacts on land productivity and water quality	0	0	3	**7**	**5**
Flooding	0	1	1	3	**11**

GOALS

We show the stakeholder feedback on goals within Hay Creek subwatershed in **Table 2**. Managing flow into the drainage system, maintaining drainage benefits, and keeping agricultural lands productive were the top ranked goals.

Table 2. Stakeholder feedback on goals for the Hay Creek subwatershed.

Goals	Very Low	Low	Medium	High	Very High
Manage flow into the system	0	0	1	**9**	**6**
Maintain drainage benefits	0	0	2	**8**	**6**
Improve water quality	0	1	**5**	**7**	3
Reduce future costs	0	0	**6**	**6**	3
Enhance habitat	1	2	**8**	2	2
Keep agricultural lands productive	0	0	1	**5**	**10**

ACTIONS

Stakeholders ranked many of the actions with High to Medium ratings. Grade control, Drainage water management, conservation tillage, residue management, and cover crops received the highest rankings.

Conservation Practice	Very Low	Low	Medium	High	Very High	Cost Share (Count Yes)
Grade control	0	1	3	**7**	2	**5**
Side water inlets	0	1	**6**	3	3	**6**
Exclusion fencing	1	3	**8**	1	0	2
Riparian corridor establishment	0	1	**8**	4	1	2
Drainage water management	0	0	**5**	**7**	4	4
Sediment control basins	0	0	**8**	4	2	3
Conservation tillage	0	0	3	**8**	3	4
Residue management	0	1	2	**9**	2	4
Cover Crops	0	1	**6**	**5**	2	**5**

NEXT STEP RECOMMENDATIONS

The results of the stakeholder engagement event suggest that there is interest among attending landowners in pursuing management opportunities within the subwatershed. We recommend that the Roseau River Watershed District consider completing the following steps based upon this feedback

1) Accelerated implementation Grant (Current Scope) – This assessment will focus on on-field (i.e., field management) and edge-of-field (i.e., structural) practices
   a) Complete a targeted implementation plan using these results as a guide for plan development
   b) Get stakeholder feedback on the targeted plan
   c) Pursue resources to implement targeted plan (assuming stakeholder buy in)
   d) Implement management solutions for Hay Creek Subwatershed

2) Local drainage and flooding issues (Future work) – Establish subwatershed project team to review and evaluate alternatives to address Public Infrastructure Improvements or Modifications
   a) Storage water and reduce runoff volume, peak, and flashiness from state land on the upper end of the subwatershed
   b) Inadequate drainage system performance and maintenance.
   c) Norland impoundment operation, drawdown, and outlet channel adequacy.
   d) Increased flooding near outlet confluence of Hay Creek, Roseau River, and east side diversion

EXHIBIT A: SURVEY USED TO GET FEEDBACK FROM STAKEHOLDERS

Farmer and Landowner Survey for Hay Creek

Please place an X for each of the following **issues** based on their importance to you:

Issue	Very Low	Low	Medium	High	Very High
Bank erosion impacts on drainage benefits					
Poor water quality					
Diminished wildlife and aquatic habitat					
Water quantity impacts on land productivity and water quality					
Flooding					

Please place an X for each of the following **goals** based on their importance to you:

Goals	Very Low	Low	Medium	High	Very High
Manage flow into the system					
Maintain drainage benefits					
Improve water quality					
Reduce future costs					
Enhance habitat					
Keep agricultural lands productive					

Please provide feedback on the possibility of implementing conservation from the list of voluntary best management practices below.

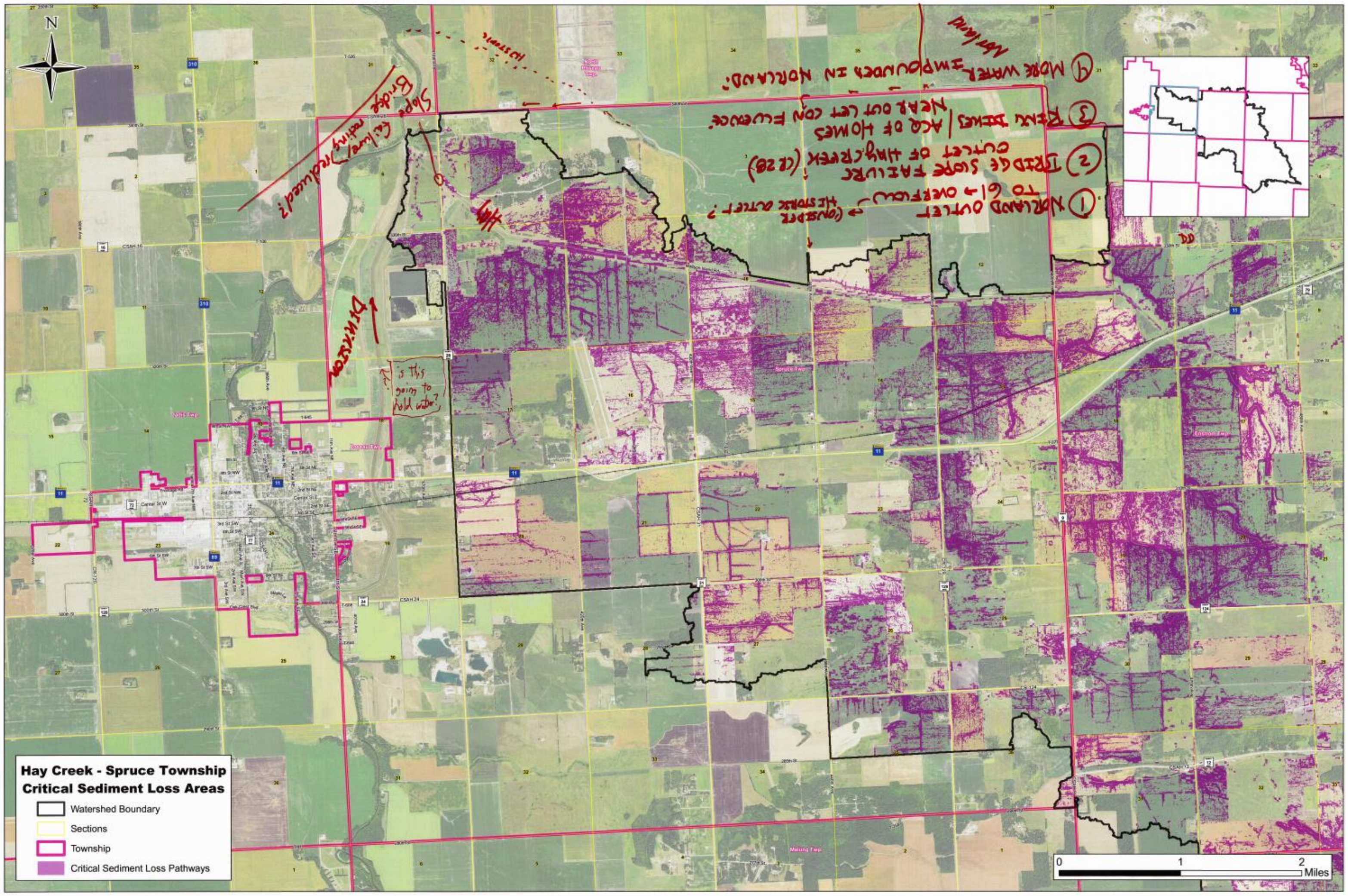
Best Management Practice	Likelihood that You Would Implement					Cost-Share Needed	
	Very Low	Low	Medium	High	Very High	Yes	No
Structural							
Grade control							
Side water inlets							
Exclusion fencing							
Riparian Corridor Establishment							
Drainage water management							
Sediment control basins							
Field Management							
Conservation tillage							
Residue management							
Cover crops							

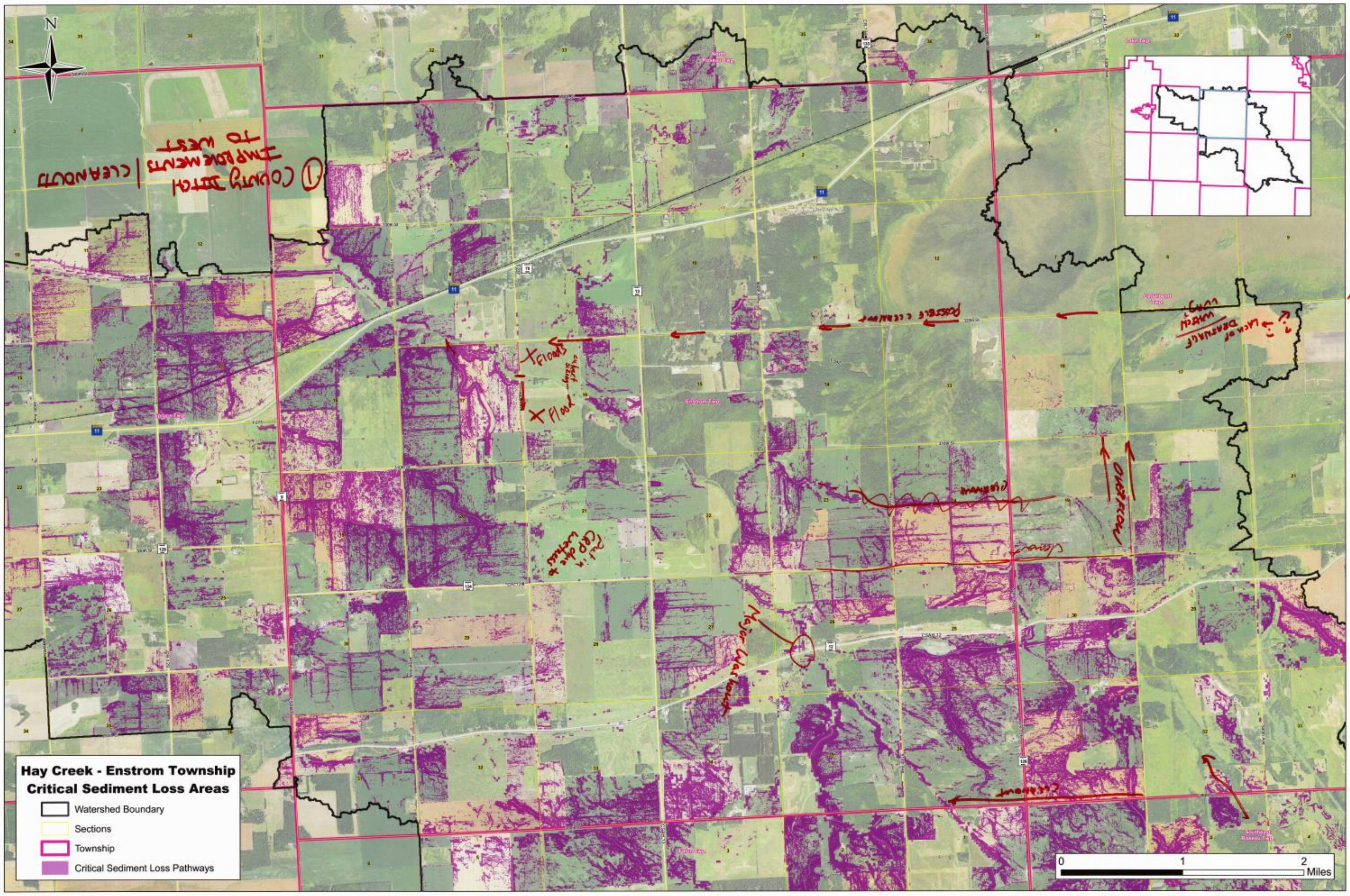
Are you willing to attend future meetings to provide additional input on the management of Hay Creek? (circle one)

