Maple Grove, MN | HEI No. 6286-0008
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WARROAD RIVER WATERSHED STORAGE IDENTIFICATION & EVALUATION

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1 INTRODUCTION

In 2012, the Warroad River Watershed District (WRWD) began working with Houston Engineering, Inc. (HEI) on a Warroad River watershed sediment source assessment project, funded by a Minnesota Board of Water and Soil Resources (BWSR) Accelerated Implementation Grant (AIG). The project included:

- the development of a hydrologically corrected digital elevation model (DEM) for the watershed;
- an analysis and estimate of the annual amount of overland sediment, total phosphorus (TP), and total nitrogen (TN) leaving the landscape and being transported to the Warroad River harbor; and
- an analysis and estimate of annual total sediment deposition to the harbor.

Completed in 2013, the project results also included mapping of recommended priority management areas for targeting sediment loss on the landscape. This targeting was based on the Revised Universal Soil Loss Equation (RUSLE) sediment yields and the Stream Power Index (SPI) values for targeting gully erosion (HEI, 2013).

Sediment that is deposited in the harbor comes from one of two places:

1. It is either eroded from overland sources, washed into the river, and transported to the harbor or;
2. It comes from the river bottom and its banks via in-channel erosion and is transported to the harbor.

While the 2012 AIG study focused on estimating overland sediment sources and total sediment delivered to the harbor, it did not identify in-channel contributions. In 2016 the WRWD received an additional AIG to study in-channel sediment loading and its contribution to the harbor. The results of this study filled in the missing “in-channel erosion” piece of the river sediment mass balance.

<u>River Sediment Mass Balance</u>

Overland Sediment + In-Channel Erosion = Harbor Sediment Deposition

The study also identified key sections of the river system that should be targeted for bank stabilization and restoration in order to reduce sediment to the harbor and provided cost-benefit analysis for sediment reduction (HEI, 2019).

In 2017, the WRWD began collaborating with Roseau and Lake of the Woods counties and their respective Soil and Water Conservation Districts (SWCD) to develop the Lake of the Woods Watershed (LOWW) Comprehensive Plan. This was undertaken as part of the BWSR One Watershed, One Plan (1W1P) program (LOWW 1W1P Planning Group, 2019). The LOWW Comprehensive Plan was completed and approved by BWSR in 2019. Included in the implementation section of the plan are actions related to hydrologic analysis, hydrologic and hydraulic modeling, and analysis of critical project areas, peak flows, flow duration, and flood risk (Action DM-10, pg. 4-57, LOWW 1W1P Planning Group, 2019). One of the focus areas for these actions includes the Warroad River headwaters. The intent of these actions is to identify future projects for implementing water retention in the headwaters, thus reducing peak flows, flow duration, flooding, and sediment transport within the lower reach of the Warroad River and ultimately reducing sedimentation to the Warroad Harbor.

In 2019, the Warroad River Watershed District submitted a request for funding to implement action DM-10 for the Warroad River Planning Region (LOWW 1W1P Planning Group, 2019). This report and its accompanying project portfolios are the result of the implementation of this action.

2 PROJECT GOALS & TECHNICAL OBJECTIVES

A key initial step in a project is to develop project goals and technical objectives, based on the project purpose and stakeholder input. The following sections outline the project goals and technical objectives, as determined through this meeting.

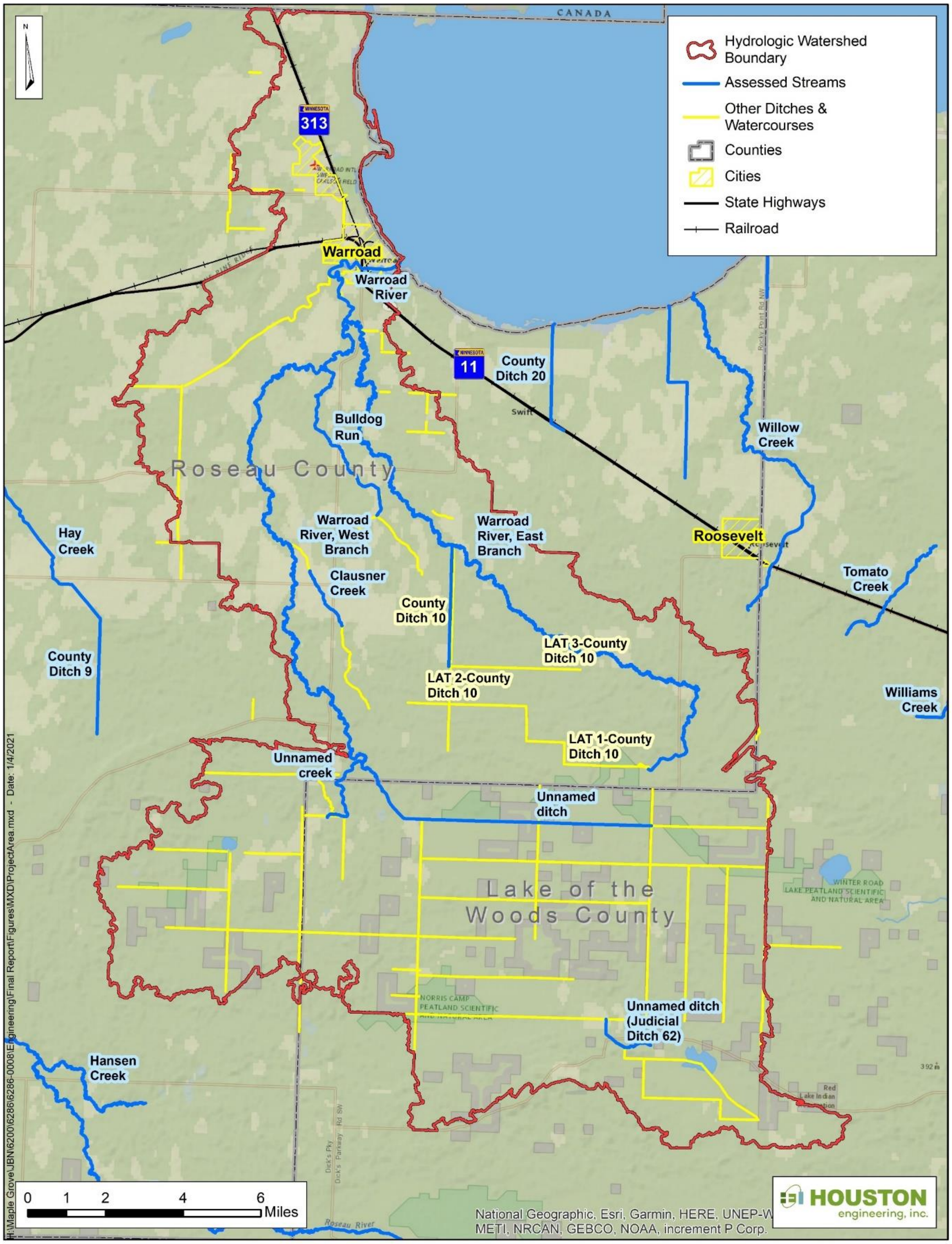
2.1 PROJECT GOALS

Project goals are established at the beginning of a project to ensure that all the stakeholders involved understand and agree with the desired outcome of the project. A narrative project goal describes the desired outcomes for a project. A concept or design alternative, developed as part of the project, must be able to attain the project goal to be considered feasible.

The goal of this project is to identify and evaluate potential water retention project alternatives within the upstream watersheds of the east and west branches of the Warroad River and County Ditch 10 (CD 10). The evaluation of the alternatives should focus the reduction of downstream erosive peak flows and sediment transport to not only reduce in-channel sediment transport to the Warroad Harbor, but also to further protect future in-channel stream restoration projects by reducing peak flows within the systems.

The project area is shown in **Figure 1**.

Figure 1. Project area.



2.2 TECHNICAL OBJECTIVES

Technical objectives are established as a series of criteria needed to obtain the project goal(s). One or more technical objectives are needed to support the project goal(s). Technical objectives are specific, measurable, actionable, realistic, and time-bound conditions that are established and used to accomplish the goal(s).

The technical objectives for this project are:

1. Gather appropriate data and previous model(s) to be expanded, modified, and used for analysis of the project concepts;
2. Use stakeholder engagement to help gather initial information, identify potential project locations, assist with future stewardship, and participate in the development of the potential project concepts;
3. Develop goal-driven metrics that can be used to evaluate the costs and benefits of the potential project concepts; and
4. Utilize the model(s) to evaluate metrics for all project concepts and present them for future planning efforts and project development.

3 PROJECT PLAN

On July 22, 2020, HEI convened a project input meeting with various stakeholders knowledgeable about the types of water retention project alternatives that are feasible, likely, or most beneficial within the watershed. The meeting included stakeholders from:

- Lake of the Woods and Roseau counties and their respective Soil and Water Conservation Districts (SWCDs);
- WRWD; and
- State agencies including the Minnesota Department of Natural Resource (MnDNR) and the Board of Water and Soil Resources (BWSR).

The meeting included discussion of the Warroad River watershed history and the existing tools available for analysis. The majority of the meeting was spent having a roundtable discussion about nuances of the watershed and its hydrology/hydraulics, what types of storage projects are feasible, locations of potential storage projects, and the various processes required to implement them (i.e., political implications, permitting, coordination, land procurement, etc.).

The project plan largely follows the technical objectives of the project. The following project plan was developed:

1. Utilize existing data to modify the original Hydrologic Engineering Center River Analysis System (HEC-RAS) model to meet the project evaluation needs for the east and west branches of the Warroad River and County Ditch 10 (CD10).
2. Verify the existing condition model to use as a baseline for comparison when evaluating project alternatives.
3. Determine what types of project alternatives will be considered and develop a methodology for how to simulate these alternatives in modeling scenarios.
4. Develop a set of metrics to evaluate the project alternatives versus the project goal(s).

5. Evaluate the project alternatives using the metrics and develop project portfolios that summarize the metric results.
6. Make recommendations for pursuing project alternatives that meet the project goals.

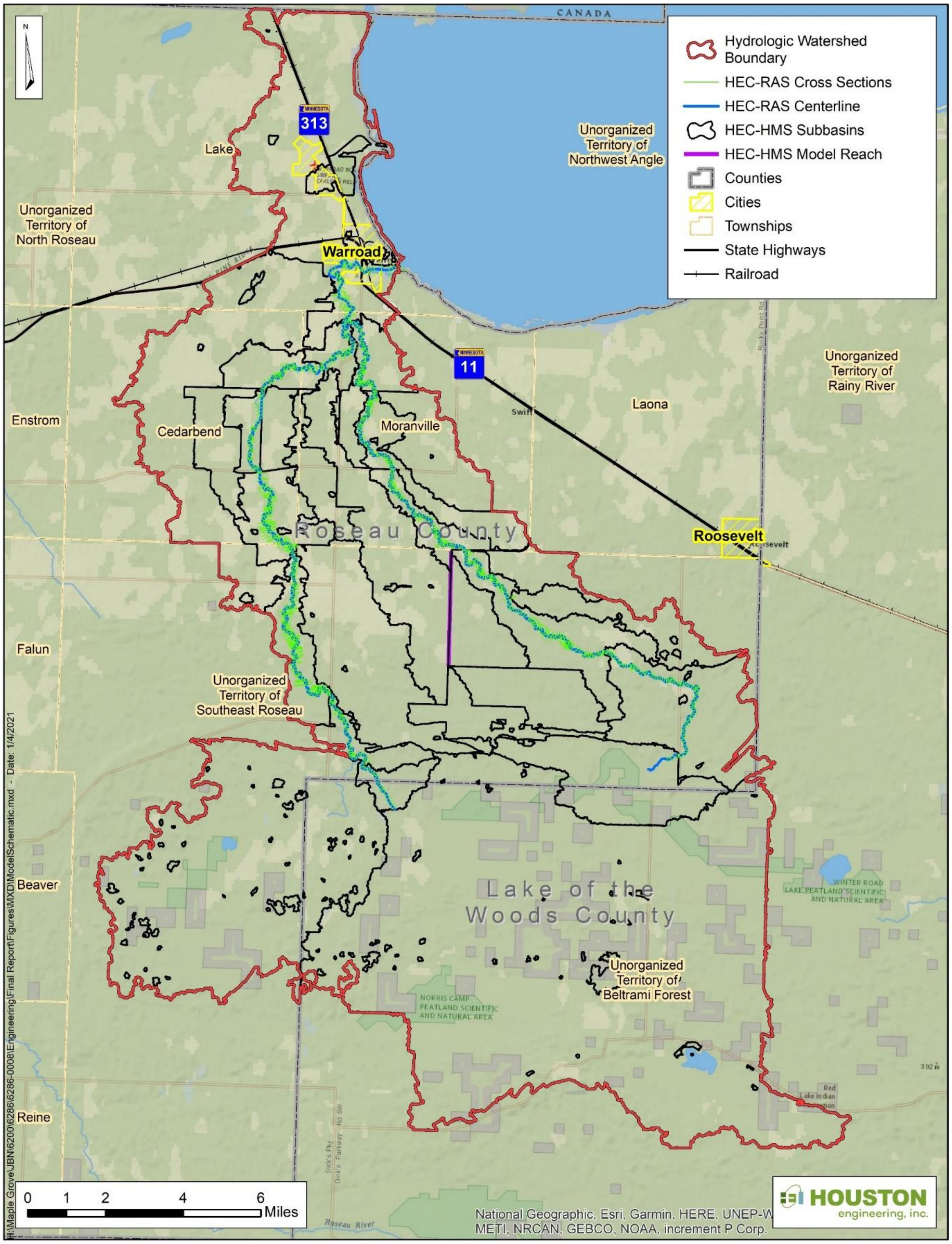
3.1 METHODOLOGY

3.1.1 MODEL DEVELOPMENT

The modeling used for this project is based on the HEC-RAS model developed from the 2016 AIG (HEI, 2019). The model was created to estimate velocity gradient measurements to be used in the Near-Bank Stress (NBS) estimates for the Bank Assessment for Non-point source Consequences of Sediment (BANCS) assessment. The HEC-RAS model extents included the East Branch and West Branch of the Warroad River. The model extends from near the boundary between Roseau County and Lake of the Woods County to the outlet at the Warroad harbor. The modeling extents are shown on **Figure 2**.

To utilize the hydraulic HEC-RAS model to analyze potential water retention projects, the model needed to be modified and updated. The updates included converting the model from steady state to an unsteady state model which can simulate a runoff hydrograph. A Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) hydrology model was developed to generate runoff hydrographs for the hydraulic model. PTMApp data developed during the LOWW Comprehensive Plan process was utilized for subbasin delineation and to calculate subbasin parameters for the HEC-HMS model (LOWW 1W1P Planning Group, 2019). CD10 was modeled with the reach routing modeling component within HEC-HMS. The HEC-RAS and HEC-HMS modeling schematic is shown on **Figure 2**. Rainfall events were simulated in the HEC-HMS model to determine the excess precipitation and develop runoff hydrographs. The runoff hydrographs were then applied to the HEC-RAS model. The 2-, 5-, 10-, 25-, 50-, and 100-year events were simulated based on NOAA Atlas 14, 24-hour rainfall depths. Peak flows in the HEC-RAS model were verified by comparing modeled peak flows at various locations to peak flows calculated using USGS Regression Equations.

Figure 2. Hydrologic & Hydraulic Model.



3.1.2 PROJECT ALTERNATIVES

The project alternatives that were analyzed included installing ditch plugs, constructing regional storage, and making improvements to Bednar Dam. The project alternatives, their locations within the watershed, estimated storage volumes, and their descriptions are summarized in **Table 1**.

Table 1. Summary of project alternatives.

Subwatershed	Project Alternative	Description	Approximate Storage Volume (ac-ft)
West Branch Warroad River	Peatland Storage via Ditch Plugs	Additional water retention created by the strategic placement of ditch plugs in the upstream peatlands.	800
	Clausner Creek Storage 50%	Additional water retention within the Clausner Creek watershed. The scenario assumes 50% of the 25-year, 24-hour storm event is captured.[1]	527
	Bulldog Run Storage 50%	Additional water retention within the Bulldog Run watershed. The scenario assumes 50% of the 25-year, 24-hour storm event is captured.[1]	491
East Branch Warroad River	Bednar Dam Improvements	Modification of the dam outlet structure to allow additional water to be held back in the peatlands. This would require some combination of constricting the dam outlet weir and potentially raising the top of the dam structure (overflow).	150
	Peatland Storage via Ditch Plugs	Additional water retention created by the strategic placement of ditch plugs in the upstream peatlands.	100
CD 10	Regional Storage 50%	Additional water retention within the CD 10 watershed. The scenario assumes 50% of the 25-year, 24-hour storm event is captured.[1]	778
	Regional Storage 25%	Additional water retention within the CD 10 watershed. The scenario assumes 25% of the 25-year, 24-hour storm event is captured.[1]	389
	Peatland Storage via Ditch Plugs	Additional water retention created by the strategic placement of ditch plugs in the upstream peatlands.	65

[1] Depth of rainfall for the 25-year, 24-hour storm event ranges from 4.2 - 4.3 inches.

3.1.3 EVALUATION METRICS

As indicated in **Section 2.1**, alternatives should focus on the reduction of downstream erosive peak flows and sediment transport to not only reduce in-channel sediment transport to the Warroad Harbor, but also to further protect future in-channel stream restoration projects by reducing peak flows within the systems. To determine if a project alternative will work towards meeting the project goals, several evaluation metrics were developed.

An evaluation metric is a quantifiable result used for comparison and evaluation of a scenario. An example evaluation metric is the peak flow, at a specific location, for a given storm event. A scenario can be modeled, and the peak flow metric can be compared to the existing condition in order to determine the effectiveness of the scenario.

The following metrics and a description of how they indicate progress towards these goals, are described in the following sections.

DOWNSTREAM (WARROAD RIVER) PEAK FLOW REDUCTION

Increases in peak flows within a river system are generally caused by altered hydrology within the watershed. Water runs off the landscape faster and in larger quantities, enters the river, and concentrates more quickly, creating periods of intense high flows. These higher flows can result in increased erosion of the streambanks, greater sediment transport, and a number of other impacts including flash flooding and loss of habitat along the river.

Project alternative impacts to peak flow were evaluated at a point near the outlet of the Warroad River. The location of this point is shown in **Figure 3**. Both the existing condition and project alternative models were run for various design storm events and the change in downstream peak flows were compared. In general, a project resulting in a decrease in peak flows downstream is beneficial to the project goals.

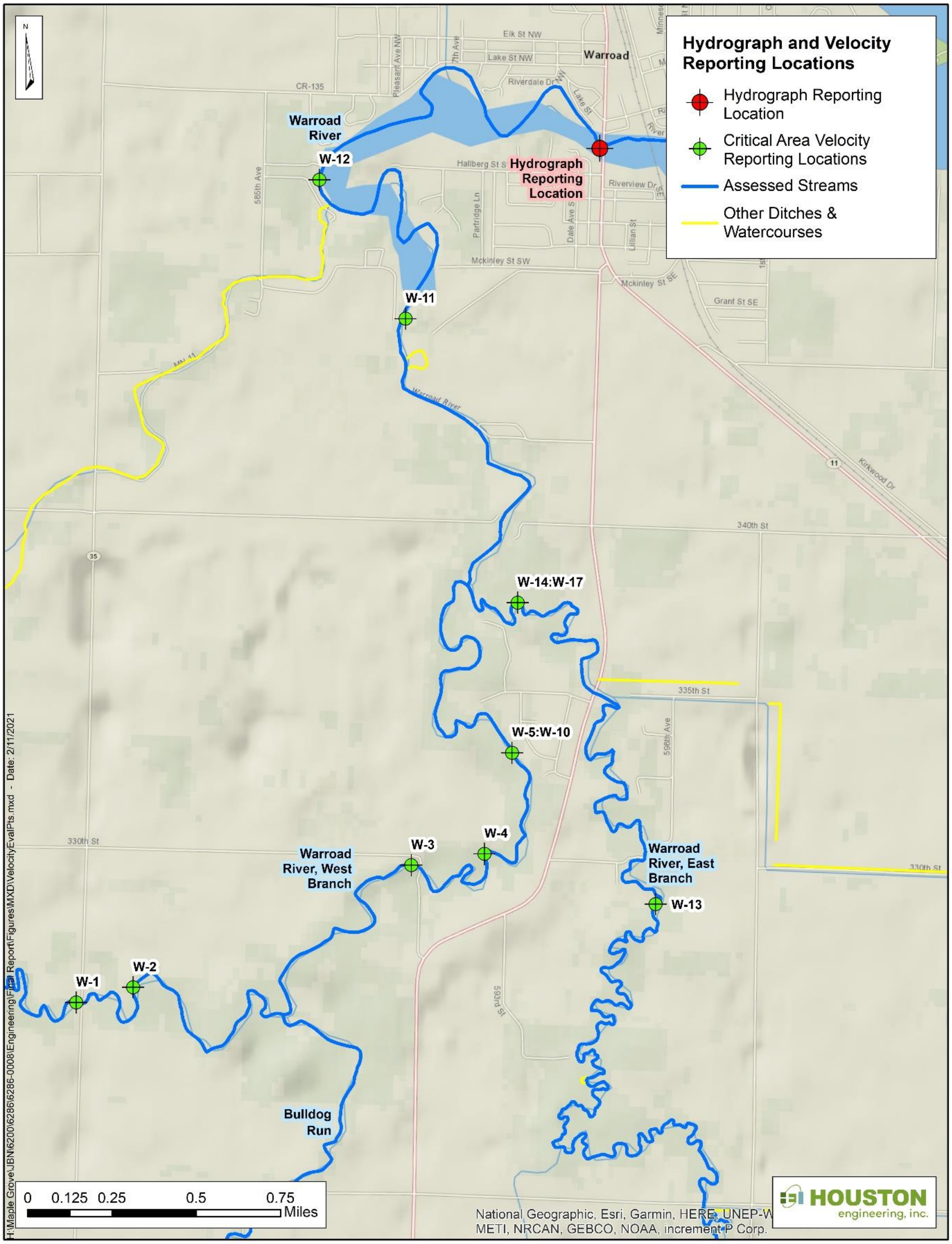
PEAK VELOCITY AT CRITICAL AREAS

Similar to high flows, high velocities can also have detrimental impacts to river systems. Velocity is associated with shear stress, which can cause erosion and scouring along the riverbank. Sustained shear stress will lead to bank undercutting, bank failure, and ultimately sediment and nutrients entering the stream where they can be transported downstream to the harbor.

During both the LOWW Comprehensive Plan process and the initial stakeholder meeting for this project, the MnDNR and others expressed interest in implementing storage within the watershed as a way to mitigate the need for and/or lessen the cost of stream stabilization projects downstream. For example, a relatively expensive streambank stabilization project could be made less expensive if additional storage is implemented upstream, reducing the peak velocities at the downstream project site. If the two projects (upstream storage and downstream stabilization) are less expensive in tandem than a more expensive downstream stabilization, implementing the two projects would be a wise use of project dollars.

Project alternative impacts to peak velocities were evaluated at nine points throughout the watershed. These points are shown in **Figure 3**. These evaluation points are based on the locations of potential in-channel projects from the LOWW Comprehensive Plan (LOWW Planning Partners, 2019). Portions of the river that have multiple project segments in succession were consolidated and reported as one location. Both the existing condition and project alternative models were run for various design storm events and the change in peak velocities at these points were compared. Evaluating this metric at these locations helps determine if storage project alternatives can lessen the need for streambank stabilization projects.

Figure 3. Peak flow and peak velocity evaluation points.



SEDIMENT TRANSPORT POTENTIAL

While flow and velocity are factors leading to sediment transport, it is possible to make estimates of annual sediment transport itself. Sediment transport, as a metric, estimates are intended to provide a method for assessing how project alternatives will likely:

- Impact the delivery of sediment to the Warroad Harbor; and
- Impact the overall capacity of the assessed streams ability to carry sediment downstream.

Many techniques exist for evaluating sediment transport in rivers and streams, all of which have uncertainty. The Lane Principle is a widely utilized planning level assessment of sediment transport capacity (i.e., sediment discharge) relative to particle diameter, water discharge, and the slope of the stream. This project utilized an adapted derivation of Lane's equation, available from South Dakota State University to assess how sediment transport to the harbor and within the streams will likely be impacted from the project alternatives (Ponce, 2021).

Sediment discharge (Q_s) was calculated using the following equation:

$$Q_s = 58.7\ k_1\ \gamma\ Q_w\ S_o\ (R/d_s)^{1/3}$$

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 median particle size was used for this project (i.e., d_{50}). The HEC-RAS model was used to generate Q_w, S_o, and R. Soil Survey Geographic (SSURGO) soils data was used to extract sediment textures for soils in the area to establish d_{50} as shown in **Table 2**. The sediment transport parameter (k_1) is a dimensionless calibration parameter that was set to 0.0055 for this assessment.

Table 2. Median particle size used for various soil types.

Soil	d50 (mm)
Bouldery loamy coarse sand	0.18
Clay	0.023
Clay loam	0.018
Coarse sandy loam	0.16
Extremely gravelly loamy coarse sand	0.2
Fine sand	0.16
Fine sandy loam	0.08
Loam	0.035
Loamy coarse sand	0.18
Loamy fine sand	0.12
Loamy sand	0.135
Moderately decomposed plant material	0.0001
Muck	0.023
Mucky peat	0.023
Mucky silt loam	0.027
Mucky silty clay loam	0.025
Sand	0.17
Sandy clay loam	0.019
Sandy loam	0.098
Silt loam	0.027

Soil	d50 (mm)
Silty clay	0.024
Silty clay loam	0.025
Very fine sandy loam	0.035

The sediment transport potential estimates for this project represents the annual sediment load exported from the watershed (i.e., deposited into Warroad Harbor). Both the existing condition and project alternative models evaluated for sediment transport potential. Comparing the results, the reduction in annual sediment transport potential (tons/year) was estimated for the watershed, for each of the project alternatives. It should be noted that the sediment reduction potential calculated for this project does not include reduction at the practice(s) itself (i.e., sediment retained within a regional storage basin or at the ditch plugs) as this this is highly dependent on the design of the practice. The values are included in the project portfolios (**Appendices B** through **D**) and in the summary in **Section 5**.

COST

Often the most important metric in evaluation a project alternative is the cost of the project. Project implementation costs can varying widely and often include factors such as land procurement, engineering/design, construction, and long-term maintenance. When costs are weighed versus anticipated benefits, a cost-benefit analysis can be performed across multiple project alternatives.

Depending on what project alternative is being considered, costs can vary significantly. Typically, regional storage is costed out on a “per acre-foot of storage” basis. Regional storage projects within the nearby Red River Valley tend to range from $1,500 to $2,000 per acre foot of storage. Cost estimates for ditch plug alternatives are typically based on the number of plugs installed. Ditch plug construction costs can also vary case by case, based primarily on access and legal proceedings, but a general range from $10k to $50k per site would be a conservative cost. Lastly, existing structure modifications, such as dams, can vary in cost as well, with estimates ranging from $1M to $3M based on the size of the structure and ease of access.

3.1.4 PROJECT ALTERNATIVE MODELING

The HEC-HMS and HEC-RAS models were used to model the 2-year, 10-year, and 25-year events for each project alternative. All three types of project alternatives (ditch plugs, regional storage, and dam modification) were modeled using a similar methodology. The total amount of storage for each alternative was estimated using LiDAR data and GIS. The curve number values were altered within the corresponding subwatersheds in the HEC-HMS model to reflect the reduction in runoff volume based on the storage calculations for each alternative. The revised runoff hydrographs for each alternative were then simulated in the HEC-RAS to determine the effects of the alternative.

For the sediment transport analysis, 13 representative cross sections were selected throughout the model extent. The sediment transport potential was calculated for each event at the representative cross sections based on the model outputs for discharge, slope, and hydraulic radius. The individual cross section results were then weighted and averaged to determine a sediment transport potential for each event. The event based sediment transport for the 2-, 10-, and 25-year was then annualized to determine an average annual sediment transport potential. The annual sediment transport was calculated for both the existing condition and the project alternatives and compared to indicate estimated changes.

4 RESULTS

4.1.1 EXISTING CONDITIONS

The HEC-HMS and HEC-RAS models were used to develop “stacked hydrographs” at the peak flow evaluation point shown in **Figure 3**. By sequentially “turning off” portions of the watershed (i.e., they do not contribute any runoff to the model), a stacked hydrograph can be developed that depicts the runoff volume and timing of the runoff originating from specific subwatersheds of the Warroad River watershed. An example stacked hydrograph, for the 25-year, 24-hour design storm event, is shown in **Figure 4**. The color-coded map of the corresponding watersheds is shown in **Figure 5**. A complete set of the stacked hydrographs for the various design storm events (2-, 5-, 10-, 25-, 50-, and 100-year, 24-hour) is included in **Appendix A**.

The colored bands in the hydrographs represent the water “removed” when the subwatershed with the corresponding color is “turned off.” It is important to note that the stacked hydrographs in this report represent the following sequential order of subwatershed removal:

1. East Branch above CD10;
2. CD10;
3. East Branch below CD10;
4. Upper West Branch;
5. West Branch; and
6. Local (below confluence).

The stacked hydrographs are a valuable planning tool in targeting areas of the watershed for various types of practices. For example, storage practices in the Upper West Branch (dark pink) will not impact peak flows within the City of Warroad, but it will have an impact on the trailing limb of the hydrograph (as indicated by the dark pink portion of the stacked hydrographs). Storage practices in CD 10 (light blue) or the West Branch (green) have the greatest potential for reducing peak flow rates within the City of Warroad because they have the highest volume contributing at the peak (height of the color band at the time of peak). The stacked hydrographs were used to assist the development of alternatives that were analyzed. Project alternatives were chosen based on perceived impacts according to the stacked hydrographs.

Figure 4. Stacked hydrograph for 25-year, 24-hour event.

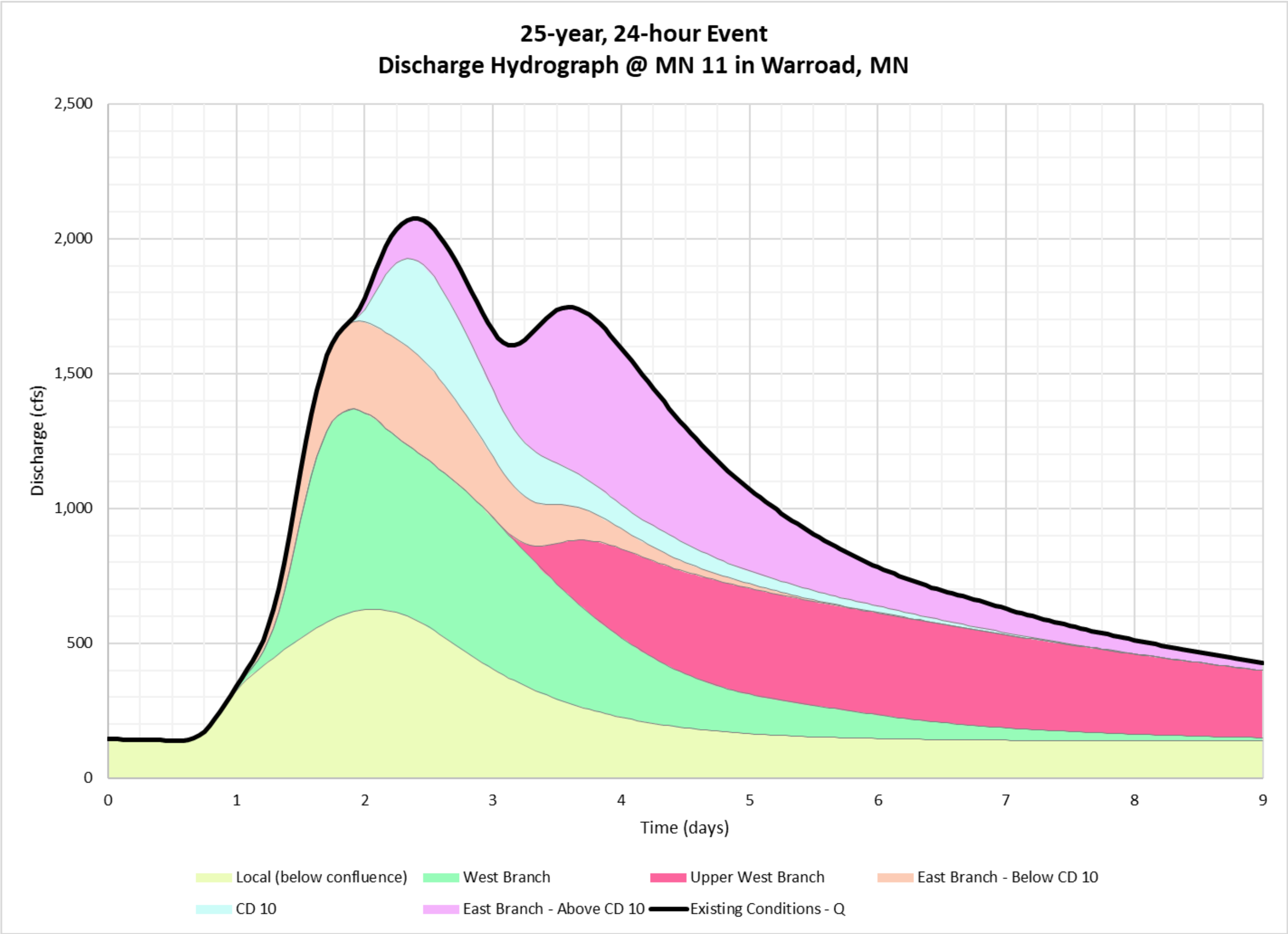
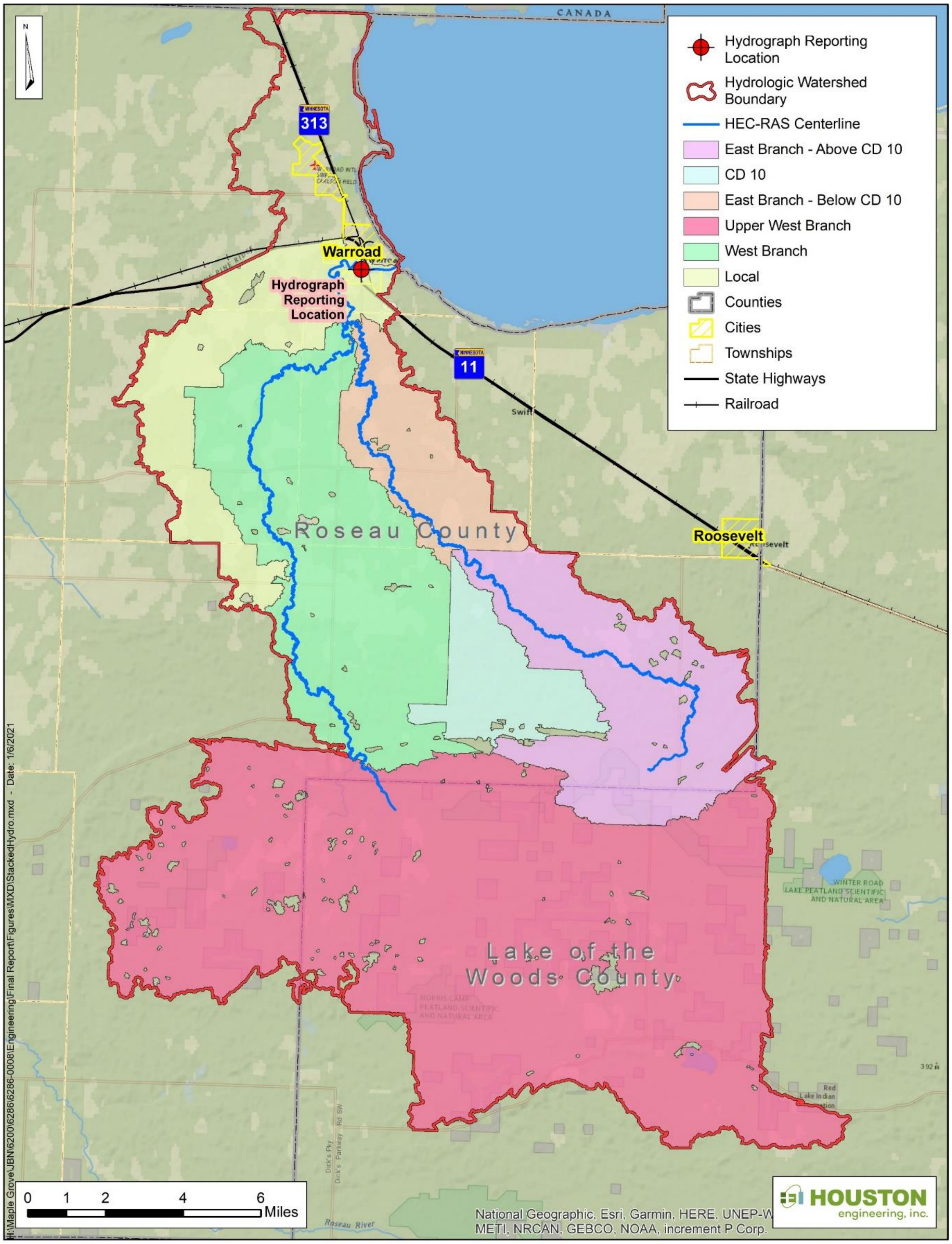


Figure 5. Stacked hydrograph reference map.