Yes No

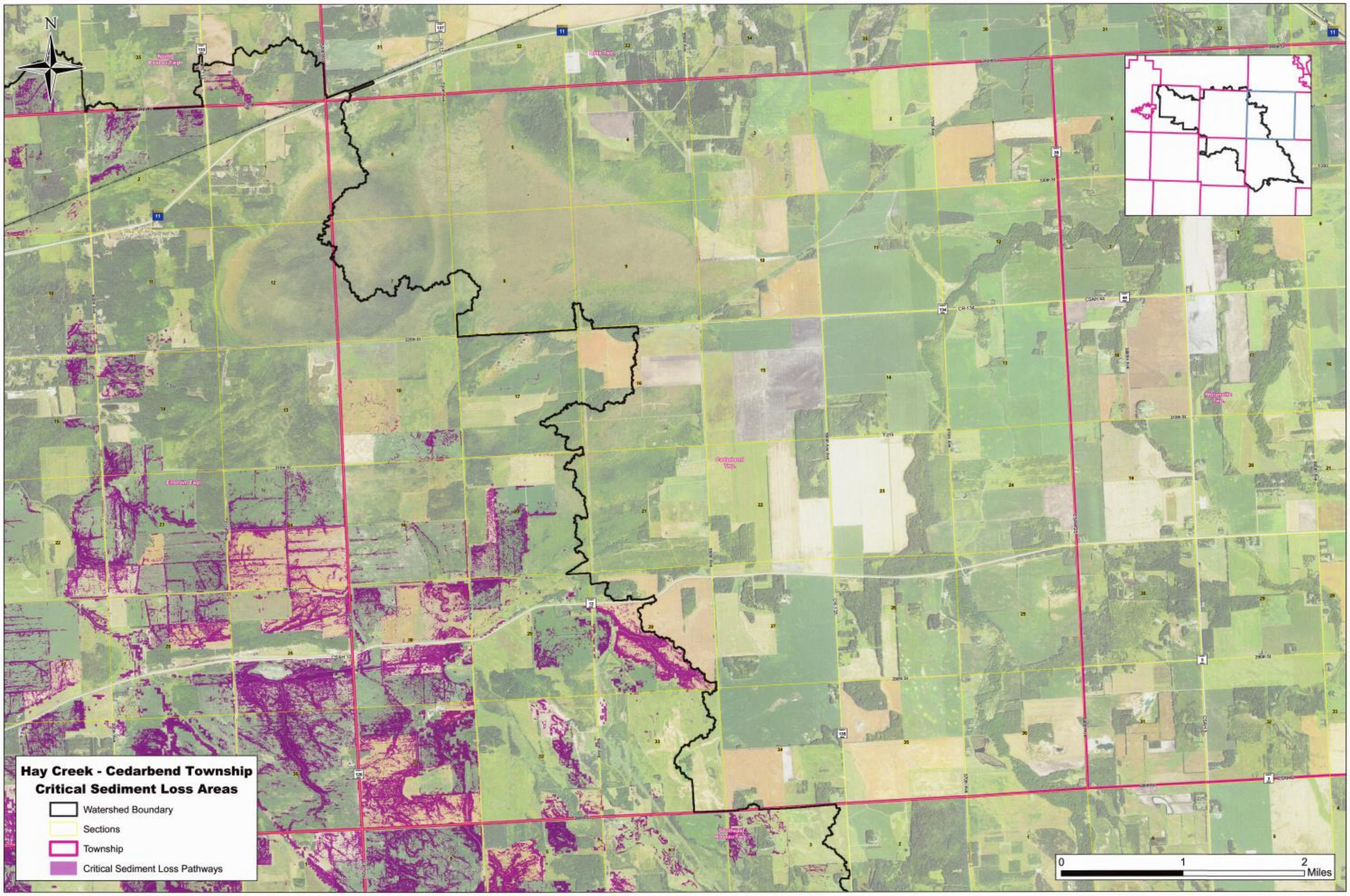
If yes, please provide your contact information:	
Name:	
Phone:	
Address:	
Email:	

EXHIBIT B: MAPS OF HAY CREEK SUBWATERSHED WITH STAKEHOLDER INPUT

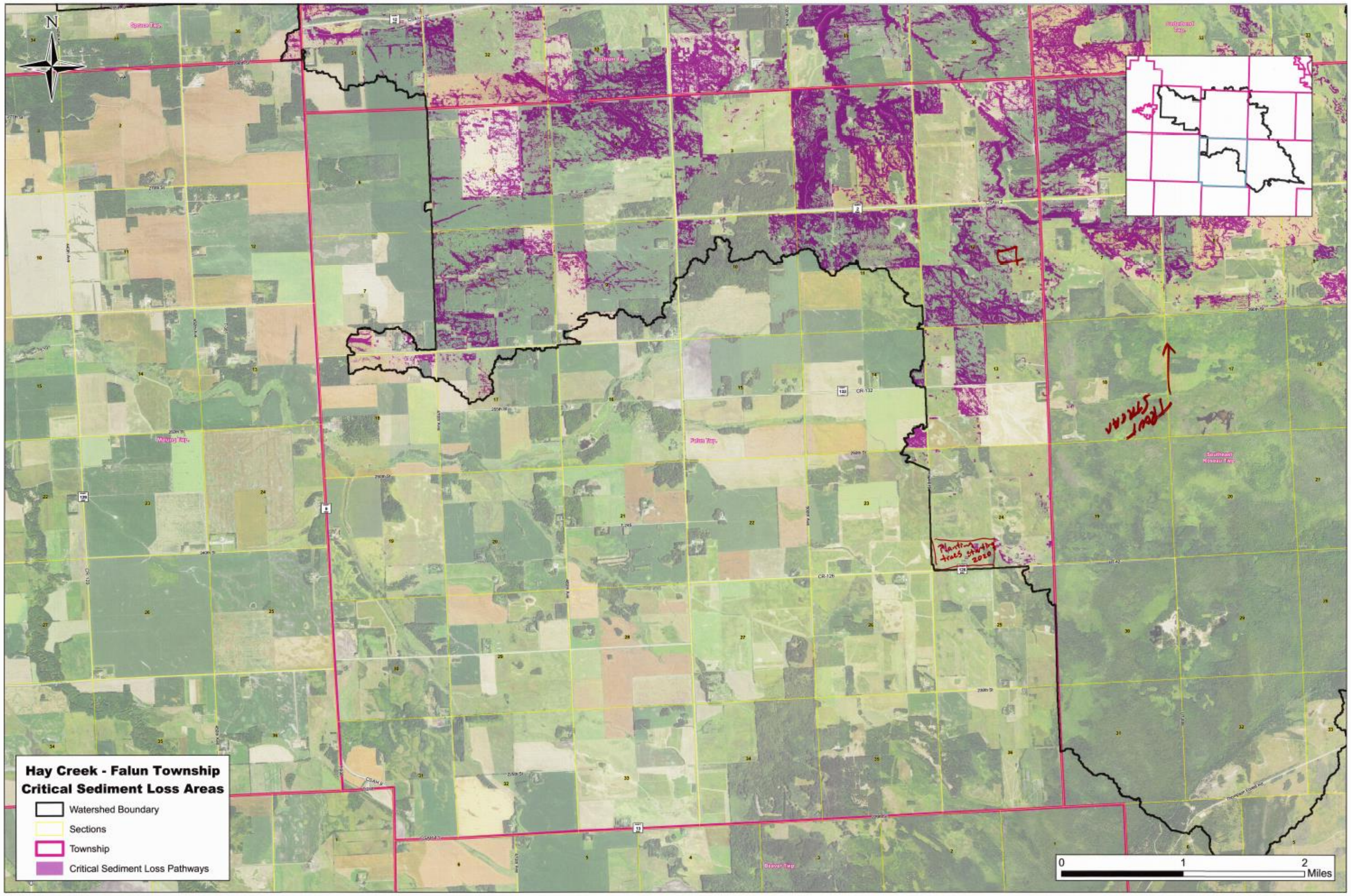


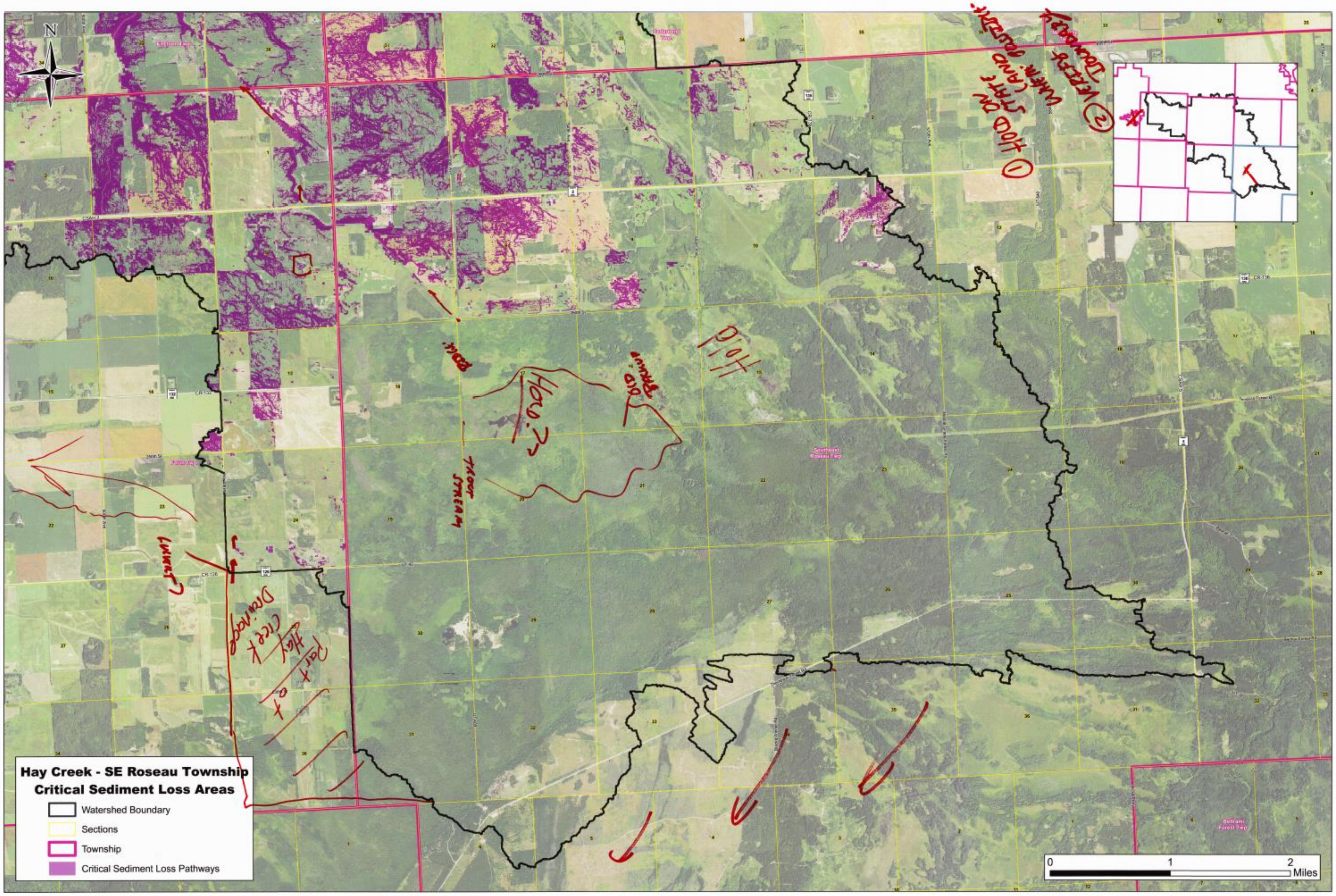


Hay Creek - Enstrom Township
Critical Sediment Loss Areas
Watershed Boundary
Sections
Township
Critical Sediment Loss Pathways
0
1
2
Miles
N



N
Hay Creek - Cedarbend Township
Critical Sediment Loss Areas
Watershed Boundary
Sections
Township
Critical Sediment Loss Pathways
0
1
2
Miles


N
Hay Creek - Falun Township
Critical Sediment Loss Areas
Watershed Boundary
Sections
Township
Critical Sediment Loss Pathways
0
1
2
Miles
Trout Stream
Planting trees started 2020


Hay Creek - SE Roseau Township
Critical Sediment Loss Areas
Watershed Boundary
Sections
Township
Critical Sediment Loss Pathways
0
1
2
Miles
N

TECHNICAL MEMORANDUM

PURPOSE

"Altered hydrology" has become a buzzword used to describe watersheds in Minnesota that contain unstable streams and rivers that are impacted by climate and land use changes. These impacts can result in increased sediment and nutrient transport, unstable river banks, and decreases in the quality of aquatic habitat. However, water management practitioners often lack methods of targeting solutions for managing "altered hydrology" in rural agricultural areas.

The purpose of this technical memorandum (TM) is to describe the technical methods used to estimate the "altered hydrology" benefits of targeted conservation practices. The goal of this TM is to establish a process that can be used across Minnesota to estimate the progress of specific conservation efforts towards "altered hydrology" goals. This TM will be used, in part, to define the methods that will support targeting practices. This TM will be used to get feedback from technical experts on the suitability of the approach for achieving the goals and objectives of the study.

METHODS

In the developed modeling framework, a concept of a cascaded catchment-based flow drainage network is proposed, which describes an essential property of watershed configuration, i.e., hydrologic connectivity of catchments. The proposed cascaded flow drainage network is used in a hydrologic simulation to guide how water flows and accumulates across a watershed in a hydrologic simulation. The Clark Unit Hydrograph method is applied to translate and attenuate precipitation excess for the catchments throughout the watershed.

This framework is meant to provide an easily replicable method for estimating progress towards altered hydrology goals from specific conservation efforts. This method will take place not just at the practice, but also at downstream waterbodies.

A CASCADED CATCHMENT-BASED FLOW DRAINAGE NETWORK

A watershed can be delineated into a number of catchments based on different criteria. **Figure 1** shows major components of the catchment configuration, i.e., catchments, catchment Pour Points (e.g., C1), and Priority Resource Points (e.g., PRP-1). Catchment is the basic calculation unit in the Prioritize, Target, and Measure Application (PTMApp) - Desktop toolbar. A number of datasets used in this analysis are derived from the PTMApp-Desktop toolbar. Documentation on the methods used to derive these datasets can be found at http://ptmapp.rrbdin.org/User/Documentation. Each catchment has one Pour Point, through which water transfers from this catchment to its downstream catchment (**Figure 1**). For example, catchment C1, C2, and C4 drains water to downstream catchment C3 (**Figure 1**), and catchment C5 is the downstream catchment of catchment C3.

The framework automatically delineates a cascaded catchment-based flow drainage network. This process is achieved by two steps: (1) identifying downstream catchment of each catchment by tracking the flow direction of its catchment Pour Point grid and checking the catchment IDs of the surrounding grids, and (2) a searching loop process to sort all catchments based on their contributing relationships. This cascaded catchment-based flow drainage network is a list of unique catchment identifiers (catchment ID) with contributing relationship from upstream catchments to downstream catchments built in. In the hydrologic routing process, the flow hydrograph is transferred from upstream to downstream by following the sequence of the catchment IDs in the cascaded drainage system. The generated drainage network guides how water flows and accumulates throughout the watershed in the hydrologic routing process.

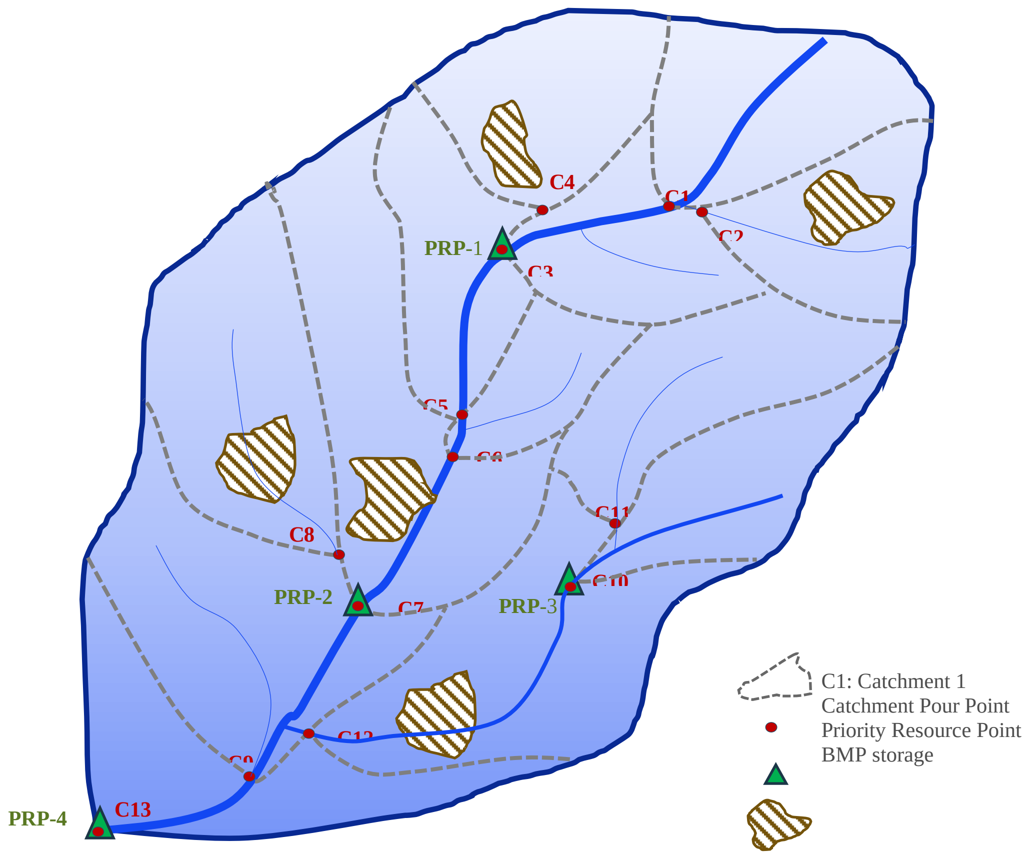


Figure 1. Catchment configuration.