4.1.2 PROJECT ALTERNATIVE PORTFOLIOS

A project alternative portfolio was created to summarize the results for each of the eight project alternatives. The portfolio is divided across three appendices, based on the subwatershed:

- **Appendix B** – West Branch Warroad River
- **Appendix C** – East Branch Warroad River
- **Appendix D** – CD 10

The project alternatives each have various information boxes, which are described in the sections below.

DESCRIPTION

The upper left hand corner of the portfolio includes a brief description of the project alternative, similar to those included in **Table 1**.

PROJECT ALTERNATIVE MAP

The lower left hand corner of the portfolio includes a map of the project alternative area. Some general features included in all of the alternative maps and consistent with the LOWW Comprehensive Plan include:

- base mapping with roads, waterbodies, topography, etc.;
- the project alternative drainage area;
- river and streams assessed by the Minnesota Pollution Control Agency (MPCA);
- other ditches and watercourses;
- public lands; and
- potential Prioritize, Target, and Measure Application (PTMApp) identified storage from the LOWW Comprehensive Planning.

For ditch plug project alternatives, the maps include the locations of potential ditch plugs and their corresponding storage areas. Potential ditch plug locations were identified by manually reviewing the topography and determining locations where plugs could provide significant storage before the retained water overtops the natural topography and routes around the plug. The identified storage areas shown on the maps are an areal “footprint” of the storage provided by each ditch plug. For the East Branch project portfolios, the Bednar Dam is also indicated on the maps.

HYDROLOGIC & HYDRAULIC RESULTS

Included for each project alternative is a hydrograph analysis for the 2-, 10-, and 25-year, 24-hour storm events. As discussed in the evaluation metrics (**Section 3.1.3**), the hydrograph is shown for a downstream point near the outlet of the Warroad River (see **Figure 3**). The hydrographs include overlapping plots for the existing and alternative project conditions. Also included on the hydrographs are the percent reduction in peak flow and volume. It is important to note that runoff volume reductions are only valid assuming runoff is retained at the storage site and infiltrated. If runoff is temporarily stored and slowly released, the runoff volume reductions are 0%.

CRITICAL AREA PEAK VELOCITY REDUCTIONS

This section of the portfolios provides a summary of the peak velocities at critical areas, as described in **Section 3.1.3**. Peak velocities are provided for the existing and alternative (proposed) conditions and the percent reduction is reported. Velocities/reductions are reported for all of the relevant areas (i.e., if an alternative does not have to potential to impact an area, it is not reported. For example, critical areas in the upstream portion of the East Branch Warroad River are not impacted by alternatives in the upstream West Branch Warroad River). The velocities/reductions are reported for the 2-, 10-, and 25-year, 24-hour storm events.

POTENTIAL ANNUAL SEDIMENT TRANSPORT REDUCTION

This section of the portfolios provides results of the potential sediment transport analysis. The estimated annual sediment transport is provided for the existing condition and the alternative conditions. The sediment reduction is reported in both mass (tons) and percent. The sediment reduction potential calculated does not include reduction at the practice(s) itself; this this is highly dependent on the design of the practice.

COST

This section of the portfolios provides approximate estimates of cost. Cost estimates are based on information provided in **Section 3.1.3**. A qualitative cost rating is also provided for summary.

SUMMARY

Lastly, each portfolio includes a summary sections that identifies the pros and cons of the project alternative. These are based primarily on the evaluation metrics but also on additional factors such as land ownership and anticipated project collaboration needs.

5 SUMMARY & RECOMMENDATIONS

5.1.1 PROJECT ALTERNATIVE PORTFOLIO SUMMARY

Each of the project alternative pages in the portfolio includes results for the evaluation metrics. To compare projects, the metrics results have been combined in a matrix for all of the project alternatives, shown in **Table 3**.

Some general takeaways from the results matrix:

- The results of this analysis do not validate or suggest modifications to the water retention (storage) goals presented in the LOWW Comprehensive Plan (LOWW, 2019). The analysis simply reports progress towards the existing goals. The storage goals established in the LOWW Comprehensive Plan are based on 1/4” of water across the entire watershed (long-term goal) and 1/8” across the entire watershed (short-term goal). This equates to 7,335 acre-feet and 3,668 acre-feet, respectively. The storage goals are reported for the entire LOWW (i.e., they are not separated by planning region). For reference, the Warroad River Planning Region is approximately 43% of the LOWW.
- Ditch plug projects do little to reduce peak flows/velocities, but are generally better at reducing annual sediment transport potential due to reduced sustained flows;
- Regional storage is better at reducing peak flows/velocities than ditch plug storage;
- Regional storage in the Bulldog Run subwatershed is generally more beneficial than regional storage in the Clausner Creek subwatershed.
- The greatest overall benefits (flows, volume, velocities, and sediment transport) are achieved from regional storage in the CD10 subwatershed;
- Bednar Dam improvements, as modeled, do little to impact peak flows/velocities; and
- In general, ditch plugs are assumed to be less costly than regional storage.

Table 3. Summary matrix of project alternative metrics.

Subwatershed	Project Alternative	Storage: Approximate Storage Volume (ac-ft)	Hydrology & Hydraulics[1]: Warroad River Peak Flow Reduction (%) 2-yr	10-yr	25-yr	Hydrology & Hydraulics[1]: Runoff Volume Reduction (%) 2-yr	10-yr	25-yr	Critical Areas[1]: Peak Velocity Reductions (Max %) 2-yr	10-yr	25-yr	Sediment Transport: Annual Reduction (%)[2]	Cost Range: Min	Cost Range: Max
West Branch Warroad River	Peatland Storage via Ditch Plugs	800	0%	0%	0%	6%	5%	3%	0%	0%	0%	12%	$110,000	$550,000
	Clausner Creek Storage 50%	527	0%	1%	3%	3%	4%	3%	1%	4%	4%	4%	$1,050,000	$1,580,000
	Bulldog Run Storage 50%	491	14%	11%	7%	4%	3%	2%	16%	12%	7%	1%	$982,000	$1,470,000
East Branch Warroad River	Bednar Dam Improvements	150	0%	0%	0%	2%	1%	1%	0%	0%	0%	4%	$1,000,000	$3,000,000
	Peatland Storage via Ditch Plugs	100	0%	0%	0%	1%	1%	0%	0%	0%	0%	3%	$40,000	$200,000
CD 10	Regional Storage 50%	778	0%	12%	13%	5%	4%	3%	29%	22%	9%	9%	$1,550,000	$2,330,000
	Regional Storage 25%	389	0%	10%	6%	4%	2%	1%	28%	8%	4%	5%	$778,000	$1,170,000
	Peatland Storage via Ditch Plugs	65	0%	2%	1%	1%	0%	0%	4%	1%	1%	1%	$40,000	$200,000

[1] Duration of all rainfall events is 24 hours.

[2] Represents the annual sediment transport reduction potential of the Warroad River channel. Sediment reduction on the landscape or within regional storage is not included in this estimate.

5.1.2 RECOMMENDATIONS

Based on the results of this analysis, it is recommended to pursue projects in the following order:

CD 10 - REGIONAL STORAGE 50% OR 25%

Pursuing anywhere from 300 to 800 acre-feet of additional storage within the CD10 subwatershed would provide substantial benefit both in peak flow/velocity and sediment transport reduction. To achieve the greatest benefit, storage should be located as near to the ditch confluence with the East Branch Warroad River as possible; this will allow more water to be retained. Challenges with this option will most certainly be locating land for the regional storage, however, the majority of the land within the subwatershed is public. Coordination with state agencies will be crucial. PTMApp analysis only identifies a small amount of potential storage possible with the naturally occurring landscape (8 acre-feet). It is likely that a regional basin would need to be constructed.

Potential progress towards the applicable goals in the LOWW Comprehensive Plan are shown in **Table 4** for the 50% project alternative and **Table 5** for the 25% project alternative.

Table 4. Potential progress towards the applicable goals in the LOWW Comprehensive Plan – CD10 50% storage option.

	Annual Sediment (tons)	Annual Phosphorus (lbs)	Storage (ac-ft)
Applicable Measurable Goal(s)	**MG-4**	**MG-5**	**MG-7**
Short-Term Goal (Reduction)[1]	864	1,119	3,668
Project Alternative Potential Reduction[2]	849	1,885	778
Potential Progress Toward Plan Goal (%)[3]	**98%**	**168%**	**21%**
Cost Range	**$1,550,000 - $2,330,000**		

[1] Short-term goals are taken from the LOWW Comprehensive Plan and represent the 10-year plan goal. The storage goal listed is for the entire LOWW. The sediment and phosphorus goals are specific to the Warroad River Planning Region. For reference, the Warroad River Planning Region is approximately 43% of the LOWW.
[2] Phosphorus reduction is estimated using the same ratio of phosphorus to sediment that was used in the LOWW Comprehensive Plan (2.2 lbs of phosphorus per ton of sediment).
[3] Percent of progress towards the storage goal is for the entire LOWW. Percent of progress towards the sediment and phosphorus goals is for the Warroad River Planning Region only. See footnote 1.

Table 5. Potential progress towards the applicable goals in the LOWW Comprehensive Plan – CD10 25% storage option.

	Annual Sediment (tons)	Annual Phosphorus (lbs)	Storage (ac-ft)
Applicable Measurable Goal(s)	**MG-4**	**MG-5**	**MG-7**
Short-Term Goal (Reduction)[1]	864	1,119	3,668
Project Alternative Potential Reduction[2]	508	1,128	389
Potential Progress Toward Plan Goal (%)[3]	**59%**	**101%**	**11%**
Cost Range	**$778,000 - $1,170,000**		

[1] Short-term goals are taken from the LOWW Comprehensive Plan and represent the 10-year plan goal. The storage goal listed is for the entire LOWW. The sediment and phosphorus goals are specific to the Warroad River Planning Region. For reference, the Warroad River Planning Region is approximately 43% of the LOWW.
[2] Phosphorus reduction is estimated using the same ratio of phosphorus to sediment that was used in the LOWW Comprehensive Plan (2.2 lbs of phosphorus per ton of sediment).
[3] Percent of progress towards the storage goal is for the entire LOWW. Percent of progress towards the sediment and phosphorus goals is for the Warroad River Planning Region only. See footnote 1.

WEST BRANCH WARROAD RIVER – PEATLAND STORAGE VIA DITCH PLUGS

Pursuing installation of ditch plugs and/or the abandonment of ditching within the West Branch Warroad River could provide approximately 800 acre-feet of additional storage and reduce sustained flow duration in the Warroad River. This leads to the greatest reduction (12%) in annual sediment transport potential. However, ditch plug installation is not likely to provide much reduction in peak flows and peak velocities. This project alternative is not likely to have major impacts on bank erosion within the watershed. Potential ditch plug locations have been identified in the project alternative portfolio. Challenges with this option will include significant cooperation with the MnDNR and other state agencies responsible for managing peatland areas. Coordination with the counties (Roseau and Lake of the Woods) will also be needs, as these counties are the ditch authorities. PTMApp analysis identifies an additional 107-acre feet of storage possible within the peatlands. However, the accuracy of these storage is questionable, due to the nature of the landscape and the resolution of the LiDAR data.

Potential progress towards the applicable goals in the LOWW Comprehensive Plan are shown in **Table 6** for the project alternative.

Table 6. Potential progress towards the applicable goals in the LOWW Comprehensive Plan – Peatland Ditch Plugs – West Branch Warroad River.

	Annual Sediment (tons)	Annual Phosphorus (lbs)	Storage (ac-ft)
Applicable Measurable Goal(s)	**MG-4**	**MG-5**	**MG-7**
Short-Term Goal (Reduction)[1]	864	1,119	3,668
Project Alternative Potential Reduction[2]	1,248	2,771	800
Potential Progress Toward Plan Goal (%)[3]	**144%**	**248%**	**22%**
Cost Range	**$110,000 - $550,000**		

[1] Short-term goals are taken from the LOWW Comprehensive Plan and represent the 10-year plan goal. The storage goal listed is for the entire LOWW. The sediment and phosphorus goals are specific to the Warroad River Planning Region. For reference, the Warroad River Planning Region is approximately 43% of the LOWW.

[2] Phosphorus reduction is estimated using the same ratio of phosphorus to sediment that was used in the LOWW Comprehensive Plan (2.2 lbs of phosphorus per ton of sediment).

[3] Percent of progress towards the storage goal is for the entire LOWW. Percent of progress towards the sediment and phosphorus goals is for the Warroad River Planning Region only. See footnote 1.

WEST BRANCH WARROAD RIVER – BULLDOG RUN STORAGE 50%

Pursuing approximately 500 acre-feet of additional storage within the Bulldog Run subwatershed would provide sizable reductions in the peak flows and velocities downstream. To achieve the greatest benefit, storage should be located as near to the ditch confluence with the West Branch Warroad River as possible; this will allow more water to be retained. Challenges with this option will also include locating land for the regional storage, particularly because nearly all of the land is private. Private landowner outreach will be critical on the part of the WRWD. PTMApp analysis only identifies a small amount of potential storage possible with the naturally occurring landscape (6 acre-feet). It is likely that a regional basin would need to be constructed.

Potential progress towards the applicable goals in the LOWW Comprehensive Plan are shown in **Table 7** for the project alternative.

Table 7. Potential progress towards the applicable goals in the LOWW Comprehensive Plan – Bulldog Run 50% storage option.

	Annual Sediment (tons)	Annual Phosphorus (lbs)	Storage (ac-ft)
Applicable Measurable Goal(s)	**MG-4**	**MG-5**	**MG-7**
Short-Term Goal (Reduction)[1]	864	1,119	3,668
Project Alternative Potential Reduction[2]	139	309	491
Potential Progress Toward Plan Goal (%)[3]	**16%**	**28%**	**13%**
Cost Range	**$982,000 - $1,470,000**		

[1] Short-term goals are taken from the LOWW Comprehensive Plan and represent the 10-year plan goal. The storage goal listed is for the entire LOWW. The sediment and phosphorus goals are specific to the Warroad River Planning Region. For reference, the Warroad River Planning Region is approximately 43% of the LOWW.
[2] Phosphorus reduction is estimated using the same ratio of phosphorus to sediment that was used in the LOWW Comprehensive Plan (2.2 lbs of phosphorus per ton of sediment).
[3] Percent of progress towards the storage goal is for the entire LOWW. Percent of progress towards the sediment and phosphorus goals is for the Warroad River Planning Region only. See footnote 1.

OTHER PROJECTS

The remaining projects analyzed in this report are not recommended as priority projects.

While the Clausner Creek storage does achieve greater sediment transport reduction benefits than its Bulldog Run counterpart, it does not achieve better peak flow, velocity, and volume reduction benefits. It is also estimated to be more costly due to its greater storage volume. Bulldog Run is the preferred subwatershed for regional storage.

Due to the nature of the topography, the Bednar Dam improvements are unlikely to gain significant additional storage. This is due to the topography; raising the dam height will likely result in stored water finding another pathway into either CD 10 or the East Branch Warroad River. Coupled with the estimated extremely high cost of the dam modification, this project option is not cost-effective.

Similarly, the topography makes finding additional storage through the implementation of ditch plugs difficult in both CD 10 and the East Branch Warroad River, as indicated by the minimal additional storage volumes identified in their respective project portfolios. This minimal storage results in poor performance in the evaluation metrics, irrespective of the low cost estimates.

6 PROJECT LIMITATIONS

As with all modeling-related feasibility projects, there are several limitations worth noting. They are discussed below, along with their impacts to the results reported.

- Estimates and analysis requiring topography are based on Minnesota Department of Natural Resources (MnDNR) Light Detection and Ranging (LiDAR) digital elevation models (DEM), collected between 2008 and 2010. MnDNR LiDAR typically has a resolution of 1 meter in the horizontal and 15 cm in the vertical (MnDNR, 2021). LiDAR data is known to be less accurate within wetlands such as the peatlands area of the Warroad River watershed. A vertical uncertainty of inches can result in storage volume uncertainties well within the hundreds of acre-feet. As a result, storage estimates within the peatland likely have large uncertainty (greater than or less than) depending on how well LiDAR data captured the normal water surface elevation and surrounding topography. This is applicable to the ditch plug and Bednar Dam improvements project scenarios.

- Similar to storage estimates, all profile and cross-sectional data utilized within the HEC-RAS modeling is based on LiDAR DEM data. No additional survey data was collected to refine the model. Model refinements often include collecting cross-sections near channel constrictions such as culverts and bridge piers. These types of model refinements often result in more accurate model results for smaller, bank full, flows.

- While the HEC-RAS model was validated against nearby regression flows, a formal calibration, based on flow/stage monitoring data was not performed as sufficient data did not exist. Additionally, modeling performed is based on 24-hour synthetic rainfall events. Events with varying durations, such as longer duration spring snowmelt runoff, may produce different results.

- As indicated in the project portfolios and the summary (**Table 3**), estimates of the reduction of sediment transport potential are limited to transport potential within the river channel and do not include any sediment reduced within the project itself. For example, a regional storage basin or ditch plug will hold back sediment within the practice. Annual estimates for this are based on the final design/size of the practice.

- Cost estimates are based entirely on unit costs, identified within the project portfolios. Ditch plug costs are based on the cost per plug; regional storage is based on the cost per stored volume, and the Bednar Dam improvements are based on similar projects within the Red River Valley. Costs can fluctuate based on access/mobilization to the site (which is likely difficult within the peatlands), procurement of land if necessary, scope of permitting (i.e., dam safety, etc.) , and general complexity of the final design. The costs in this report are meant to be a general estimate based on typical unit costs.