DEVELOPING & ROUTING HYDROGRAPHS

In general, flow routing considers two components: convection, commonly referred to as translation, and diffusion, referred to as attenuation. In watershed hydrologic routing, convection and diffusion are about equally important, and they are often accounted for separately. In this study, the Clark Unit Hydrograph method is applied to route the discrete, time-area-derived, unit-runoff hyetograph through a linear reservoir model.

The modeling framework includes four successive steps: (1) loss and precipitation excess simulation using the Soil Conservation Service (SCS) Curve Number (CN) method for all catchments, (2) time-area hydrograph simulation based on the calculated precipitation excess and time-area histograms for all catchments, (3) convection simulation by transferring time-area hydrographs from upstream catchments to downstream catchments based on the cascaded flow drainage network using the continuity equation and lag model, and (4) diffusion simulation using the linear reservoir method for the drainage area upstream of each Priority Resource Point. **Figure 2** shows the flow chart of the hydrologic routing methodology.

LOSS AND PRECIPITATION EXCESS SIMULATION

SCS CN loss model was applied to estimate the precipitation excess as a function of cumulative precipitation and CN. CN is determined using land use and soil data.

$$Pe = \frac{(P - I_a)^2}{P - I_a + S}$$

$$S = \frac{1000 - 10CN}{CN}$$

$$I_a = 0.2S$$

where *Pe* = accumulated precipitation excess at time *t*; *P* = accumulated precipitation depth at time *t*; I_a = initial abstraction; and *S* = potential maximum retention.

The incremental precipitation excess at a time interval is computed as the difference between the accumulated rain excess at the end of and the beginning of the period. The calculated precipitation excess time series data is used for the hydrologic routing.

LOCAL CATCHMENT TIME-AREA HYDROGRAPH SIMULATION

The time-area method is based on the concept of time-area histogram. A time-area histogram is developed by dividing each catchment into a number of equal time interval zones based on the time of concentration grids. The travel time for a zone refers to the time that it would take a parcel of water to travel from that zone to the catchment Pour Point. Travel times are estimated through the PTMApp-Desktop toolbar.

The time-area method transforms an effective storm hyetograph into a time-area runoff hydrograph (**Figure 2**). The rationale of the time-area method is that, according to the runoff concentration principle, the partial flow at the end of each time interval is equal to the product of precipitation excess times the contributing watershed subarea (Ponce 1989). The lagging and summation of the partial flows results in a runoff hydrograph for the given time-area histogram and effective storm hyetograph. The time interval of the effective storm hyetograph must be the same as the time interval of the time-area histogram. The time-area hydrograph simulation is conducted for all catchments of a watershed (**Figure 2**).

FLOW CONVECTION SIMULATION FOR DOWNSTREAM CATCHMENTS

A lag model is used to account for the convection of the hydrograph between upstream catchments and downstream catchments. The continuity equation is applied to combine the local catchment hydrograph and lagged hydrographs from upstream contributing catchments. The lag time applied to each upstream catchment hydrograph is determined by calculating the amount of time it takes from this upstream catchment Pour Point (e.g., C1) to the downstream catchment Pour Point (e.g., C3) (see **Figure 1**).

$$Q^{t}_{Convection-i} = Q^{t}_{Time\_area-i} + \sum_{j=1}^{N} Q_j^{t-tlag\_j}$$

where $Q_{Convection-i}$ = calculated time-area hydrograph for catchment *i*; Q_{Time_area-i} = time-area hydrograph from catchment *i*; *N* = the number of catchments contributing water to catchment *i*; and *tlag-j* = lag time from Pour Point of upstream catchment *j* to Pour Point of catchment *i*.

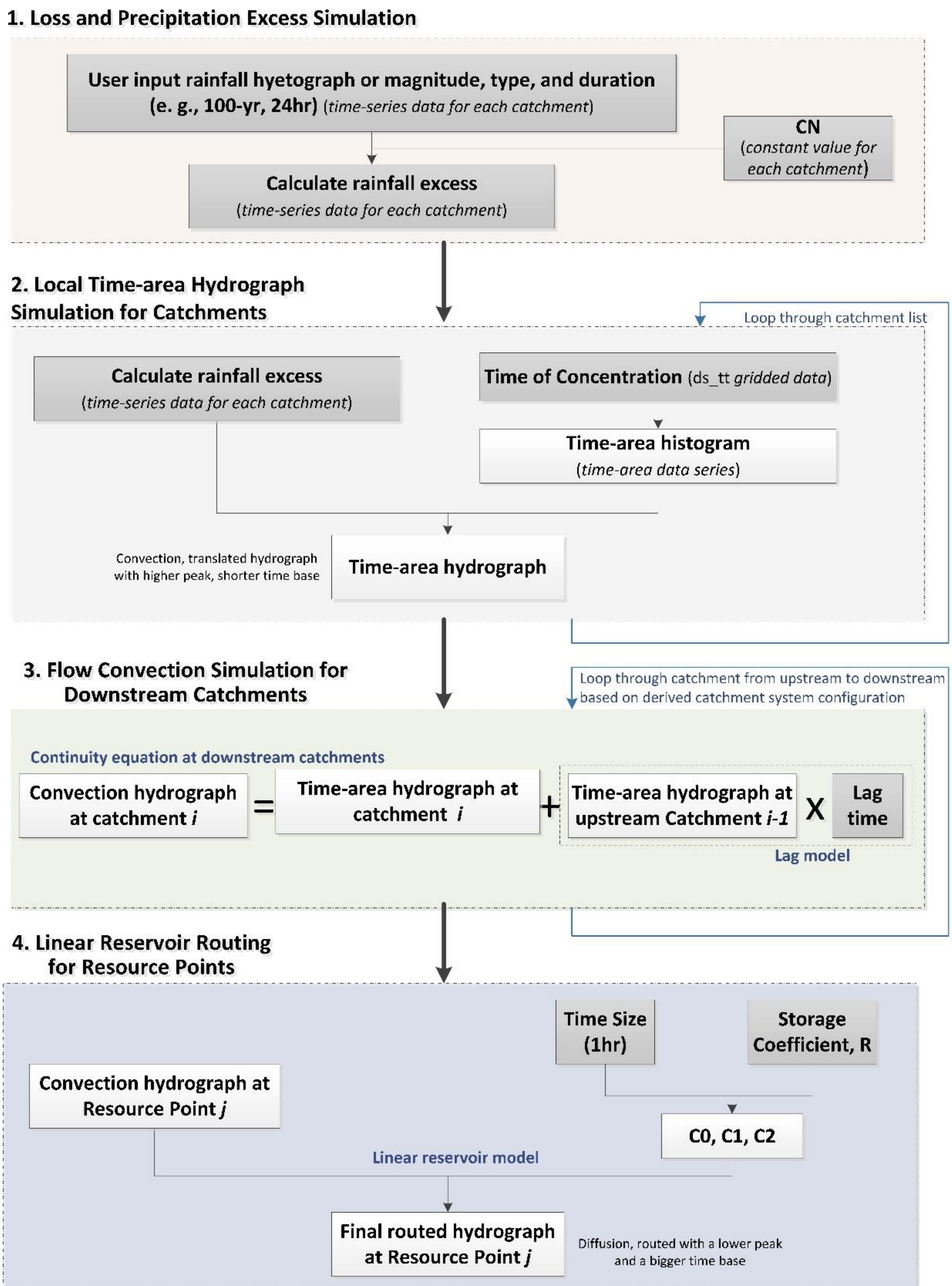


Figure 2. Framework of PTMApp hydrologic routing model.

LINEAR RESERVOIR ROUTING FOR PRIORITY RESOURCE POINTS

A linear reservoir model is used to simulate the flow hydrograph attenuation for the drainage area of Priority Resource Points. For example, the drainage area of Priority Resource Point 2 (PRP-2) includes catchments C5, C6, and C7 (**Figure 1**).

Attenuation of flow is simulated using a simple, linear reservoir model, in which storage is related to outflow as:

$$S = RO$$

Where *S* is watershed storage, *O* is the outflow from the watershed, and *R* is Watershed Storage Coefficient. The Watershed Storage Coefficient of the linear reservoir model is determined empirically in such a way as to provide the hydrograph diffusion that is necessary to simulate a realistic unit hydrograph.

The Watershed Storage Coefficient was normally used as calibration parameters for historical storm events. Due to the lack of the empirical equations from the study area, a regression equation from the Red River Basin of the North (Houston Engineering, Inc., 2011) was used in this study to calculate Watershed Storage Coefficient.

$$R / Tc = 0.1875 + 0.0721X_1 + 0.1801X_2$$

Where *Tc* is the time of concentration for the drainage area upstream of the Priority Resource Points, X_1 and X_2 are the percentages of wetlands and lake areas, respectively, upstream of the Priority Resource Points.

The linear reservoir model is then combined with the continuity equation and solved using a finite difference approximation to yield:

$$O_t = C_A I_t + C_B O_{t-1}$$

Where C_A, C_B = routing coefficients.

$$C_A = \frac{\Delta t}{R + 0.5\Delta t}$$

$$C_B = 1 - C_A$$

The average outflow during period *t* is:

$$\overline{O_t} = \frac{O_{t-1} + O_t}{2}$$

TARGETING CONSERVATION PRACTICES

There are numerous processes that can be used to account for changes in downstream hydrographs as a result of upstream conservation practices. **Figure 3** provides a conceptual overview of the process that can be accounted for when estimating the impacts of upstream conservation practices on downstream hydrographs. For the initial development of this framework, there were two processes used: Water Reaching the Land Surface – Infiltration, and Water Reaching Structural Practices – Live Storage (see **Figure 3**). The manner in which these two processes were applied for this initial development are described below. The vision for this framework is to continue to adapt additional processes and to account for continuous simulation, as opposed to just event-based simulation.

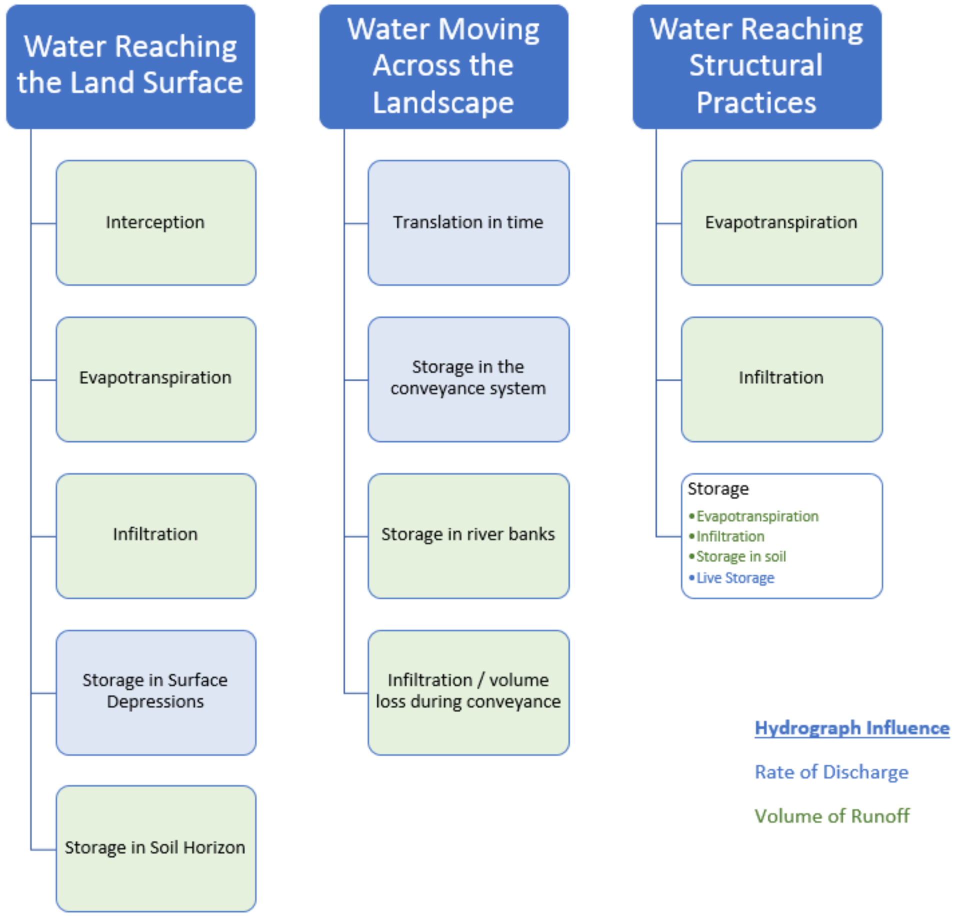


Figure 3. Range of methods available to estimate the impacts of upstream conservation practices on downstream hydrographs.

WATER REACHING THE LAND SURFACE - INFILTRATION

To account for the changes in infiltration on water reaching the land surface that result from the implementation of conservation practices, the curve number value is adjusted based upon the curve number look up table used in generating PTMApp-Desktop inputs (see http://ptmapp.rrbdin.org/User/Documentation).

Curve number values from the targeted practices are integrated into the existing condition curve number values. This integration process is an area-weighted average method taking the curve number values from the existing condition, the targeted practices (within that catchment) and their spatially covered areas into account.

The adjusted curve numbers for catchments are calculated based on the following procedures:

- Determine the majority soil group that is covered by each individual targeted practice and generate the recommended curve number grids of all targeted practices based on their majority soil groups using **Table 1**.
- Merge curve number grids for all targeted practices to generate overall curve number grids for the practices. If targeted practices overlap with each other, take the minimum curve number grids among them.
- Mosaic the generated curve number grids for the targeted practices to the existing condition curve number grids, which produces the adjusted curve number grids.
- Use the adjusted curve number grids to calculate the mean curve number values within each catchment, which will be used to represent the “altered” or “improved” hydrologic conditions with the implemented practices.

As these methods are developed, users will be able to adjust the curve number values based upon local knowledge. The adjusted curve number will be used to calculate loss and precipitation excess simulation, to update the simulated hydrographs, and evaluate the benefits from targeted practices.

Table 1 shows the recommended curve number value for specific practices within PTMApp treatment groups. These recommendations were applied based upon the primary land cover type associated with the NRCS practice type described in the field office technical guide for that practice and the hydric soil type identified in the SSURGO soils data. This list is not meant to be exhaustive, but rather a starting point for the purposes of developing this methodology.

Table 1. Recommend curve number values for practices that provide water infiltration based upon NRCS technical guide landcover and SSURGO soils hydric soil group.

Hydric Soil Group	2 - Filtration (327, 412, 390)	3 - Biofiltration (390, 393)	4 - infiltration (585)	5 - protection (342)	6 - source reduction (345, 329)
A	30	30	62	30	30
A/D	30	30	62	30	30
B	58	58	71	58	58
B/D	58	58	71	58	58
C	71	71	78	71	71
C/D	71	71	78	71	71
D	78	78	81	78	78

WATER REACHING STRUCTURAL PRACTICES – LIVE STORAGE

Water and sediment control basins are modeled as typical storage practices. The designed storage practice outlet includes an embankment, a principle outlet structure, and a secondary spillway structure. The hydrologic routing for the storage practices is accomplished in a few steps: (1) delineate the geometric properties of the storage practices, i.e., elevation-storage curves, (2) calculate the elevation-discharge curves for the storage practices based on the designed practice outlet structures and elevation-storage curves, and (3) using the Modified Puls Routing Algorithm in the hydrologic routing to simulate the outflow hydrograph for each storage practice.

1) Elevation-storage curves for the storage practices

A GIS tool with an iterative process is developed to delineate the elevation-storage curve from the bottom of the storage practice to an elevation that is high enough to account for the live storage with varying depth of water over the hydraulic structures. The drainage areas of the storage practices are used as boundaries to derive the elevation-storage curves.

Hydrologic routing for the storage practices is conducted for live storage only. Dead storage of a storage practice is considered as a 10-year sediment volume, which is estimated using the PTMApp products. These data are obtained from the attribute table of BMP products (see http://ptmapp.rrbdin.org/User/Documentation).
Dead storages for all storage practices are removed from their elevation-volume curves.

2) Elevation-discharge curves for the storage practices

Pipes are often used as outlet structures for the typical storage practices. A 24-inch corrugated metal pipe is used as the principal outlet structure of the designed storage practice. The invert of the principal outlet structure is set 0.5 foot above the elevation needed to store sediment volume for a 10-year event (i.e., dead storage). The parameters for the principal outlet structure in the hydrologic routing script include: pipe diameter, pipe length, Manning's n, and slope.

For partially full flow condition (**Figure 4**), manning's equation is used to calculate the flow through the principal pipe structure.

$$\theta = 2\cos^{-1}(1 - 2\frac{h}{D})$$

$$A = \frac{D^2}{8}(\theta - \sin\theta)$$

$$P = \frac{D}{2}\theta$$

$$R = \frac{A}{P} = \frac{D}{4}\frac{(\theta - \sin\theta)}{\theta}$$

$$Q_{Pipe} = \frac{k}{n}AR^{\frac{2}{3}}S^{\frac{1}{2}}$$

Where θ = the angle subtended by the free surface at the center of the pipe, h = flow depth (ft), D = pipe diameter (ft), A = pipe flow area (ft^2), P = wetted perimeter(ft), k = 1.49, n = manning's coefficient, R = hydraulic radius (ft), S = pipe slope, and Q_{Pipe} = discharge from principal outlet structure (cfs).

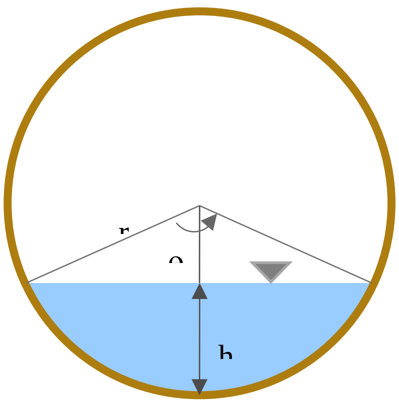


Figure 4. Partially full pipe flow parameters.

For the full flow condition, Bernoulli and continuity equations can be used to derive pipe flow equation (NRCS, 1984).

$$Q_{Pipe} = A\,(\frac{2gH}{1 + K_m + K_p PL})^{0.5}$$

$$K_p = \frac{5087n^2}{D^{\frac{4}{3}}}$$

Where A = Pipe cross sectional area (ft^2), g = acceleration of gravity (ft/s^2), H = elevation head differential (ft), km = coefficient of minor losses, Kp = pipe friction coefficient, and PL = pipe length (ft).

Rectangular, broad-crested weir is used for the secondary spillway. The invert of the spillway weir is set two feet below the dam embankment crest elevation and the embankment crest height is determined by searching an inflection point on the elevation-volume curve for storage practices.

With some sensitivity analysis, the maximum average of the secondary derivatives of the elevation-volume curve with an increase in the elevation is selected as a critical variable to determine the inflection points. This process is automated with the python script. The default minimum of the embankment crest height is set to 6, and maximum height is set to 15 feet above the invert of primary structure (NRCS, Conservation Practice job Sheet 638) in the hydrologic routing scripting. There is also an option for users to determine the inflection points i.e., the top of embankment, by reviewing the elevation-storage curves. The width of the spillway weir is set to 50 ft.

The discharge over the broad-crested weir is determined using the following equation (Brater and King, 1976).

$$Q_{Weir} = C_W WL(2gh)^{\frac{3}{2}}$$

Where Q_{Weir} = discharge from the secondary structure (cfs), *Cw* = dimensionless weir discharge coefficient, *WL* = effective spillway weir length (ft), and *h* = water depth above the crest (ft).