- Regional storage projects outlined in this report are generalized volumes and do not include specific locations for regional storage projects. This is done primarily to avoid using resources to analyze specific projects, only to find that they are not feasible for design and construction (i.e., unwilling landowner, unsuitable site, etc.). By generalizing the storage volumes and applying them to the subwatershed in general, the WRWD and LOWW plan partners can get a general idea of how storage implementation within the subwatershed impacts the evaluation metrics and progress towards the LOWW Comprehensive Plan goals. This can then be used to target specific projects in the future.

7 REFERENCES

Houston Engineering, Inc. (HEI). 2013. Warroad River Watershed Sediment Source Assessment Project. Final Report. July 29, 2013.

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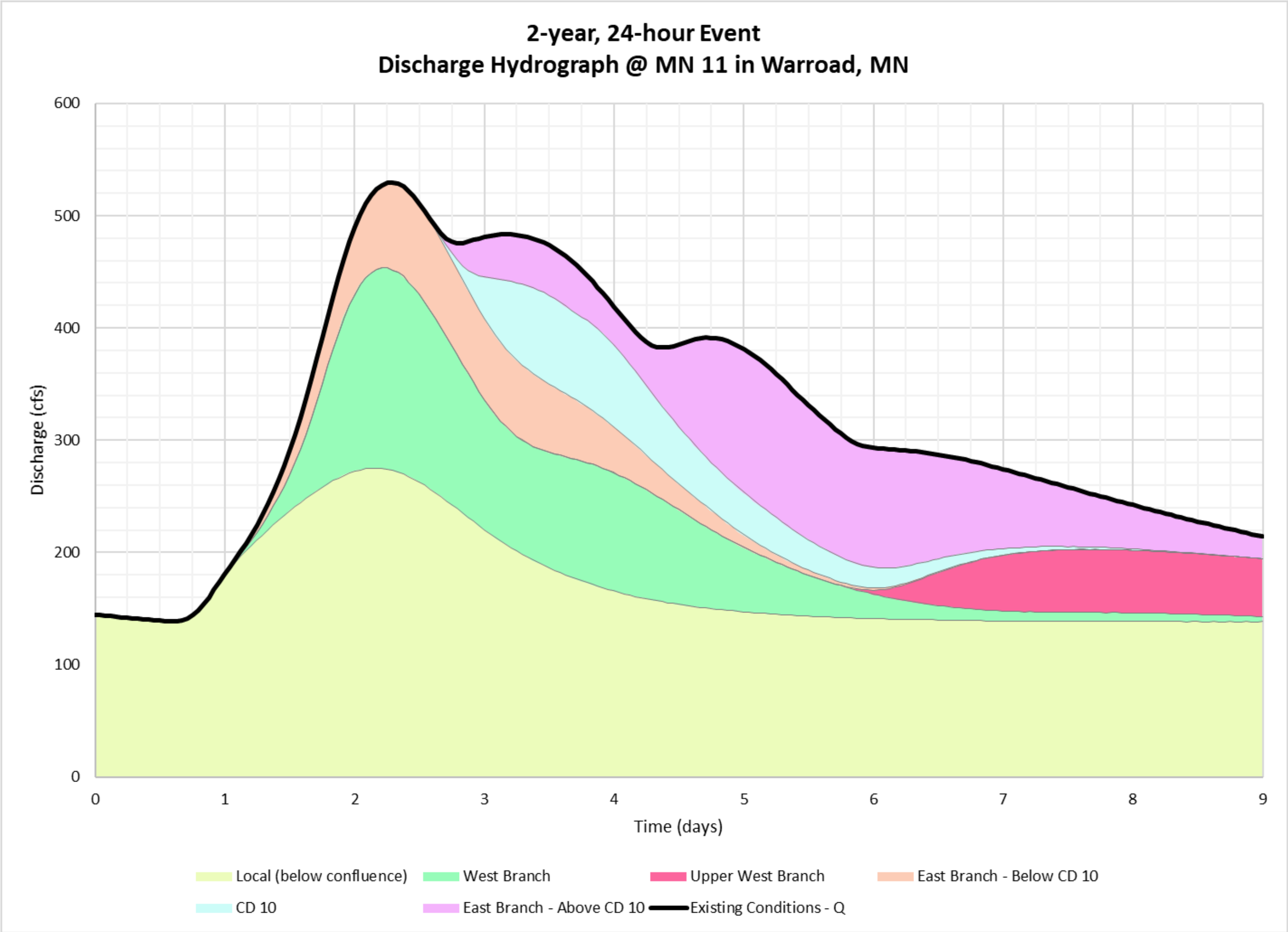
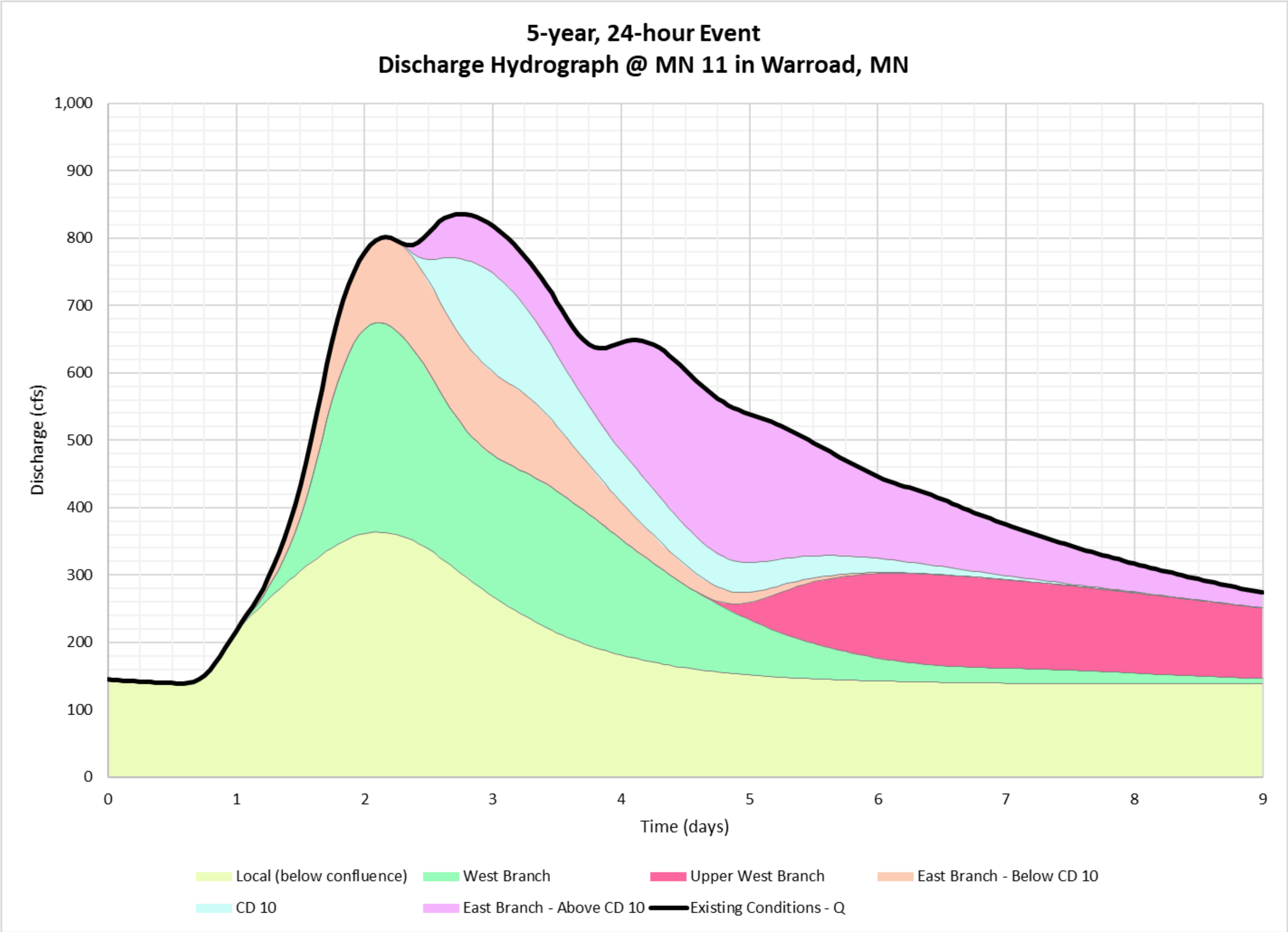
Minnesota Department of Natural Resources (MnDNR). 2021. Lidar Elevation Data for Minnesota: 2008-2012. Website accessed February 15, 2021. https://www.mngeo.state.mn.us/chouse/elevation/lidar.html

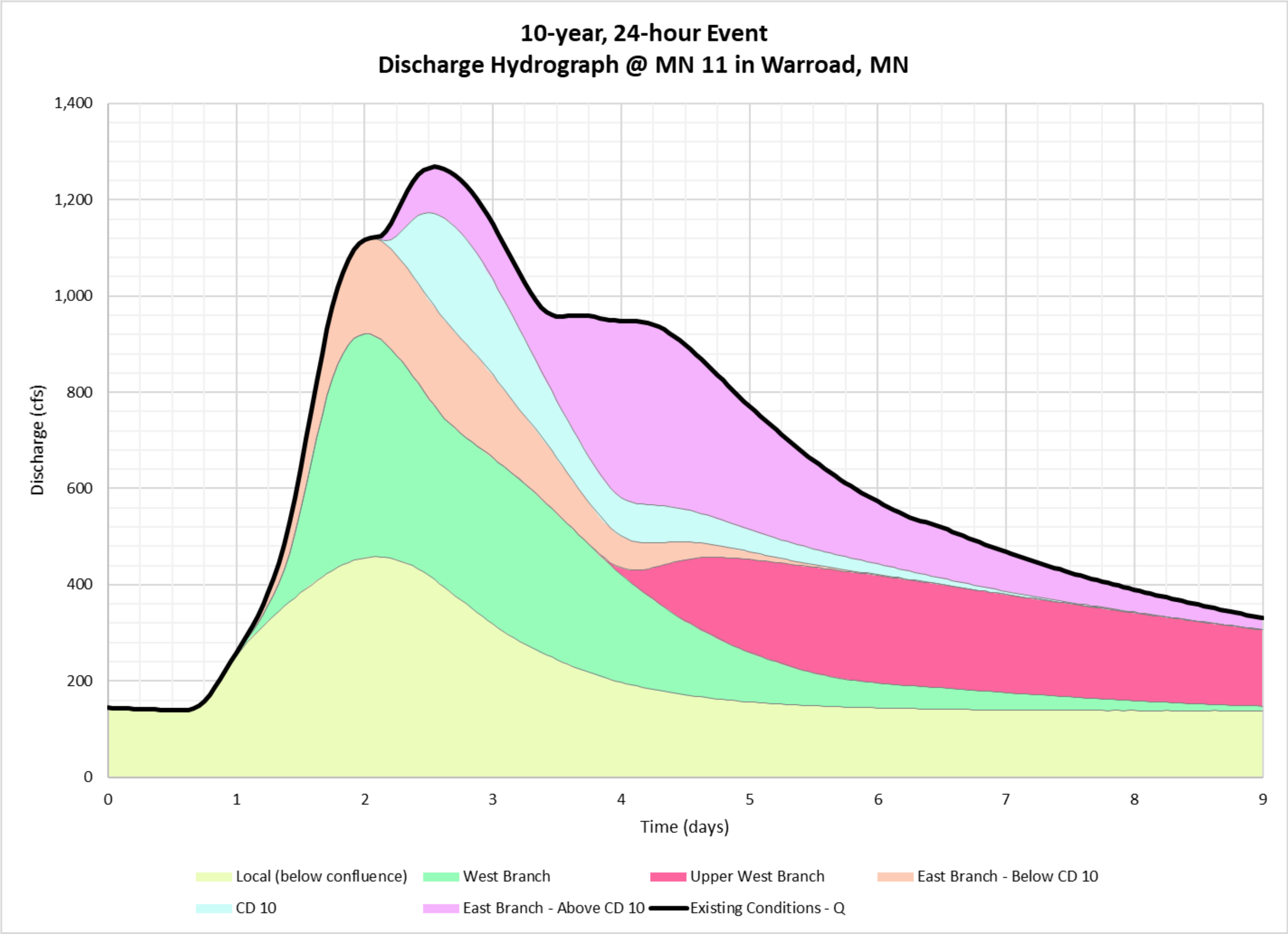
Ponce, Victor M. 2021. Website: The Lane Relation Revisited. Website accessed January 18, 2021. http://lane.sdsu.edu/

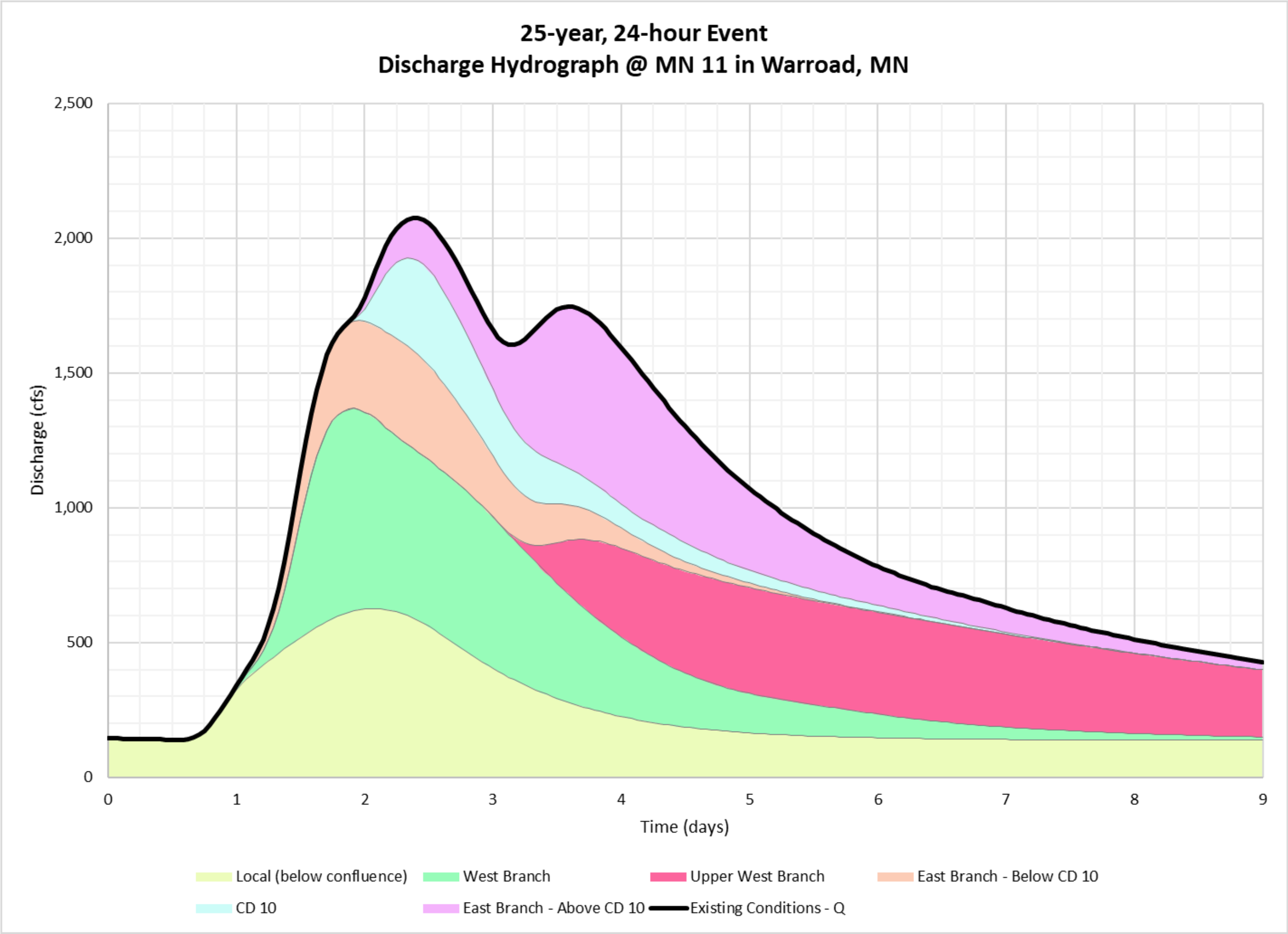
APPENDICES

APPENDIX A – STACKED HYDROGRAPHS

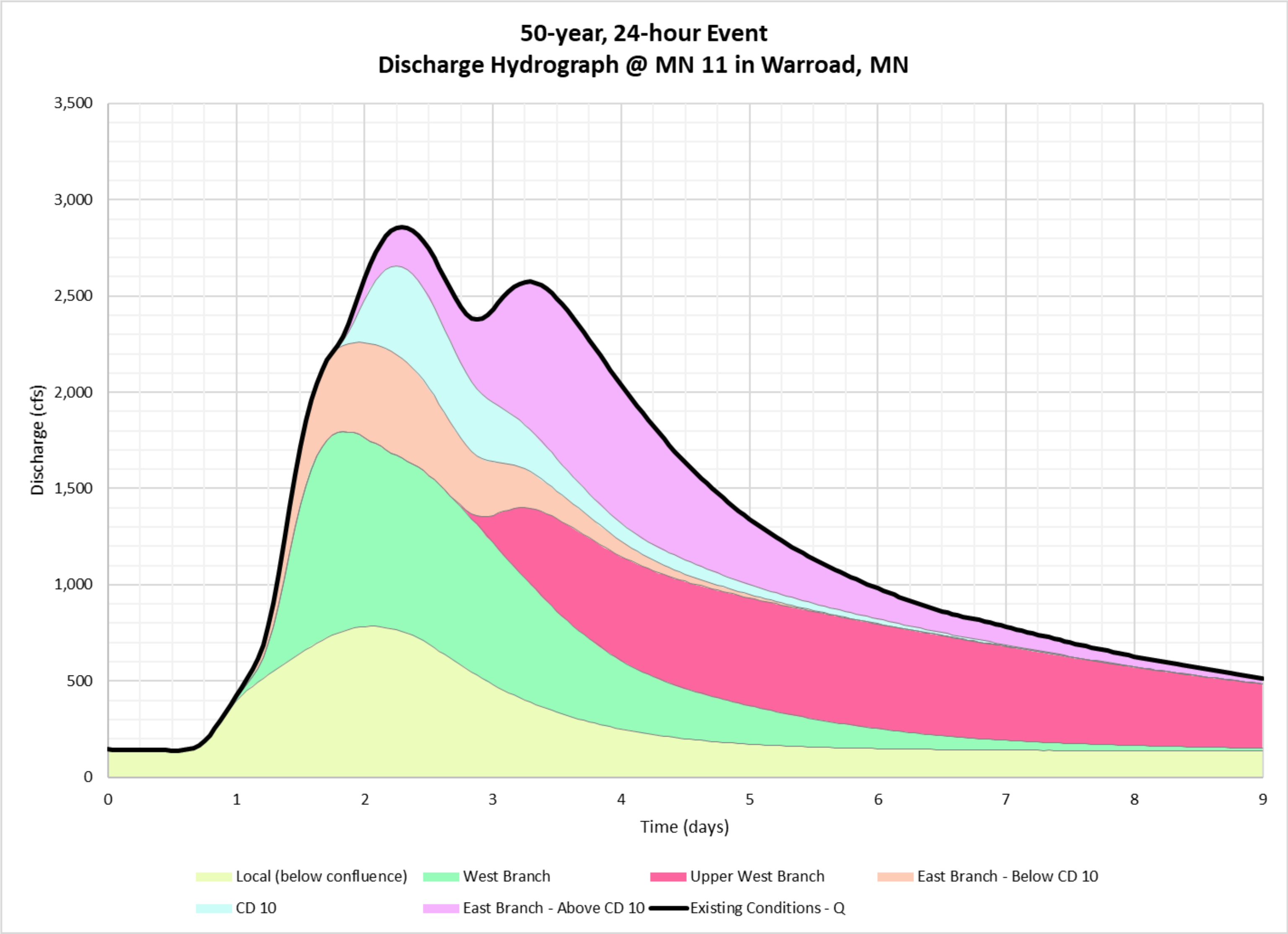

2-year, 24-hour Event
Discharge Hydrograph @ MN 11 in Warroad, MN
Discharge (cfs)
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
Time (days)
Local (below confluence)
West Branch
Upper West Branch
East Branch - Below CD 10
CD 10
East Branch - Above CD 10
Existing Conditions - Q