The total combined discharge (Q_{total}) from the principal outlet structure and secondary spillway structure can be calculated as:

$$Q_{Total} = Q_{Weir} + Q_{Pipe}$$

3) Modified Puls hydrologic routing for the storage practices

Modified Puls (i.e., level-pool) routing method is used to simulate outflow hydrograph from storage practices with horizontal water surface, given its inflow hydrograph and storage-outflow relationship. This method is based upon a finite difference approximation of the continuity equation, coupled with an empirical representation of the momentum equation (Henderson, 1966).

$$\frac{dS}{dt} = I(t) - Q(t)$$

$$\int_{S_j}^{S_{j+1}} dS = \int_{j\Delta t}^{(j+1)\Delta t} Idt - \int_{j\Delta t}^{(j+1)\Delta t} Qdt$$

$$\frac{S_{j+1} - S_j}{\Delta t} = \frac{I_{j+1} + I_j}{2} - \frac{Q_{j+1} + Q_j}{2}$$

$$\frac{2S_{j+1}}{\Delta t} + Q_{j+1} = I_{j+1} + I_j + \frac{2S_j}{\Delta t} - Q_j$$

Where *I* = the inflow hydrograph (cfs), *S* = the storage (ft^3), and *Q* = the outflow (cfs), Δt = the simulation time step (hr), and *j* and *j+1* = time step *j* and *j+1*.

In the hydrologic routing process, the routed hydrographs using the Clark method serve as the inflow hydrographs for the storage practices. The following steps show how the Modified Puls method is implemented in the hydrologic routing script:

a) Develop outflow *Q* versus *Q+2S/Δt* relationship using the stage-volume-discharge relationship from the storage practices
b) Compute *Q+2S/Δt* at time step *j+1* using the inflow *I* at time steps *j and j+1*, storage *Sj* at time step *j*, and outflow Q_j at time step *j* :

$$\frac{2S_{j+1}}{\Delta t} + Q_{j+1} = I_{j+1} + I_j + \frac{2S_j}{\Delta t} - Q_j$$

c) Use the relationship developed in step (a) to calculate outflow discharge *Q* at time step *j+1*

INPUTS AND OUTPUTS FOR PTMAPP HYDROLOGIC ROUTING

The model input data includes basic simulation parameters, rainfall depth and distributions, PTMApp products, and targeted BMP practices. A geographic information systems (GIS) toolbar is developed to generate the input files for the hydrologic routing based on PTMApp products and user inputs.

The PTMApp hydrologic routing outputs include the following:

1) Catchment configuration (i.e., catchment-based cascaded flow drainage network)
2) Linear Reservoir Routing parameters for the Priority Resource Points
3) Loss and precipitation excess for all catchments
4) Time-area histogram for all catchments
5) Stage-volume-discharge curves for the designed storage practices
6) Routed hydrographs for the storage practices, catchments, and Priority Resource Points.
7) Mass balance for precipitation, loss, storage practices, and outflow for all catchments and whole watershed.

ACKNOWLEDGEMENTS

Houston Engineering, Inc would like to acknowledge the investment of the Minnesota Soybean Research and Promotion Council (MSR&PC). MSR&PC provided the funding that was needed to develop the technical approach for estimating the hydrology benefits of targeted conservation practices. This investment will empower conservation professionals to target conservation for both water quality and water quantity benefits.

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Technical Memorandum

INTRODUCTION

PROJECT BACKGROUND

This technical memorandum outlines the methodology of a bank erosion assessment developed by Houston Engineering, Inc. Work from this assessment will aid in targeting locations for best management practices (BMP), both in-channel and upstream, that ensure the geomorphic stability of the waterways and serve to further inform development of restoration and protection strategies and targeting of on-the-ground projects utilizing the PTMApp. The on-the-ground projects and practices targeted through this project will result in measurable local water quality improvements to waterbodies, regional benefits downstream, and state/international benefits for waters along state or national boundaries.

METHODS FOR GEOMORPHIC ASSESSMENT

A geospatial analysis was conducted to identify and target banks susceptible to erosion along with recommending in-channel and upland practices to improve geomorphic stability of streams/waterways within the District. The technique was designed to leverage PTMApp data as the inputs for calculations (**Table 1**). From these inputs, several geoprocessing operations were executed to create a host of intermediate data resulting in two final feature classes including, a file focused on riverbanks and a file focused on the riparian corridor.

The basic methodology is as follows:

1. Generate stream centerlines and select reaches for analysis
2. Generate banks and riparian corridors for selected streams
3. Calculating attributes for stream banks and riparian corridors
4. Applying a criteria to identify potential bank susceptibility to erosion and management actions

Inputs	Application	Data Origin
Roads Layer	Flag banks where attribute calculations (e.g. bank height) may be influenced by the presence of roads	MN DOT
Wall Lines	If the Digital Elevation Model (DEM) used in PTMApp was modified to increase elevations within the river corridor, remove they areas for the assessment where elevations were modified.	User Input to create PTMApp Fill DEM

Fill DEM / Raw DEM	Derive Banks, Attribute Calculations	PTMApp\MN DNR
Slope Raster	Attribute Calculation	PTMApp
10-year 24-hour discharge Raster	Attribute Calculation	PTMApp
SPI Rank Raster	Attribute Calculation	PTMApp
Surface Flow Accumulation	Used to derive waterways, Attribute Calculation	PTMApp
SSURGO Surface Texture	Attribute Calculation	SSURGO
SSURGO K Factor	Attribute Calculation	PTMApp\SSURGO
PTMApp BMP Feature Classes	Attribute Calculation	PTMApp

Table 1: A list of the base inputs needed for the GIS-based analysis.

Generating Banks and Riparian Corridors

Once the reaches are selected (project specific methodology), stream banks were identified by analyzing the DEM for variations in slope. These areas were then further filtered to eliminate small, errant, polygons (**Figure 1A**).

Next, the stream reaches were segmented on an equal interval and a buffer placed around the stream reach. This buffered area serves multiple purposes.

1. It is a final filter to eliminate any remaining "false-bank" delineation that does not fall within a specified range from the stream centerline.
2. It creates a Riparian Corridor (RC) (**Figure 1B**) which has the primary purpose analyzing statistics for reach segments.
3. The buffer is also split by the stream reach line to identify the left and right sides of the Riparian Corridor in order to calculate statistics which are not inform for the segment as a whole (**Figure 1C**). This layer of analysis will be referred to as the Split Riparian Corridor (SRC). The SRC serves as the primary spatial file for displaying management recommendations.

Since stream widths and riparian corridors are not uniform, a representative number had to be assigned to each reach based on sample widths. The goal was to minimize as many exterior, non-riparian related influences as possible while still capturing the waterway system as a whole.

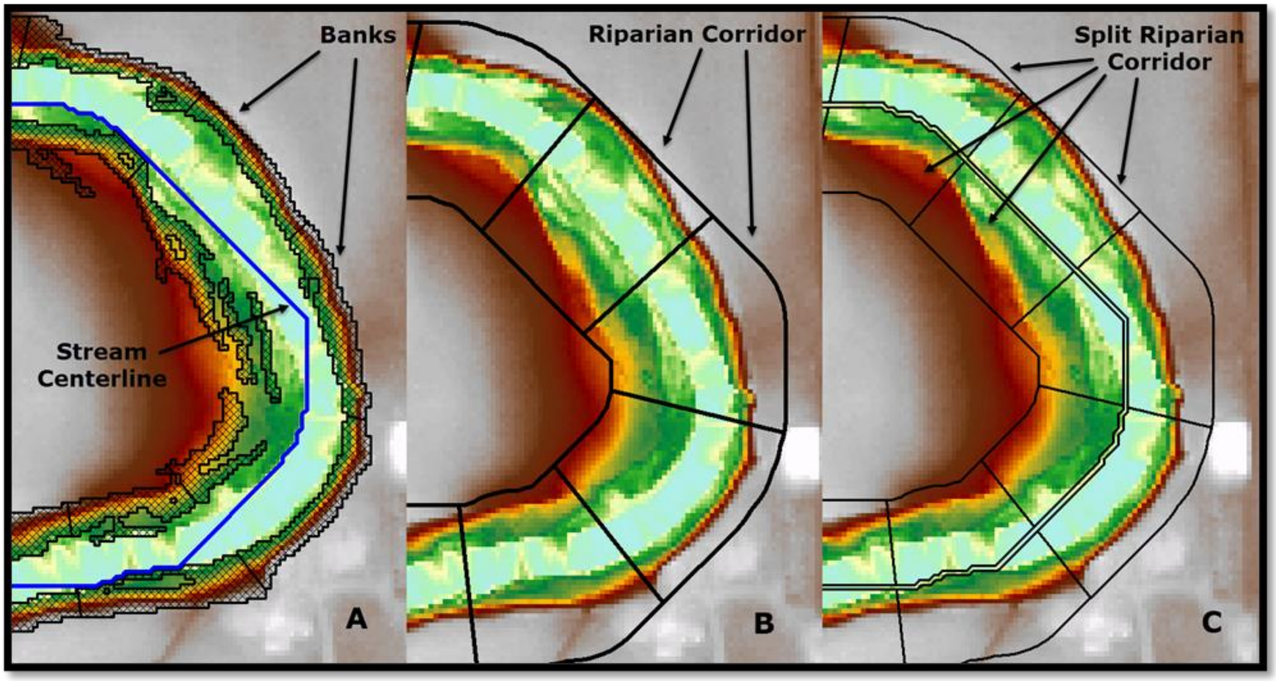

Figure 1: A) Banks delineated from LiDAR analysis. B) Riparian corridors which represents stream reach segments for analysis. C) Split riparian corridors which isolate left and right sides of each stream reach segment for individualized analysis of each side of the corridor.

Calculating Attributes

This section describes the calculations that were applied to the generated Banks, RCs, and SRCs for each reach. These calculations serve as the basis for identifying bank susceptibility to erosion, recommending in-channel and upland practices to improve geomorphic stability of waterways, and supplying additional information (e.g. PTMApp identified practices falling within riparian corridors).

Zonal Statistic Calculations

"Zonal Statistics" is a GIS method where statistical information can be pulled from a raster dataset for defined zones. In the case of this study the defined zones are the Banks, RCs, SRCs for each reach (**Figure 2**). **Table 2** summarizes the study-specific use of this operation.

Table 2. Information pulled from GIS data to evaluate riparian corridors and river banks.

Input Raster	Zones of Interest	Statistic Pulled	Purpose
SPI Ranks	SRC	Maximum	Identify areas with high SPIs
K Factor	SRC, Banks	Mean	Determine Soil Erodibility Factor
Slope	Banks	Mean	Identify banks with high slopes
DEM	Banks	Range	Identify bank heights
10-year 24-hour discharge	RC associated with SRC and Banks	Maximum	Identify segments of a given reach with the highest discharges

Soil Texture	SRC associated with Banks	Mean	(Sediment discharge Calculation)

Sinuosity Calculation

Sinuosity was calculated for every stream segment using a sinuosity ratio which is as follows:

$$Sinuosity\ Ratio = \frac{Stream\ line\ distance\ for\ each\ segement\ of\ stream}{Straight\ line\ distance\ between\ upstream\ and\ downstream\ points\ of\ the\ segment}$$

Due to the inherent jaggedness of the streamlines generated from a raster, a smoothing technique was applied to the data to create more accurate results. The sinuosity ratio attribute was joined with both the Banks and SRCs.

Spatial Proximity Calculations

Bank height and Bank slope are two of the metrics used to evaluate bank stability in this study. Therefore, it is important to try to eliminate or account for as many non-bank features that will display characteristics (e.g. large slopes) as possible. Roadways often display high slopes and are falsely delineated in the GIS environment as fitting the criteria for a bank. On top of this, they are often the highest feature on the landscape in the study area. Consequently, these roadways will influence slope and bank height calculations. To account for this, a road centerline was added and buffered by 65ft. Any banks intersecting this buffer were flagged with a “1”. This attribute serves to note that calculations in these areas may be influenced by the presence of the road.
To further the utility of both PTMApp generated data and data from this analysis’s outputs, the SRCs also queried PTMApp identified BMP opportunities to see if they intersected. Attributes were added with six fields (one for each BMP type) to the SRC, and assigned a “1” if the BMP is present.

Bend Modeling

Channel geometry can also be an indicator of banks that may be susceptible to erosion due to the distribution of velocities around channel bends. Generally, highest velocities are observed in the thalweg (deepest part) of the channel which corresponds with the outer bends of a channel. Conversely, slowest velocities and deposition is associated with inside bends (**Figure 2**). In order, to identify these areas in a GIS environment, a series of geoprocessing operations was executed based on centerline/bank relationships.

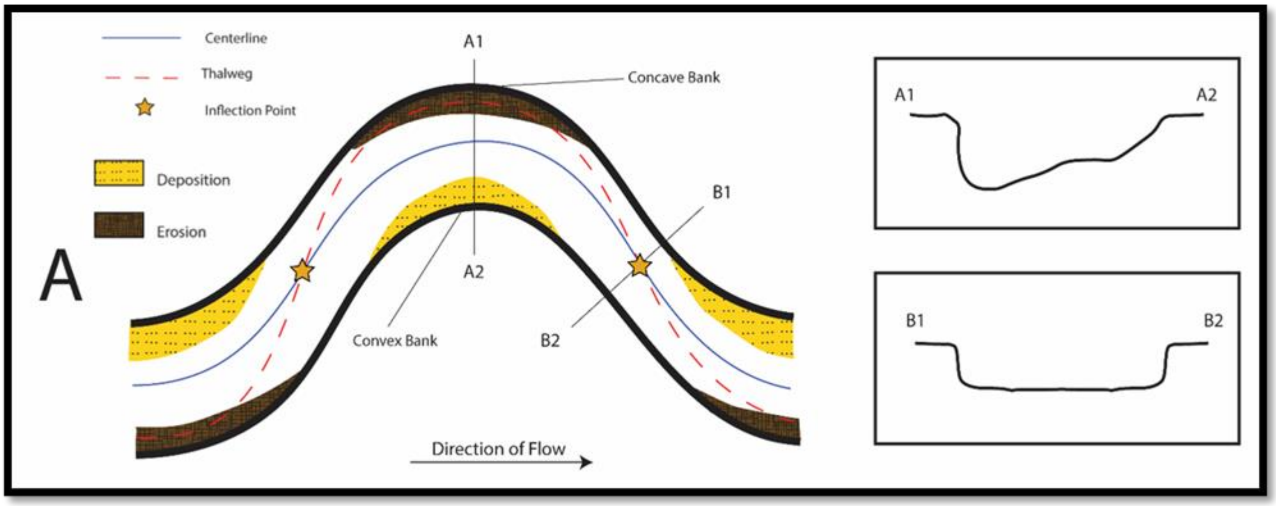

Figure 2: Depicts a simplistic example of a meander with erosion concentrated on the outer (concave) bank and deposition occurring on the inside (convex) bank. On the right, cross sections of pool associated with a bend (A1 to A2) and riffle associated with a straight section of channel (B1 to B2) are displayed.

Sediment Discharge Calculation

Sediment discharge (Q_S) was calculated for each Riparian Corridor using the following equation (Ponce, n.d.):

$$Q_S = 58.7\ k_1\ \gamma\ Q_W\ S_o\ (R/d_S)^{1/3}$$

where k_1 = sediment transport parameter, γ = unit weight of water (62.7 pounds/ft^3), Q_w = water discharge (ft^3/second), S_o = bottom slope , R = hydraulic radius (ft), and d_s = particle size (ft).

The sediment transport parameter (k_1) is to be determined by calibration with the recommendation from the experience of the author ranging from 0.001 and 0.01. For this study, the median/mean value of 0.0055 was used.

The value for water discharge (Q_W) was determined by querying the maximum value of the 10-yr 24-hour event raster created in PTMApp (PeakQ_10yr) for each RC.

No data was available for bottom slope (S_o). Therefore, two different methods were implemented to serve as a proxy for this variable using the equation:

$$\text{Slope} = \frac{Y2-Y1\ (\text{Rise})}{X2-X1\ (\text{Run})}$$

where Rise (Y2-Y1) = The elevation change between the upstream and downstream point of the segment analyzed and Run (X2 – X1) = the length of the stream centerline for the respective segment. The first method used the respective stream segment line (Run) to return a slope based off the LiDAR values of the water surface elevation (Rise). However, due to erroneous measurements associated with the processing of water surfaces, it is tough to obtain reliable relief change in such short distances. Subsequently, a second method was used where the minimum upstream elevation value was subtracted from the minimum downstream elevation value for the entire reach (Rise). This was then divided by the steam length of the reach (Run) to obtain a reach slope and assigned as a constant for all stream corridor segments for the reach. Both methods were applied to the equation and the latter method for stream slope was determined to better maintain the integrity of the overall results for sediment discharge equation.

Hydraulic Radius (R) was calculated following a method developed in Minnesota Department of Natural Resource's Travel Time Tool (MNDNR, 2011). It is as follows:

$$(X)a + Y$$

where X = hydraulic radius factor 1 (default value used 0.0032), a = drainage area is square miles (calculated from the flow accumulation), and Y = hydraulic radius factor 2 (default value used 1.7288). The maximum hydraulic radius value was then queried for each corridor and assigned to variable R in the equation.

Particle size (d_s) was estimated using surface texture data from the NRCS SSURGO database. **Table 3** shows the NRCS defined textures along with assigned D_{50} in millimeters (mm). The value input into the equation queried the mean particle size for every section of the split riparian corridor and converted the measurement from mm to feet (ft).

Soil Texture Class	D_{50} (mm)
Bouldery loamy coarse sand	0.18 [a]
Clay	0.023 [b]
Clay loam	0.018 [b]
Coarse sandy loam	0.16 [b]
Extremely gravelly loamy coarse sand	0.2 [a]
Fine sand	0.16 [b]
Fine sandy loam	0.08 [b]
Loam	0.035 [b]
Loamy coarse sand	0.18 [b]
Loamy fine sand	0.12 [b]
Loamy sand	0.135 [b]
Moderately decomposed plant material	0.023 [a]
Muck	0.023 [a & c]
Mucky peat	0.023 [a & c]
Mucky silt loam	0.027 [a & c]
Mucky silty clay loam	0.025 [a & c]
Sand	0.17 [b]
Sandy clay loam	0.019 [b]
Sandy loam	0.098 [b]
Silt loam	0.027 [b]
Silty clay	0.024 [b]
Silty clay loam	0.025 [b]
Very fine sandy loam	0.035 [b]
(blank)	0.023 [a]

[a] Extrapolated from other data point and surrounding soil types in the spatial data
[b] source: Muñoz-Carpena and Parsons, 2000
[c] HMGA Water Project (2015)

Table 3: Values used to for estimated particle size (d_s) in sediment discharge equation.

Criteria to Identify Potential High-Risk Banks and Management Practices

Once all the data was calculated, several different combinations of criteria were applied to distinguish recommended management actions. With the resolution of data available, it was determined that the most reliable results could be obtained from Sinuosity, Sediment Discharge Rating (Q_s), SPI Ranks and Bank Erosion Risk (**Table 4**).

Management Action	Sinuosity	Sediment Discharge Rating (Q_s)	SPI Ranks	Bank Erosion Risk
Restore Channel	<= 1.20 value	x	x	x
Runoff Reduction	x	>= 85^{th} percentile	x	x
Protect Overland Flow	x	x	>=0.98 percentile	x
Stabilize Bank	x	x	x	>=2.5 value = high >=1.5 & < 2.5 = medium

Table 4: Criteria for determining recommended management actions for each reach.

A potential "restore" management action was marked on the RCs if had a sinuosity close to 1 (meaning relatively straight). This approach was chosen because there are general a lack of reference reaches in highly altered landscapes. Distinctions are also able to be made, by clustering of RCs that fall within the same management action recommendation. For instance, if five stream segments in a row have a restore channel management action recommendation, it is more compelling that channel restoration may be warranted as compared to an instance where only one segment has a restore channel recommendation.