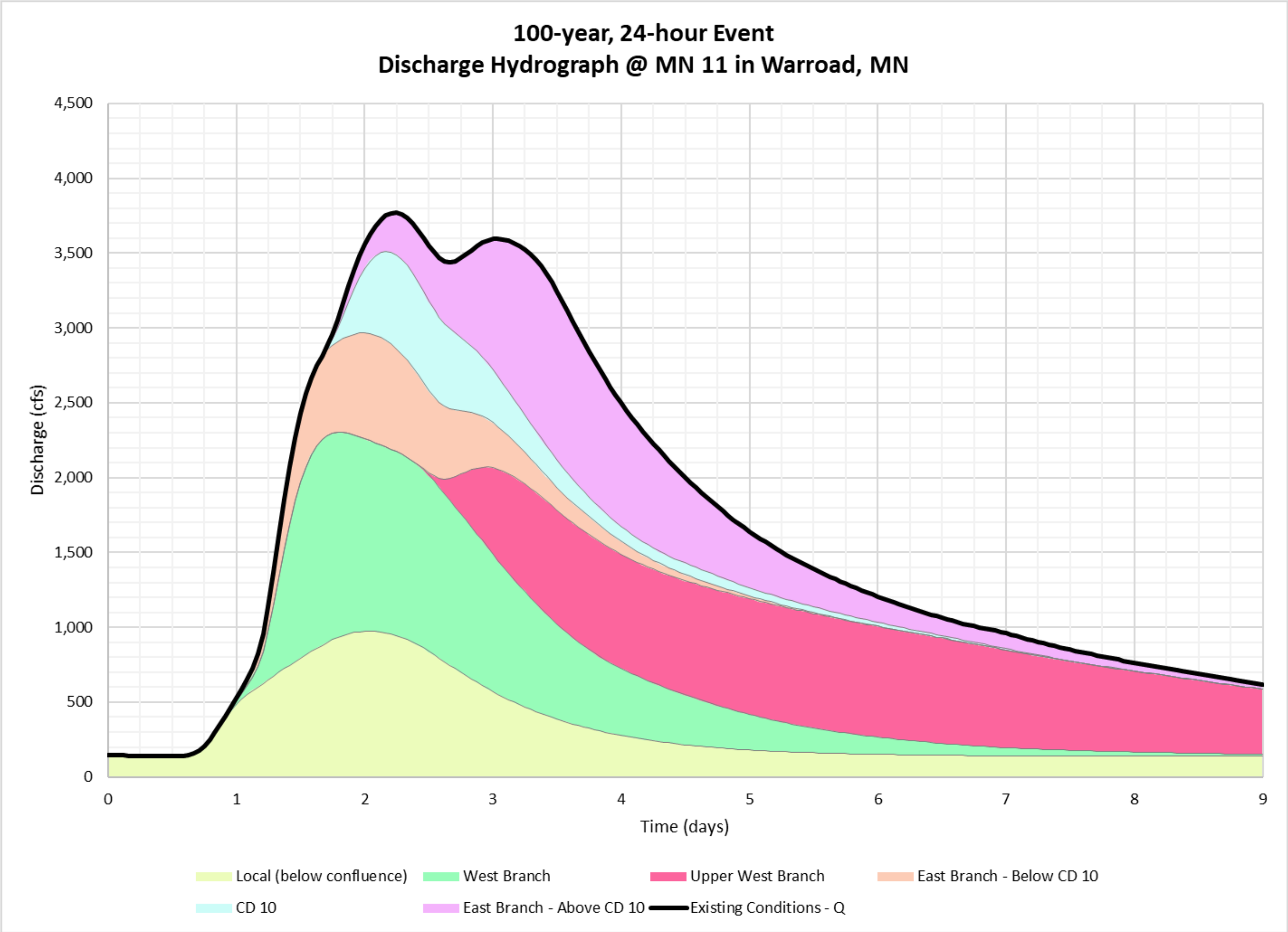

5-year, 24-hour Event
Discharge Hydrograph @ MN 11 in Warroad, MN
1,000
900
800
700
600
500
400
300
200
100
0
Discharge (cfs)
0
1
2
3
4
5
6
7
8
9
Time (days)
Local (below confluence)
West Branch
Upper West Branch
East Branch - Below CD 10
CD 10
East Branch - Above CD 10
Existing Conditions - Q


10-year, 24-hour Event
Discharge Hydrograph @ MN 11 in Warroad, MN
1,400
1,200
1,000
800
600
400
200
0
Discharge (cfs)
0
1
2
3
4
5
6
7
8
9
Time (days)
Local (below confluence)
West Branch
Upper West Branch
East Branch - Below CD 10
CD 10
East Branch - Above CD 10
Existing Conditions - Q



25-year, 24-hour Event
Discharge Hydrograph @ MN 11 in Warroad, MN
Discharge (cfs)
2,500
2,000
1,500
1,000
500
0
0
1
2
3
4
5
6
7
8
9
Time (days)
Local (below confluence)
West Branch
Upper West Branch
East Branch - Below CD 10
CD 10
East Branch - Above CD 10
Existing Conditions - Q


50-year, 24-hour Event
Discharge Hydrograph @ MN 11 in Warroad, MN
Discharge (cfs)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0
1
2
3
4
5
6
7
8
9
Time (days)
Local (below confluence)
West Branch
Upper West Branch
East Branch - Below CD 10
CD 10
East Branch - Above CD 10
Existing Conditions - Q


100-year, 24-hour Event
Discharge Hydrograph @ MN 11 in Warroad, MN
Discharge (cfs)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0
1
2
3
4
5
6
7
8
9
Time (days)
Local (below confluence)
West Branch
Upper West Branch
East Branch - Below CD 10
CD 10
East Branch - Above CD 10
Existing Conditions - Q

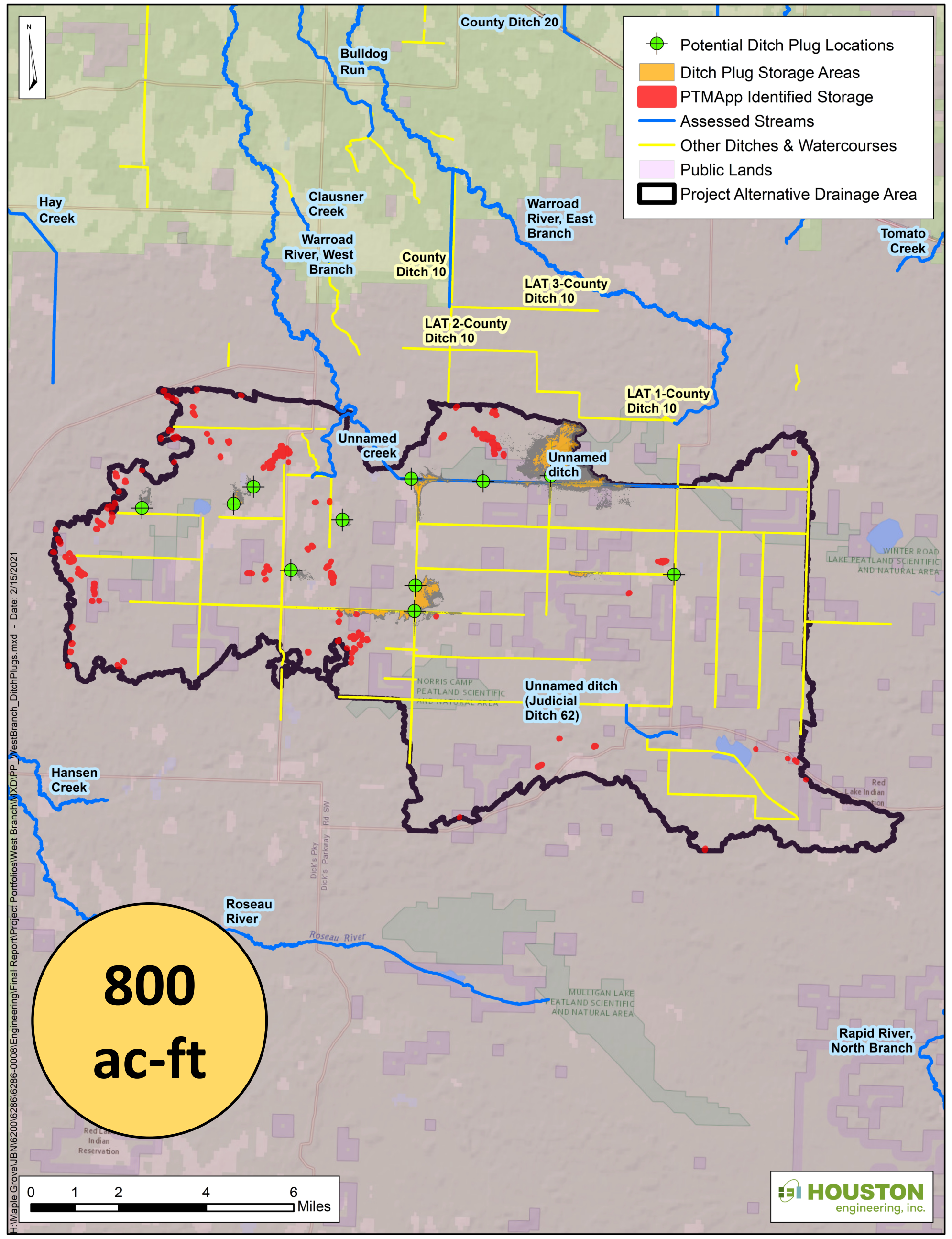
APPENDIX B – WEST BRANCH WARROAD RIVER PROJECT PORTFOLIO

West Branch Warroad River – Peatland Storage via Ditch Plugs

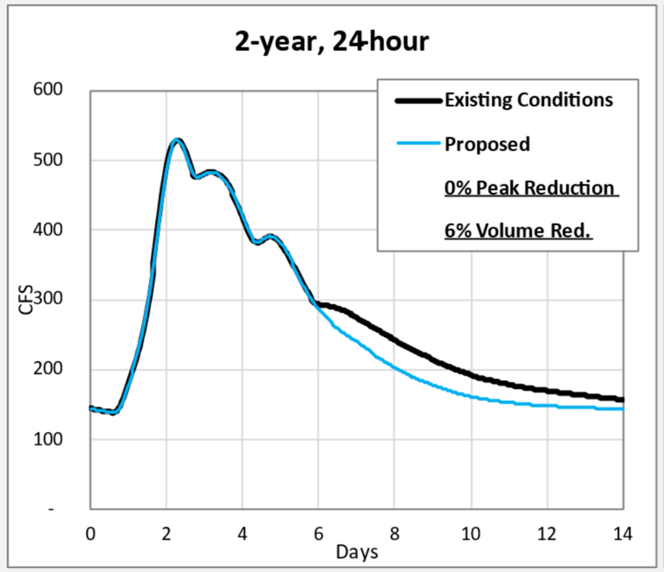
Peatland Storage via Ditch Plugs

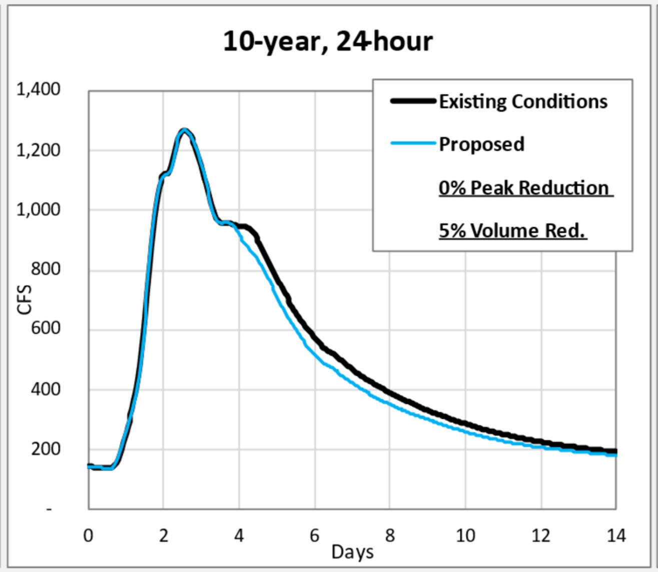
This alternative explores the potential for additional storage in the upstream peatlands using the application of ditch plugs. Ditch plug locations were strategically located to provide additional storage within the ditched wetland system. Overall, the ditch plugs shown provide approximately 800 ac-ft of additional storage. The PTMApp storage shown indicates an additional 107 ac-ft of potential storage. PTMApp storage is not included in the analysis.

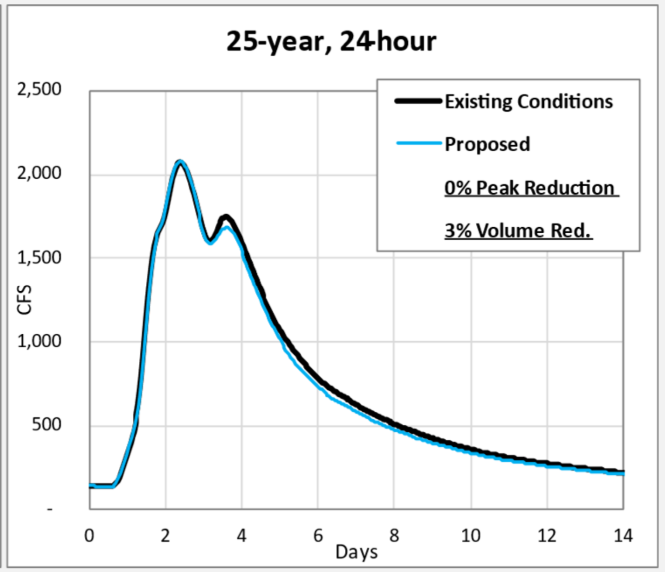
Project Alternative Area Map



Hydrologic & Hydraulic Results







Critical Area Peak Velocity Reductions

Location	2-Year 24-Hour			10-Year 24-Hour			25-Year 24-Hour		
	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction
W-12	0.6	0.6	0%	0.9	0.9	0%	1.0	1.0	0%
W-11	0.8	0.8	0%	1.3	1.3	0%	1.6	1.6	0%
W-5:W-10	1.5	1.5	0%	2.2	2.2	0%	2.6	2.6	0%
W-4	2.2	2.2	0%	2.7	2.7	0%	2.8	2.8	0%
W-3	1.1	1.1	0%	1.7	1.7	0%	2.1	2.1	0%
W-2	1.1	1.1	0%	1.5	1.5	0%	1.8	1.8	0%
W-1	2.1	2.1	0%	2.8	2.8	0%	3.4	3.4	0%

Location names correspond to those shown in **Figure 3** of the Warroad River Watershed Storage Identification & Evaluation Report and in-channel locations within the Lake of the Woods Watershed Comprehensive Watershed Plan.

Potential Annual Sediment Transport Reduction

Existing Condition: 10,443 tons

Alternative Condition: 9,196 tons

Reduction: 1,248 tons

12% reduction

Cost

Assuming a cost range of $10k-$50k per ditch plug and 11 ditch plugs, the cost range is estimated to be:

$110,000 - $550,000

*Ditch plug cost is extremely dependent on access and mobilization.

Summary

Pros

- Provides an estimated 12% reduction in annual sediment transport capacity of the Warroad River channel.
- Provides 3%-6% volume reduction (depending on design storm), assuming water is retained in the peatlands.
- Storage located on public lands.
- Cost effective compared to other project alternatives.

Cons

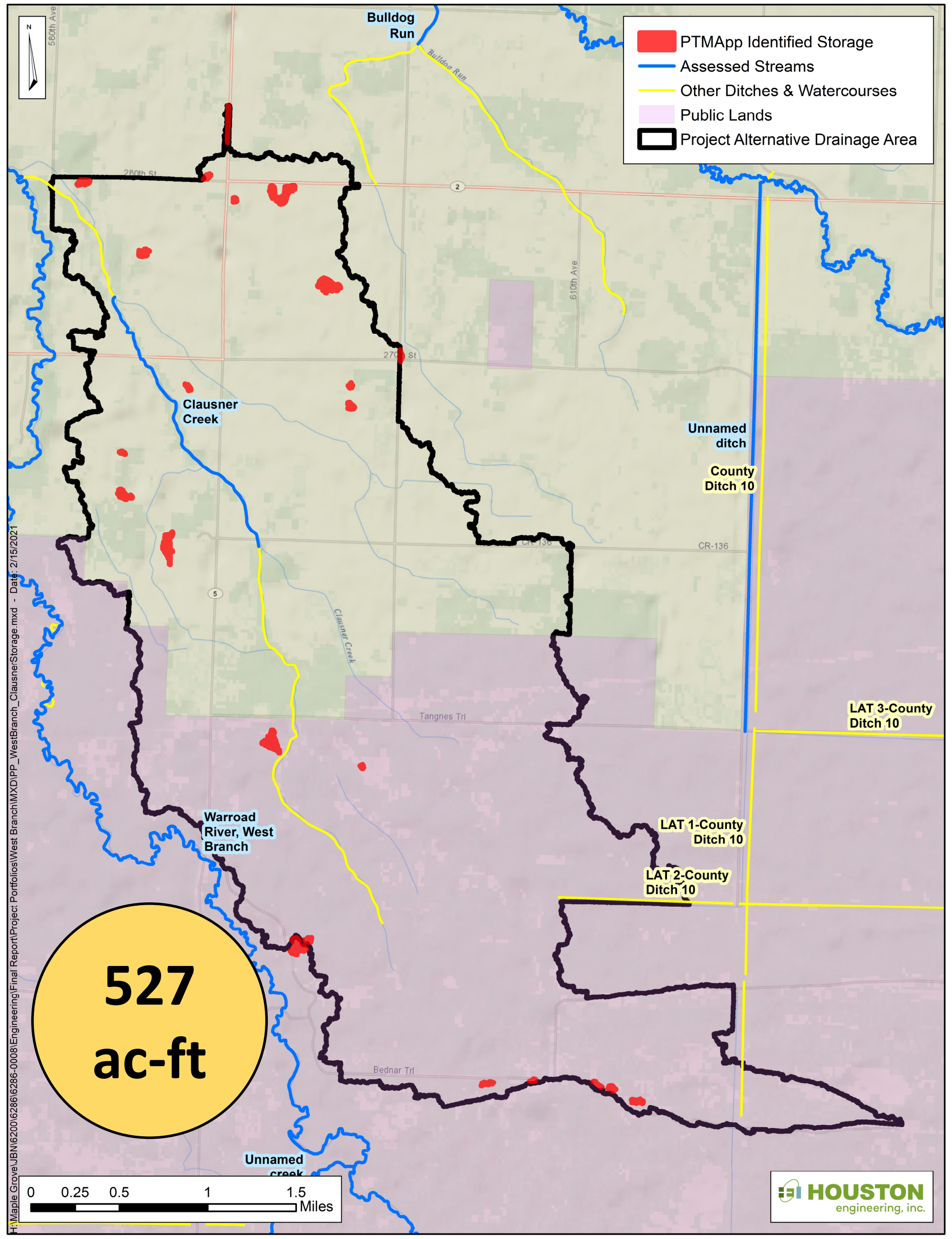
- No reduction in peak flows at the downstream analysis point on the Warroad River.
- No reduction in peak velocities at critical areas.
- Requires significant coordination with MnDNR staff to design and install ditch plugs.

West Branch Warroad River – Clausner Creek Storage 50%

Clausner Creek Storage 50%

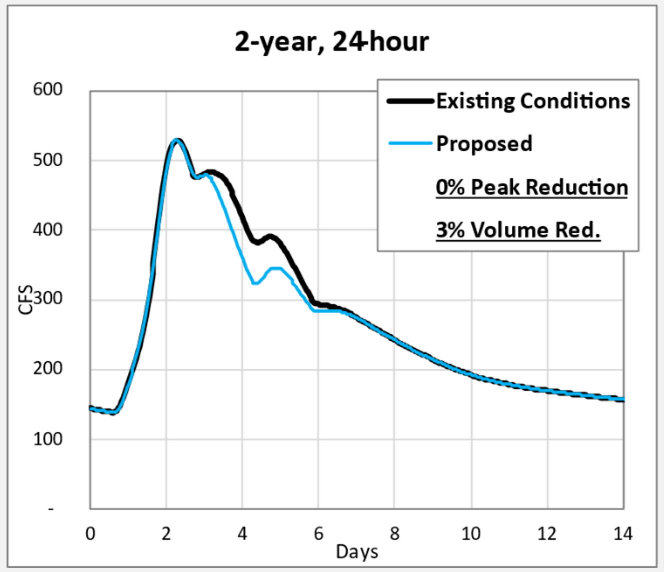
This alternative explores the potential for additional storage within the Clausner Creek subwatershed, prior to draining into the West Branch Warroad River. This alternative assumes a storage volume equal to 50% of the 25-year, 24-hour design storm event; a total storage of 527 ac-ft. Storage may be achieved via a large regional storage basin(s) or through individual smaller storage practices. The PTMApp storage shown indicates an additional 12 ac-ft of potential storage. PTMApp storage is not included in the analysis.

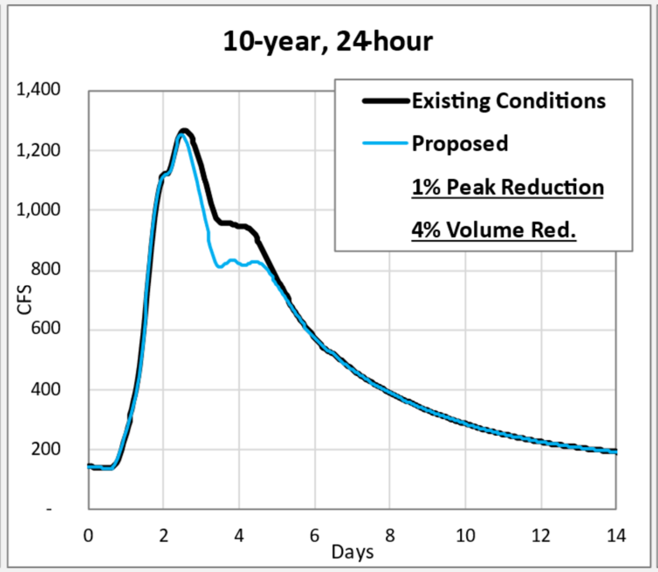
Project Alternative Area Map

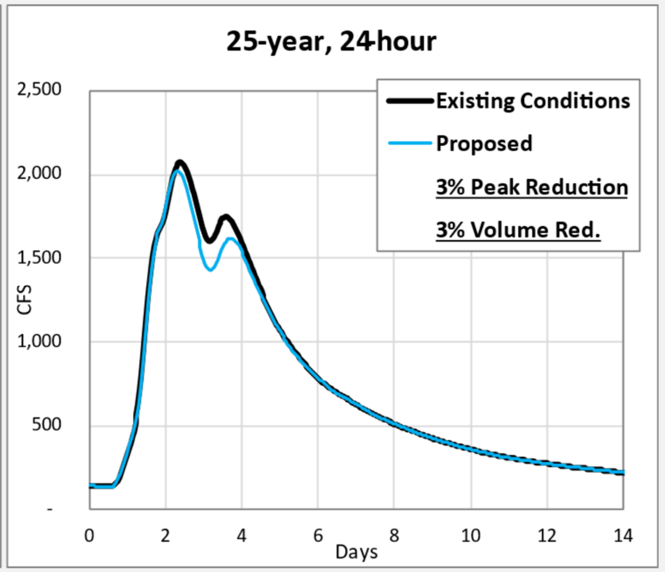


527 ac-ft

Hydrologic & Hydraulic Results







Critical Area Peak Velocity Reductions

Location	2-Year 24-Hour			10-Year 24-Hour			25-Year 24-Hour		
	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction
W-12	0.6	0.6	0%	0.9	0.8	4%	1.0	1.0	4%
W-11	0.8	0.8	1%	1.3	1.3	3%	1.6	1.6	4%
W-5:W-10	1.5	1.5	0%	2.2	2.2	0%	2.6	2.6	0%
W-4	2.2	2.2	0%	2.7	2.7	0%	2.8	2.8	0%
W-3	1.1	1.1	0%	1.7	1.7	0%	2.1	2.1	0%
W-2	1.1	1.1	0%	1.5	1.5	0%	1.8	1.8	0%
W-1	2.1	2.1	0%	2.8	2.8	0%	3.4	3.4	0%

Location names correspond to those shown in **Figure 3** of the Warroad River Watershed Storage Identification & Evaluation Report and in-channel locations within the Lake of the Woods Watershed Comprehensive Watershed Plan.

Potential Annual Sediment Transport Reduction

Existing Condition: **10,443 tons**

Alternative Condition: **10,050 tons**

Reduction: **393 tons**

4% reduction

Cost

Assuming a regional storage cost range of $2,000 - $3,000 per acre-foot of storage, the cost range is estimated to be:

$1.05M - $1.58M

*Does not include the cost of land acquisition if necessary.

Summary

Pros

- Provides an estimated 4% reduction in annual sediment transport capacity of the watershed channel.
- Provides 0%-3% peak flow reduction at the downstream analysis point on the Warroad River.
- Provides 3%-4% volume reduction (depending on design storm), assuming water is retained in the subwatershed.
- Provides up to 4% reduction in peak velocities at 2 of 9 critical areas.

Cons

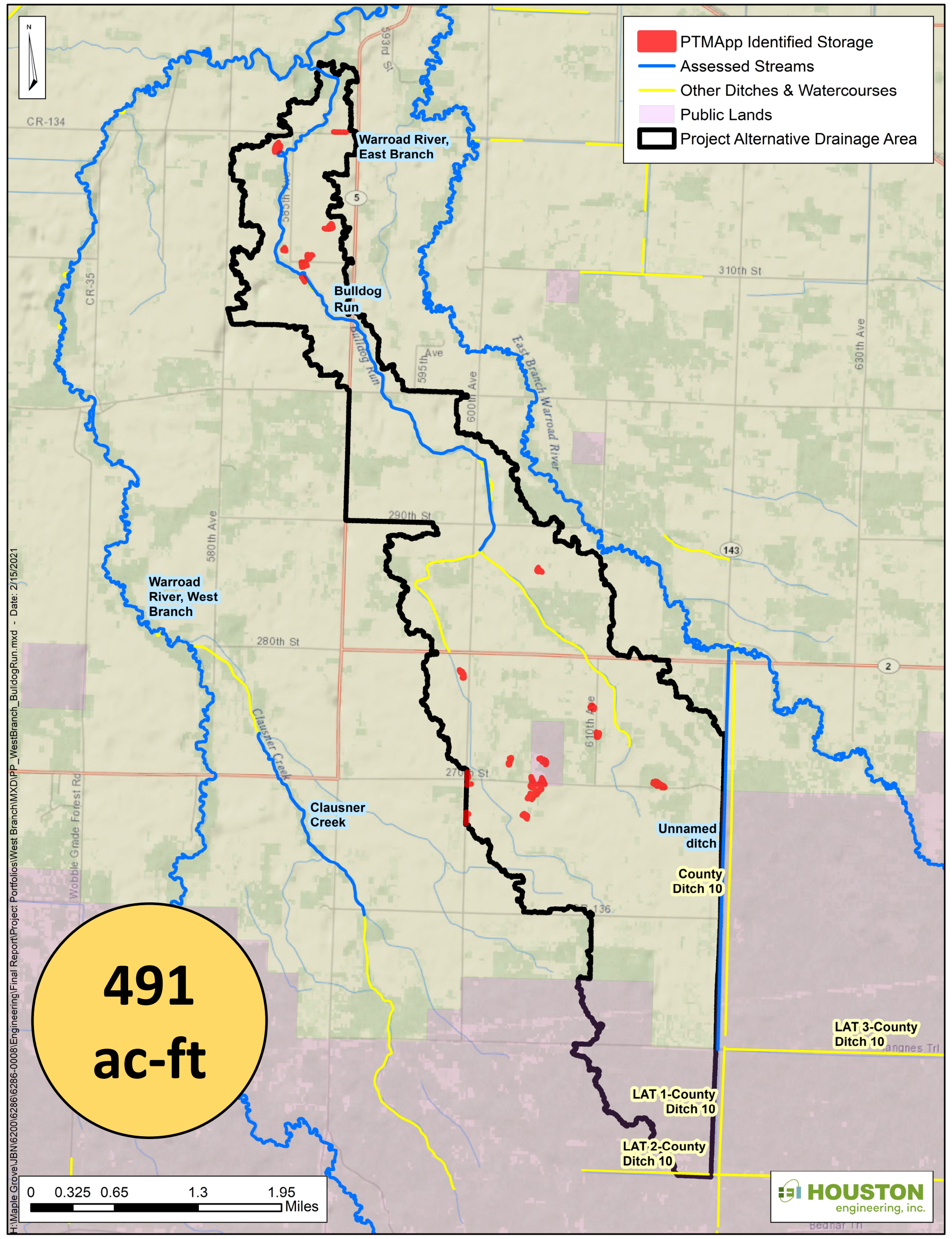
- A specific regional storage project location(s) has not yet been located.
- Large regional storage or multiple smaller storage options can be costly compared to other project alternatives.
- Requires potential coordination with private landowners and/or state agencies.

West Branch Warroad River – Bulldog Run Storage 50%

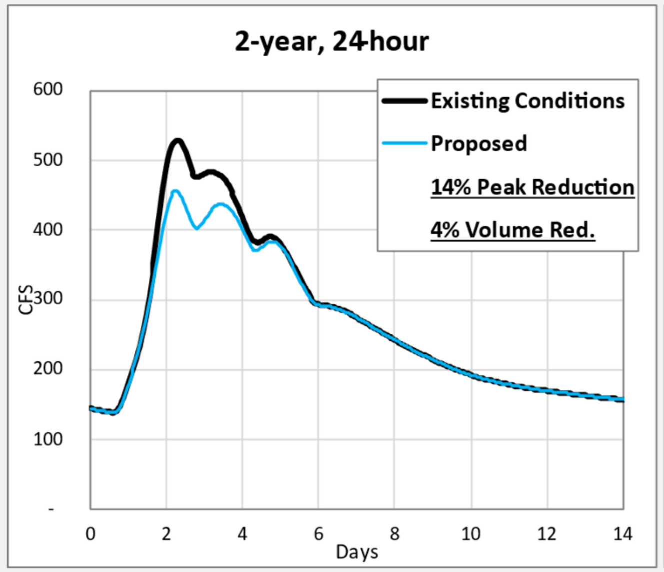
Bulldog Run Storage 50%

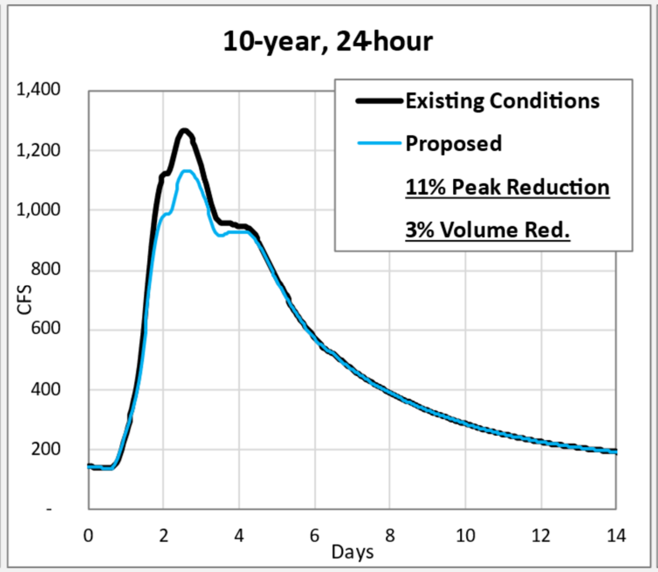
This alternative explores the potential for additional storage within the Bulldog Run subwatershed, prior to draining into the West Branch Warroad River. This alternative assumes a storage volume equal to 50% of the 25-year, 24-hour design storm event; a total storage of 491 ac-ft. Storage may be achieved via a large regional storage basin(s) or through individual smaller storage practices. The PTMApp storage shown indicates an additional 6 ac-ft of potential storage. PTMApp storage is not included in the analysis.

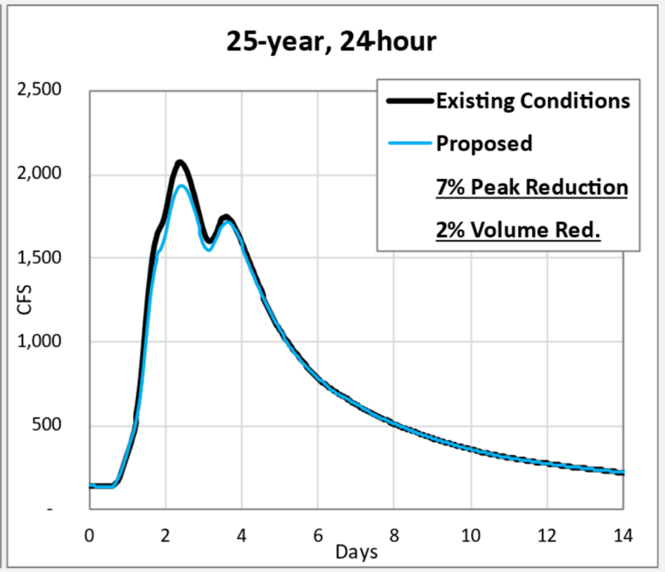
Project Alternative Area Map



Hydrologic & Hydraulic Results







Critical Area Peak Velocity Reductions

Location	2-Year 24-Hour			10-Year 24-Hour			25-Year 24-Hour		
	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction
W-12	0.6	0.5	7%	0.9	0.8	5%	1.0	1.0	3%
W-11	0.8	0.8	6%	1.3	1.2	5%	1.6	1.6	4%
W-5:W-10	1.5	1.3	16%	2.2	2.0	9%	2.6	2.5	5%
W-4	2.2	1.9	14%	2.7	2.6	3%	2.8	2.8	1%
W-3	1.1	1.0	11%	1.7	1.5	12%	2.1	2.0	7%

Location names correspond to those shown in **Figure 3** of the Warroad River Watershed Storage Identification & Evaluation Report and in-channel locations within the Lake of the Woods Watershed Comprehensive Watershed Plan.