A potential "runoff reduction" management action was marked based on the top 15% of RCPs with the greatest sediment discharge rating. These areas are potential targets for reducing upstream runoff through BMP practices (e.g. storage) that will reduce peak flows.

A potential "protect overland flow" management action was marked if a stream power index percentile greater than 0.98 (top 2%, based on PTMApp raster) was present in any given RCP. These areas rate high for near channel erosive flows which may cause overland erosion and potential gully formation into the river system. Practices such as grade stabilization and side water inlets are examples of management actions that could be taken to protect overland flow.

Finally, potential bank stabilization opportunities were characterized by querying average bank slopes and bank heights. Average bank slope is a more "stable" metric to use for identifying bank stabilization opportunities opposed to bank height. This is because non-bank features (e.g. roads) that get delineated as banks become averaged out with the rest of the bank slopes, whereas these same non-bank delineated features often set the upper limit for the range of elevation values which becomes the banks height.

Generally speaking, high average bank slopes are a proxy for stream banks with high potential for failure while high bank heights indicate potential magnitude of sediment delivered from a failure. When the two metrics are applied in tandem priority banks can be established. **Table 5** summarizes the criteria applied. It is important to recognize that there are a multitude of forces (e.g., freeze/thaw processes, seepage, piping, undercutting) that can cause a stream bank to fail. Most of these forces cannot be captured in the methods applied in this study, which is why slope and bank height are being used as qualitative indicators of areas where stream banks are likely at the greatest risk of failure.

Bank Stabilization Ranking	Average Bank Slope (Failure)	Bank Height (Magnitude)
High	>= 90th percentile	>= 90th percentile
Medium High	>= 90th percentile	80th -90th percentile
	80th -90th percentile	>= 90th percentile
Moderate	80th -90th percentile	80th -90th percentile
Low	< 80th percentile	< 80th percentile

Table 5: Criteria for determining recommend bank stabilization opportunities for each reach.

When percentiles were calculated for slope and bank height, they did not include any measurements from banks flagged for their proximity to roads. This filter was applied to keep the data from getting skewed by non-bank features. However, the percentiles were applied to all banks and subcategories were made for any banks in the moderate to high ranking which were near roads. This sub-category serves two purposes.
1) It may be a false-positive due to road features
2) It may be a top priority bank to focus on from both an economic and safety reasons as a means to protect transportation infrastructure.

A second scoring system was applied with a broader criterion as well. The values assigned individually to bank slopes and bank heights are shown in **Table 6**.

Percentile	Score
>= 90th percentile	3
80th -90th percentile	2
70th -80th percentile	1
50th -70th percentile	0.5
< 50th percentile	0

Table 6: Values assigned to bank slopes and bank heights.

Next, a weight factor was assigned to the data based on the bend geometry **(Table 7)**.

Bank Weight	Weight
Outer Bend/Straight	1
Associated with Inner-Bend	0.8
Inner-Bend	0.5

Table 7: Weighting factors assigned based upon bend geometry.

For every reach, the data was displayed spatially to ensure geometry distinctions were able to be captured. If it was not, weights were set to “1” for the category in order to make sure “false-weights” weren’t being applied. **Figure 3** shows how the data looks spatially.

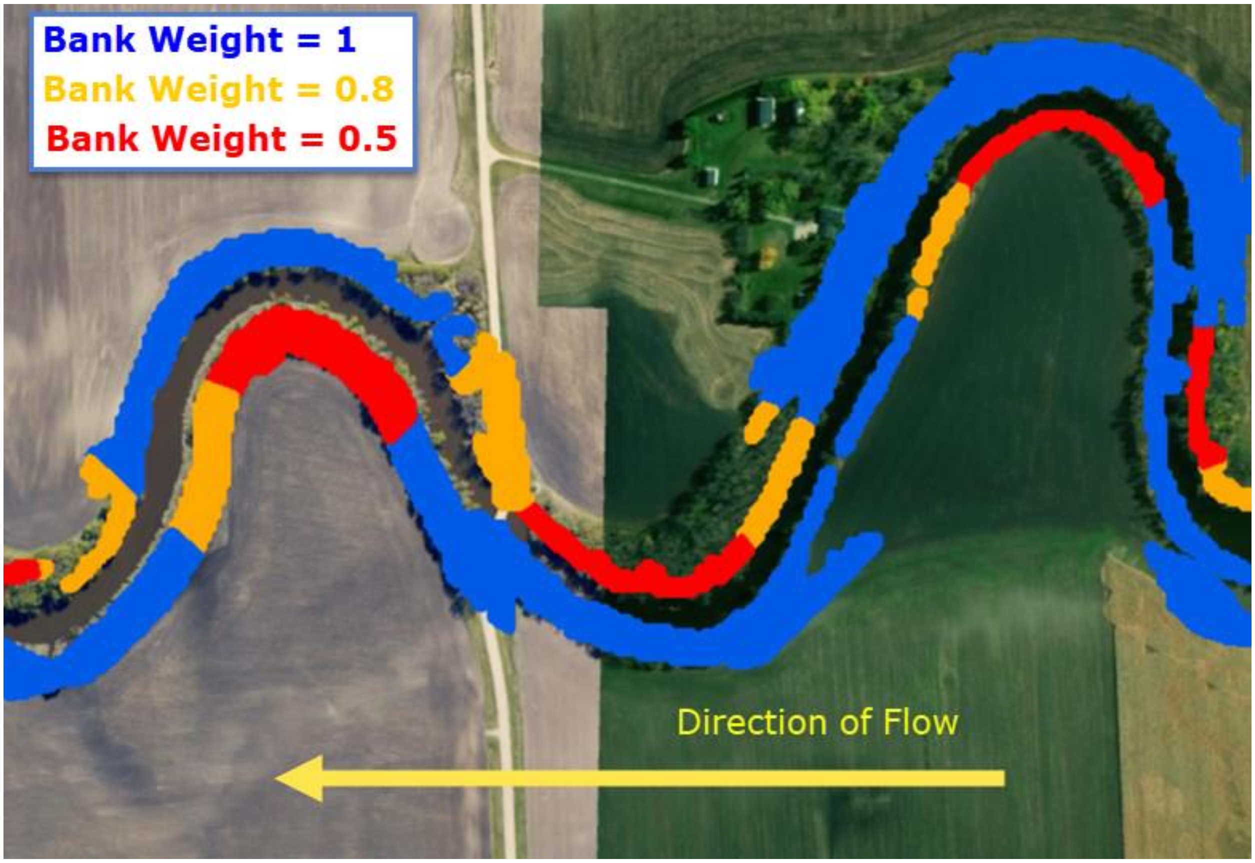

Figure 3: Banks weighting classification based on channel geometry.

Next, a ranking was calculated as follows:

*(Bank Slope Score + Bank Height Score) * Bank Weight = Final Score*

Lastly, banks with a final score =/> 2.5 are high priority stabilization banks and >1.5 but <2.5 are medium priority stabilization banks.

EVALUATION OF DATA QUALITY

Sediment Discharge

The rate of sediment discharge was also estimated from the Hydrologic-Simulation Program Fortran (HSPF) model for the Buffalo-Red River Watershed. This data was used to compare with the estimates of sediment discharge calculated in this study using Lane's relationship.

RESULTS

TARGETING BANK EROSION IN A GEOSPATIAL ENVIRONMENT

When interpreting the results, it is important to remember that the selection for potential management practices are based on the statistics of the reach itself (except "Protect Overland"). This type of approach can focus prioritization efforts for reaches with known issues as well as provide an overview to begin to understand reaches which may not have prior data and studies completed. The geospatial methods outline here could then be used to further target management actions within stream reaches that are producing the most sediment. Although the framework for the results is qualitative, it is driven by quantitative calculations. This enables the data to be easily queried or manipulated as more insight is gained on reaches.

It is important to note that SRCs marked for potential restoration need to be interpreted based on certain limitations of the method. The RCs length is based off ~100-meter intervals used to intersect the waterway centerline for sinuosity calculations. Depending on the characteristics of the system, groupings of Restore RCs may be the best indicator for restoration sites since a single 100-meter straight stretch of a waterway can be natural. Occasionally, bends in a waterway appear as having low sinuosity if they are split into two sections along the curve of the bend. Although, this is not common it is a limitation that needs to be noted since it can occur.

EVALUATION OF DATA QUALITY

Sediment Discharge

The results of the Lane's Relationship calculations for sediment discharge were compared with HSPF modeling data. HSPF data was selected as opposed to monitoring data as monitoring data generally does not collect sediment discharge samples during peak flow conditions. Two values were compared from HSPF, DEPSCR (which is daily bed/bank deposition/scour; label value) and ROSED (total daily sediment load; symbolized value). Daily values were converted to lbs/sec and would be for the 10-year event. Looking at the middle section, the average is similar to the HSPF bed/bank scour results (7 lbs/sec (HSPF) versus 10 lbs/sec (Lane's)). The differences with upstream and downstream ends are a little greater (~1 lbs/sec (HSPF) versus ~11 lbs/sec (Lane's)).

The evaluation of sediment discharge data quality suggests that the GIS based sediment discharge estimates provide a reasonable planning approach for understanding how much sediment streams in the Hay Creek Subwatershed transport during design storm events (i.e., 10-year, 24-hour event).

CONCLUSIONS

The results of this assessment show that multiple areas of within highly altered landscapes have streams that carry a large amount of in-channel derived sediment, and that geospatial analysis techniques can be used to guide efforts to target management actions that increase the geomorphic stability of streams. As a result, several potential management actions that could be undertaken within these reaches to increase the geomorphic stability of in-channel sources of sediment.

These data from this technical memorandum will be to develop a targeted approach in increase in-channel geomorphic stability and treating sources of overland sediment, TP, and total nitrogen by developing a targeted implementation. Eventually, this targeted implementation plan can be used to support the development of a One Watershed, One Plan and implementing BMPs within the watershed.

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