Potential Annual Sediment Transport Reduction

Existing Condition: 10,443 tons

Alternative Condition: 10,305 tons

Reduction: 139 tons

1% reduction

Cost

Assuming a regional storage cost range of $2,000 - $3,000 per acre-foot of storage, the cost range is estimated to be:

$982,000 - $1.47M

*Does not include the cost of land acquisition if necessary.

Summary

Pros

- Provides an estimated 1% reduction in annual sediment transport capacity of the watershed channel.
- Provides 7%-14% peak flow reduction at the downstream analysis point on the Warroad River.
- Provides 2%-4% volume reduction (depending on design storm), assuming water is retained in the subwatershed.
- Provides up to 16% reduction in peak velocities at 5 of 9 critical areas.

Cons

- A specific regional storage project location(s) has not yet been located.
- Large regional storage or multiple smaller storage options can be costly compared to other project alternatives.
- Requires potential coordination with private landowners and/or state agencies.

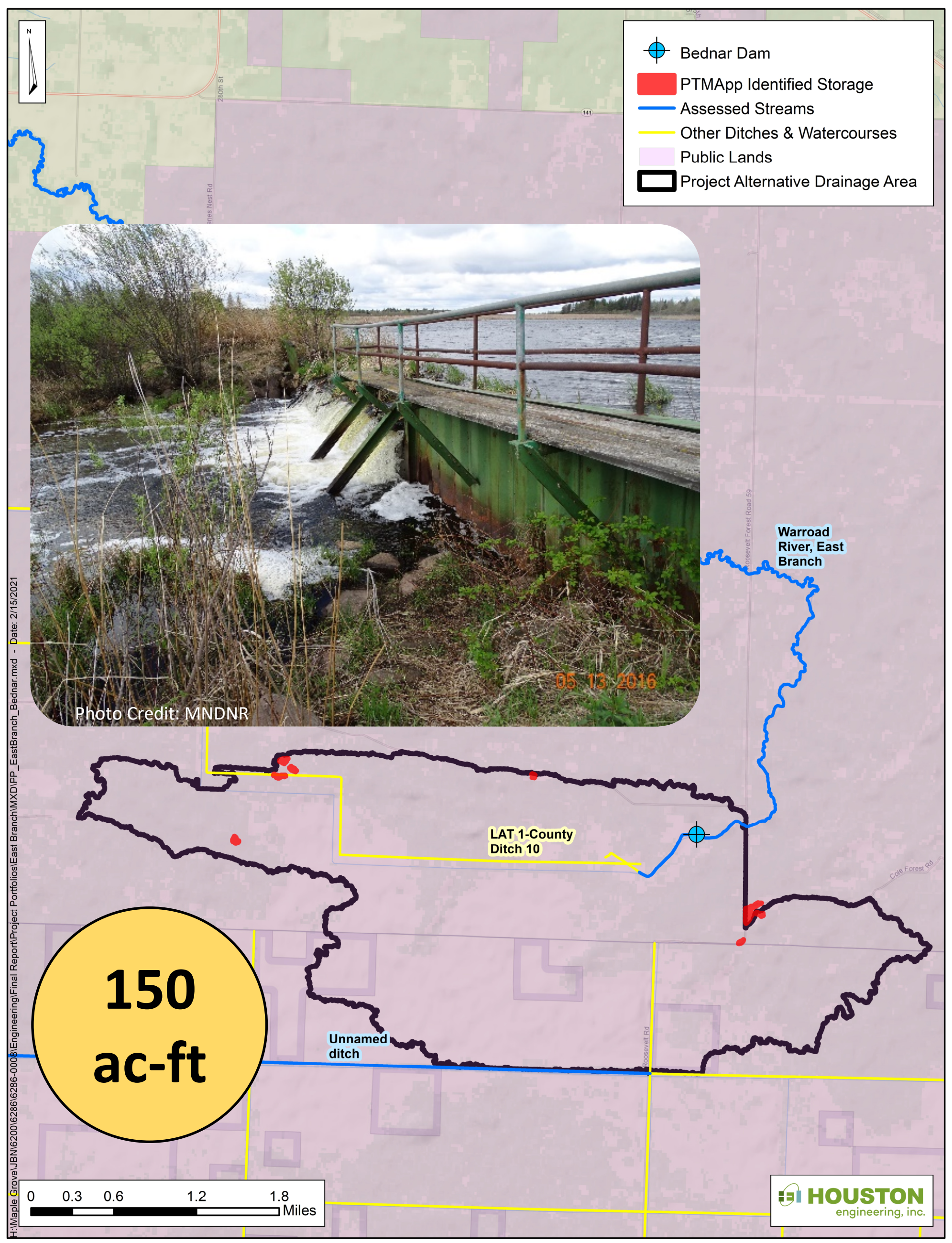
APPENDIX C - EAST BRANCH WARROAD RIVER PROJECT PORTFOLIO

East Branch Warroad River – Bednar Dam Improvements

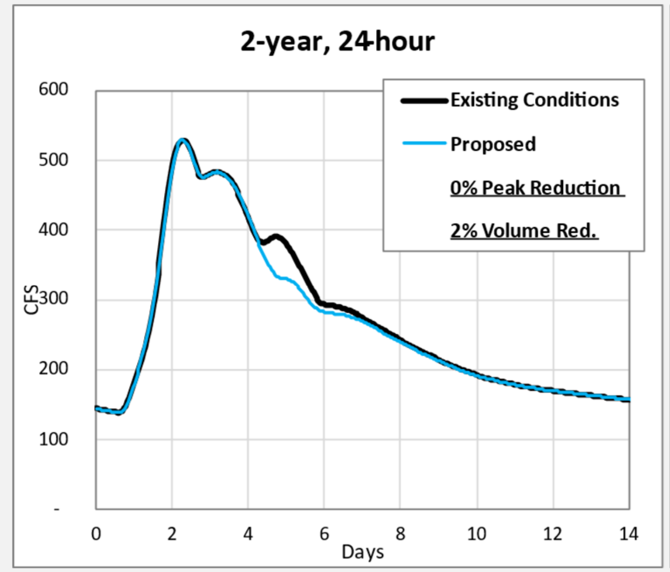
Bednar Dam Improvements

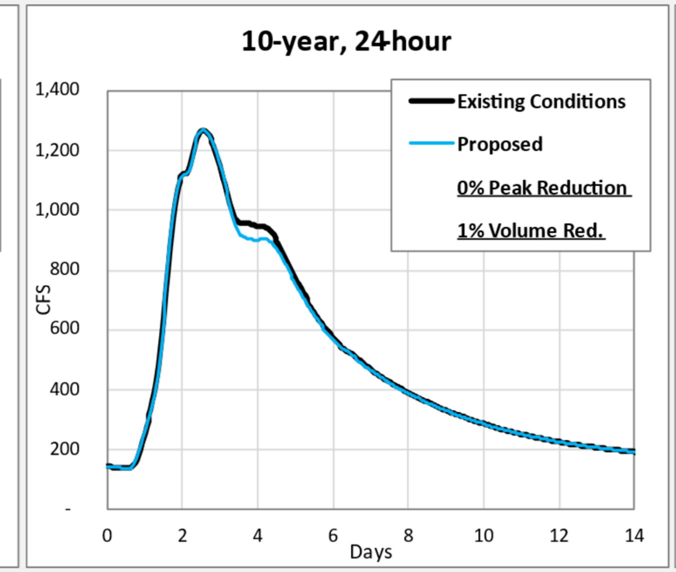
This alternative explores the potential for additional storage through modification to the Bednar Dam. This could be achieved through a combination of constricting the dam outlet weir and raising the top of the dam structure (overflow). It is estimated that the dam modifications could provide additional storage of approximately 150 ac-ft. The PTMApp storage shown indicates an additional 3 ac-ft of potential storage. PTMApp storage is not included in the analysis.

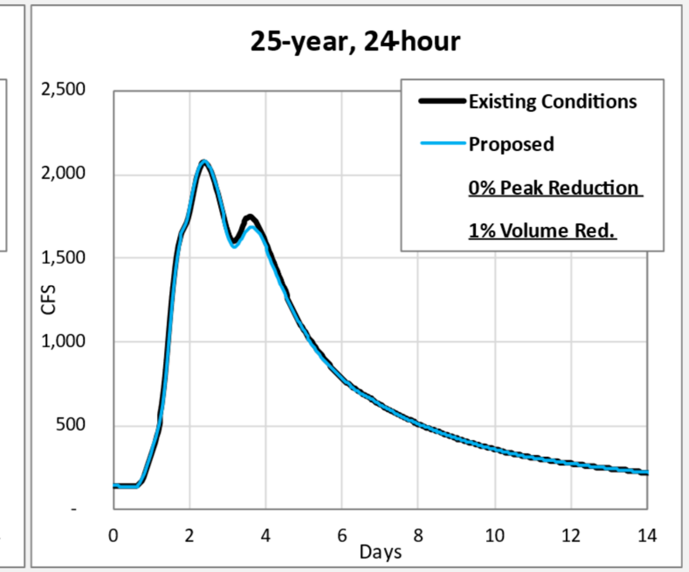
Project Alternative Area Map



Hydrologic & Hydraulic Results







Critical Area Peak Velocity Reductions

Location	2-Year 24-Hour			10-Year 24-Hour			25-Year 24-Hour		
	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction
W-14:W-17	1.9	1.9	0%	2.6	2.6	0%	3.0	3.0	0%
W-13	1.8	1.8	0%	2.8	2.8	0%	3.1	3.1	0%
W-12	0.6	0.6	0%	0.9	0.9	0%	1.0	1.0	0%
W-11	0.8	0.8	0%	1.3	1.3	0%	1.6	1.6	0%

Location names correspond to those shown in **Figure 3** of the Warroad River Watershed Storage Identification & Evaluation Report and in-channel locations within the Lake of the Woods Watershed Comprehensive Watershed Plan.

Potential Annual Sediment Transport Reduction

Existing Condition: 10,443 tons

Alternative Condition: 10,034 tons

Reduction: 409 tons

4% reduction

Cost

Depending on the extent of the modification and site access, dam improvement are estimate to range from:

$1M - $3M

Summary

Pros

- Provides an estimated 4% reduction in annual sediment transport capacity of the watershed channel.
- Provides 1%-2% volume reduction (depending on design storm), assuming water is retained in the peatlands.
- Storage located on public lands.
- Cost effective compared to other project alternatives.

Cons

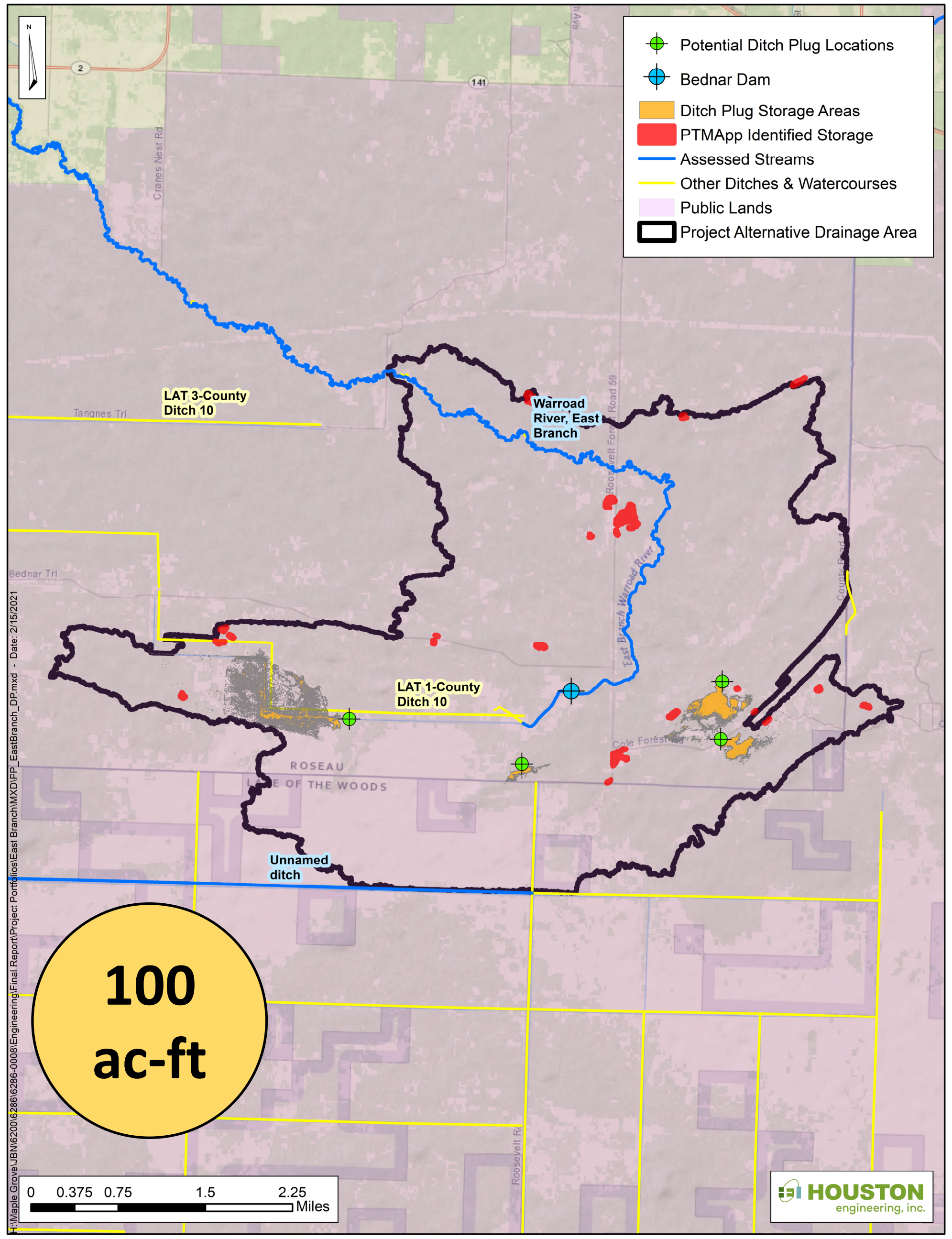
- No reduction in peak flows at the downstream analysis point on the Warroad River.
- No reduction in peak velocities at critical areas.
- Requires significant coordination with MnDNR dam safety staff.
- Reductions not as significant as compare to other project alternatives.

East Branch Warroad River – Peatland Storage via Ditch Plugs

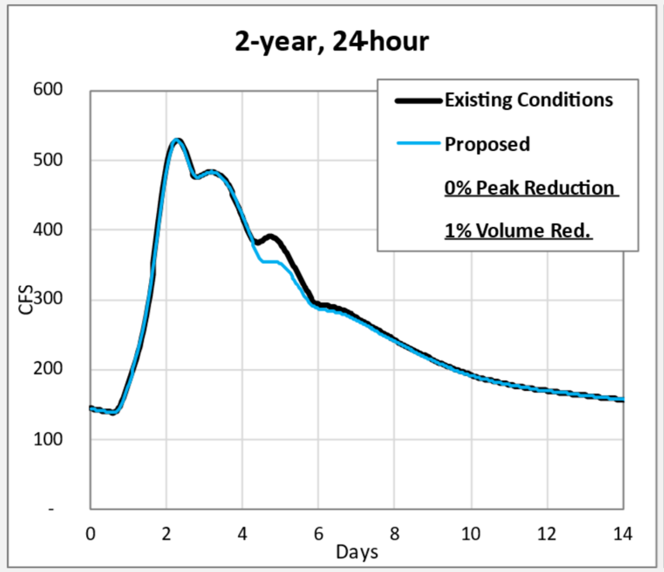
Peatland Storage via Ditch Plugs

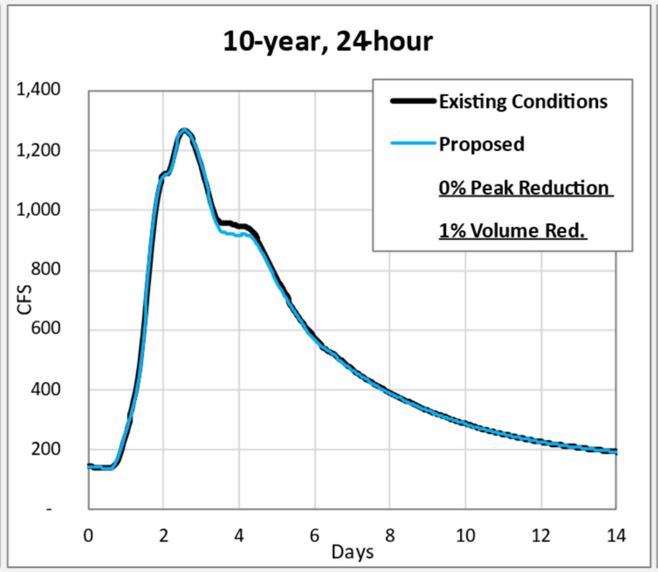
This alternative explores the potential for additional storage in the upstream peatlands using the application of ditch plugs. Ditch plug locations were strategically located to provide additional storage within the ditched wetland system. Overall, the ditch plugs shown provide approximately 100 ac-ft of additional storage. The PTMApp storage shown indicates an additional 29 ac-ft of potential storage. PTMApp storage is not included in the analysis.

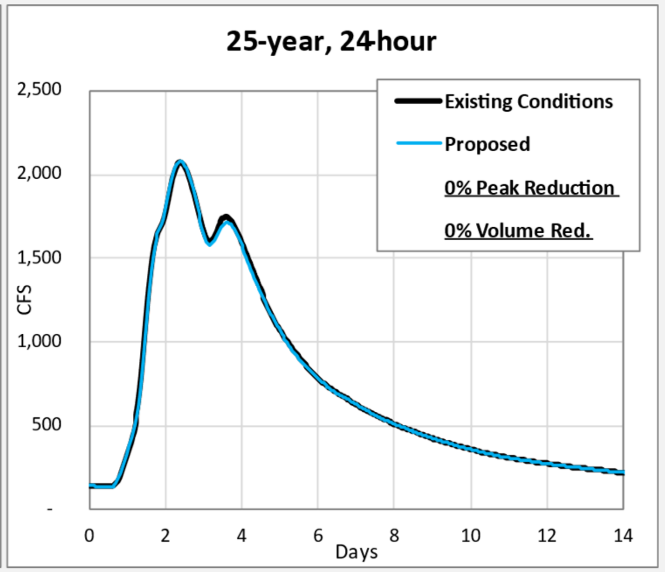
Project Alternative Area Map



Hydrologic & Hydraulic Results







Critical Area Peak Velocity Reductions

Location	2-Year 24-Hour			10-Year 24-Hour			25-Year 24-Hour		
	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction
W-14:W-17	1.9	1.9	0%	2.6	2.6	0%	3.0	3.0	0%
W-13	1.8	1.8	0%	2.8	2.8	0%	3.1	3.1	0%
W-12	0.6	0.6	0%	0.9	0.9	0%	1.0	1.0	0%
W-11	0.8	0.8	0%	1.3	1.3	0%	1.6	1.6	0%

Location names correspond to those shown in **Figure 3** of the Warroad River Watershed Storage Identification & Evaluation Report and in-channel locations within the Lake of the Woods Watershed Comprehensive Watershed Plan.

Potential Annual Sediment Transport Reduction

Existing Condition: 10,443 tons

Alternative Condition: 10,179 tons

Reduction: 264 tons

3% reduction

Cost

Assuming a cost range of $10k-$50k per ditch plug and 4 ditch plugs, the cost range is estimated to be:

$40,000 - $200,000

*Ditch plug cost is extremely dependent on access and mobilization.

Summary

Pros

- Provides an estimated 3% reduction in annual sediment transport capacity of the Warroad River channel.
- Provides 0%-1% volume reduction (depending on design storm), assuming water is retained in the peatlands.
- Storage located on public lands.
- Cost effective compared to other project alternatives.

Cons

- No reduction in peak flows at the downstream analysis point on the Warroad River.
- No reduction in peak velocities at critical areas.
- Requires significant coordination with MnDNR staff to design and install ditch plugs.

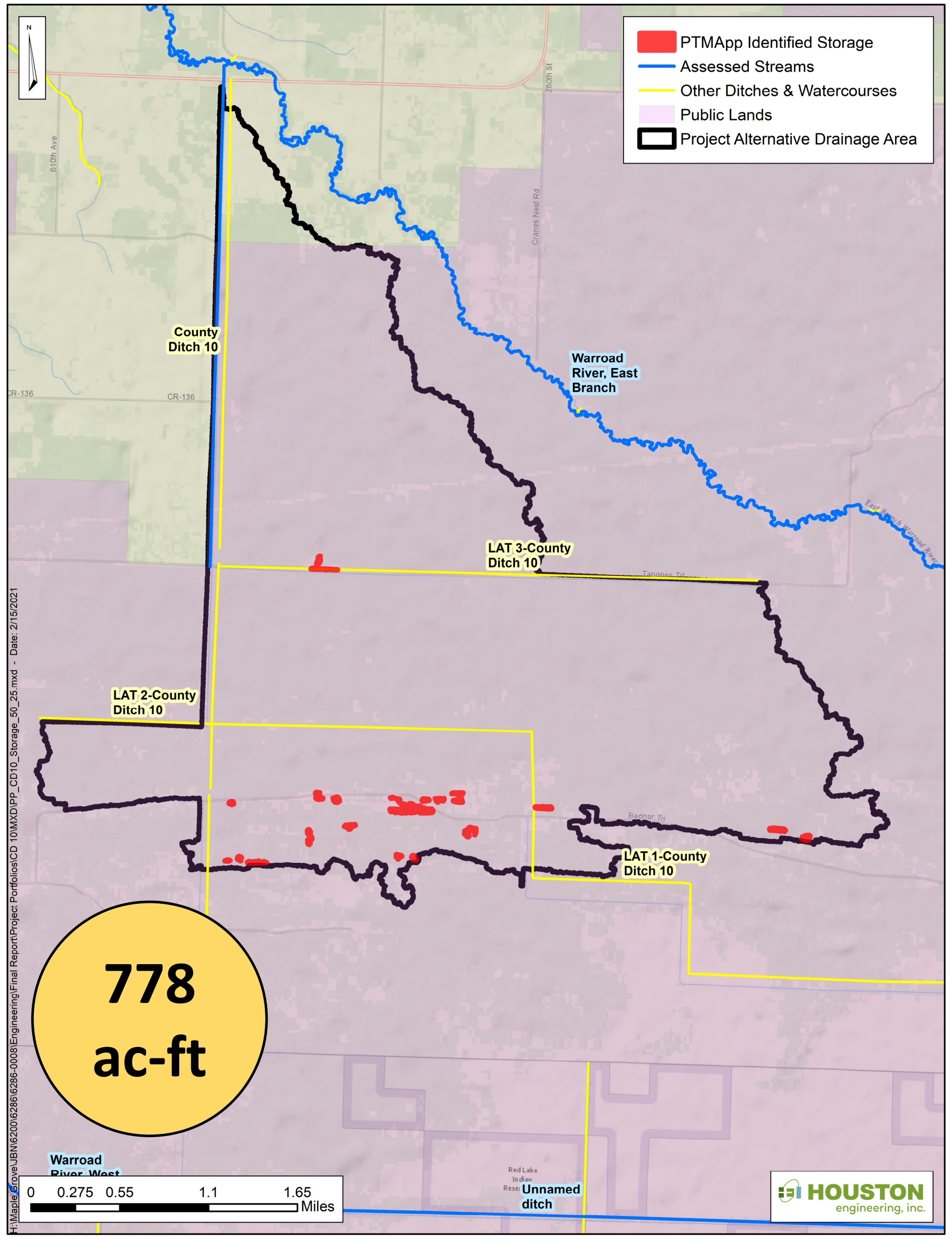
APPENDIX D – COUNTY DITCH 10 (CD10) PROJECT PORTFOLIO

County Ditch 10 – Regional Storage 50%

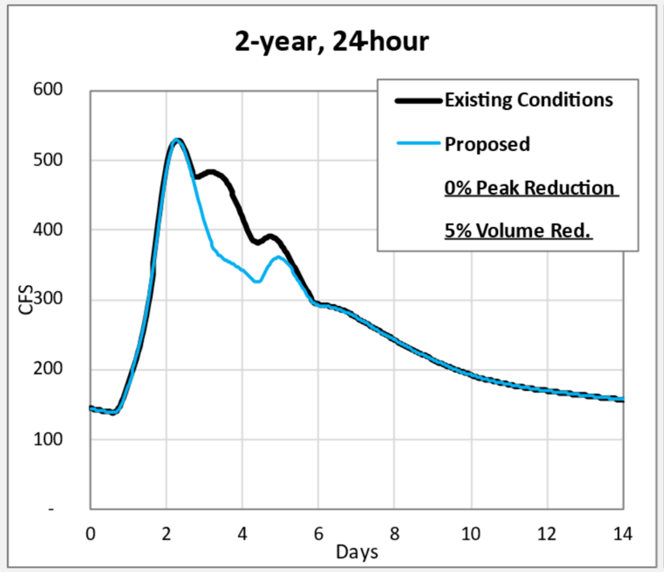
Regional Storage 50%

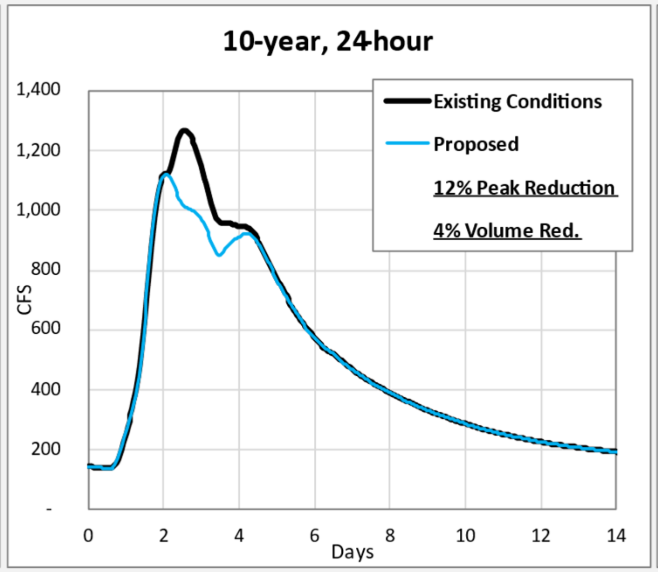
This alternative explores the potential for additional storage within the CD 10 subwatershed, prior to draining into the East Branch Warroad River. This alternative assumes a storage volume equal to 50% of the 25-year, 24-hour design storm event; a total storage of 778 ac-ft. Storage may be achieved via a large regional storage basin(s) or through individual smaller storage practices. The PTMApp storage shown indicates an additional 8 ac-ft of potential storage. PTMApp storage is not included in the analysis.

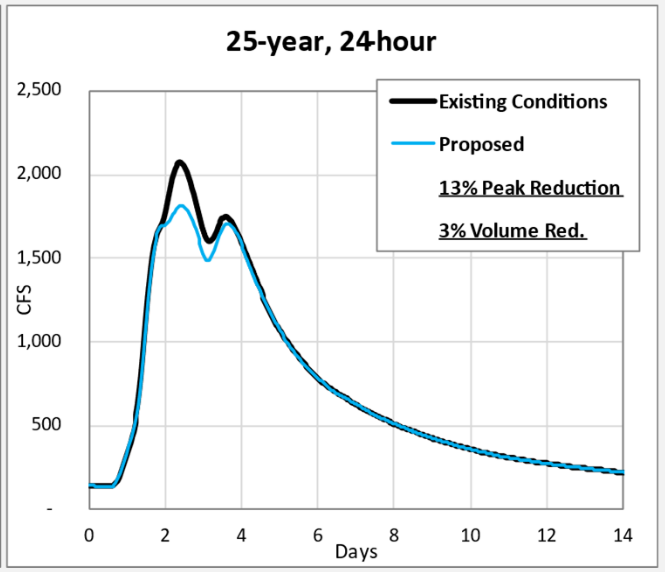
Project Alternative Area Map



Hydrologic & Hydraulic Results







Critical Area Peak Velocity Reductions

Location	2-Year 24-Hour			10-Year 24-Hour			25-Year 24-Hour		
	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction
W-14:W-17	1.9	1.4	26%	2.6	2.2	18%	3.0	2.7	9%
W-13	1.8	1.3	29%	2.8	2.2	22%	3.1	2.9	7%
W-12	0.6	0.5	9%	0.9	0.8	9%	1.0	1.0	7%
W-11	0.8	0.8	10%	1.3	1.2	12%	1.6	1.5	8%

Location names correspond to those shown in **Figure 3** of the Warroad River Watershed Storage Identification & Evaluation Report and in-channel locations within the Lake of the Woods Watershed Comprehensive Watershed Plan.

Potential Annual Sediment Transport Reduction

Existing Condition: 10,443 tons

Alternative Condition: 9,594 tons

Reduction: 849 tons

9% reduction

Cost

Assuming a regional storage cost range of $2,000 - $3,000 per acre-foot of storage, the cost range is estimated to be:

$1.55M - $2.33M

*Does not include the cost of land acquisition if necessary.

Summary

Pros

- Provides an estimated 9% reduction in annual sediment transport capacity of the Warroad River channel.
- Provides 0%-13% peak flow reduction at the downstream analysis point on the Warroad River.
- Provides 3%-5% volume reduction (depending on design storm), assuming water is retained in the subwatershed..
- Provides up to 29% reduction in peak velocities at 4 of 9 critical areas.
- Majority of the subwatershed is located on public land.

Cons

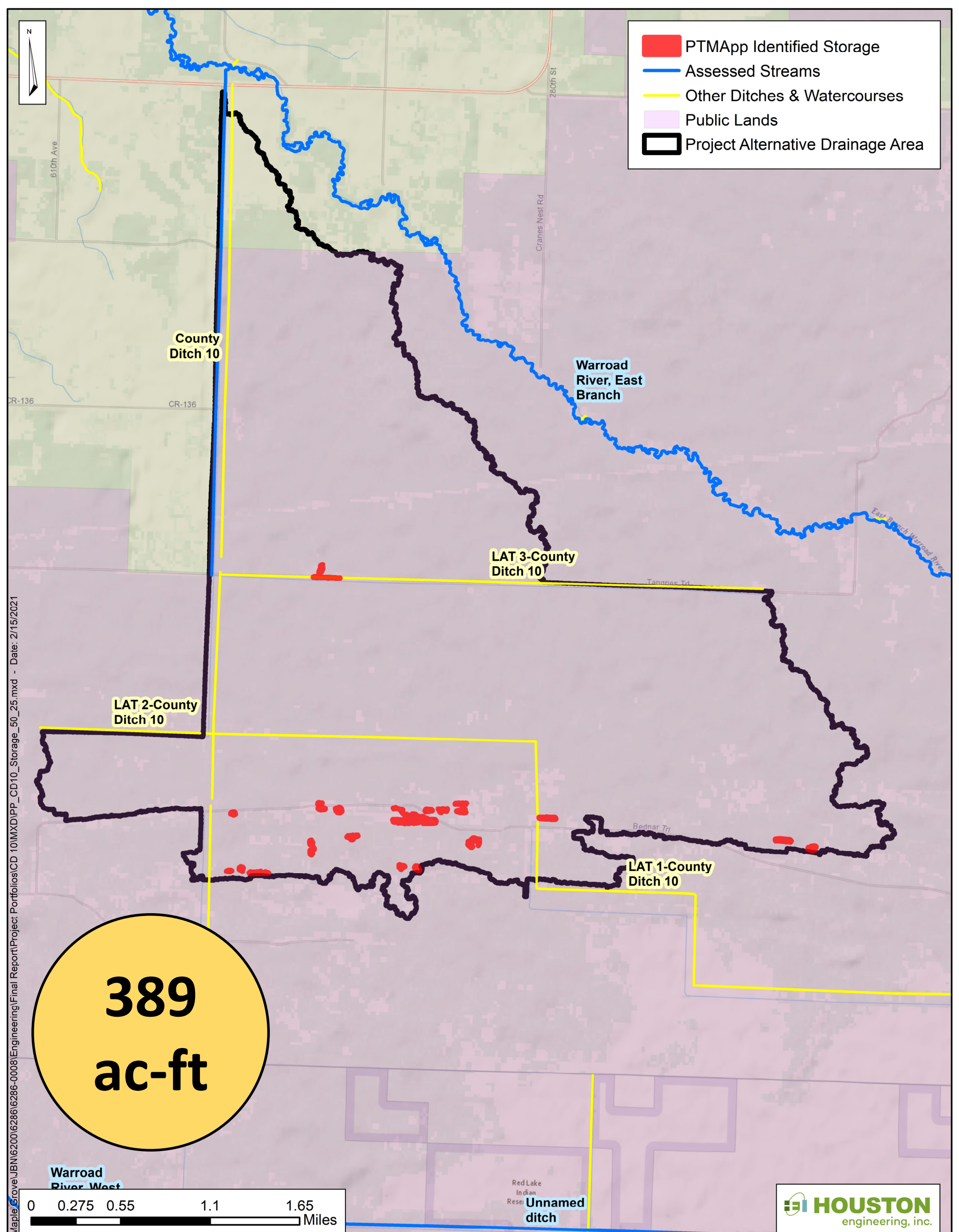
- A specific regional storage project location(s) has not yet been located.
- Large regional storage or multiple smaller storage options can be costly compared to other project alternatives.
- Requires potential coordination with private landowners and/or state agencies.

County Ditch 10 – Regional Storage 25%

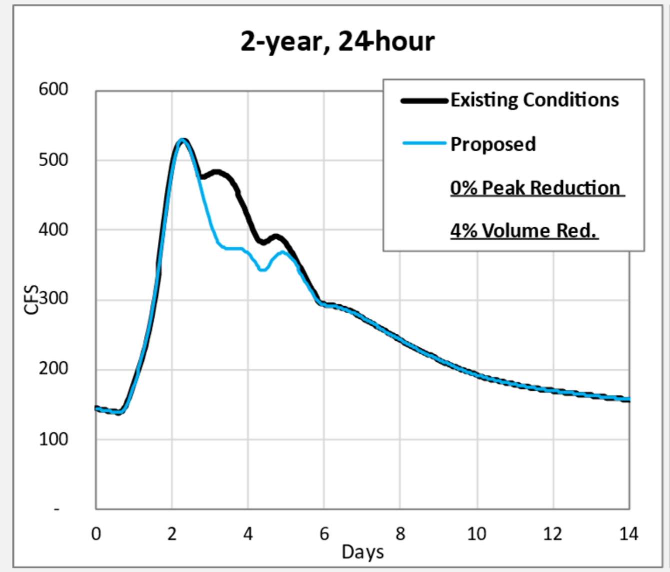
Regional Storage 25%

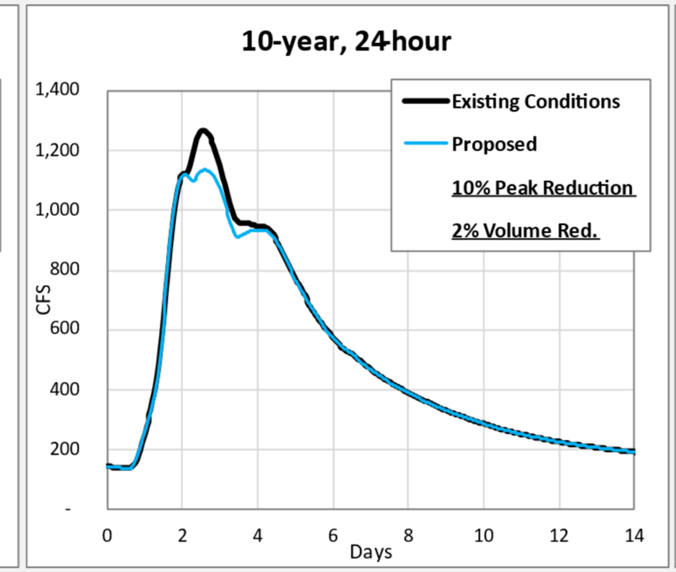
This alternative explores the potential for additional storage within the CD 10 subwatershed, prior to draining into the East Branch Warroad River. This alternative assumes a storage volume equal to 25% of the 25-year, 24-hour design storm event; a total storage of 389 ac-ft. Storage may be achieved via a large regional storage basin(s) or through individual smaller storage practices. The PTMApp storage shown indicates an additional 8 ac-ft of potential storage. PTMApp storage is not included in the analysis.

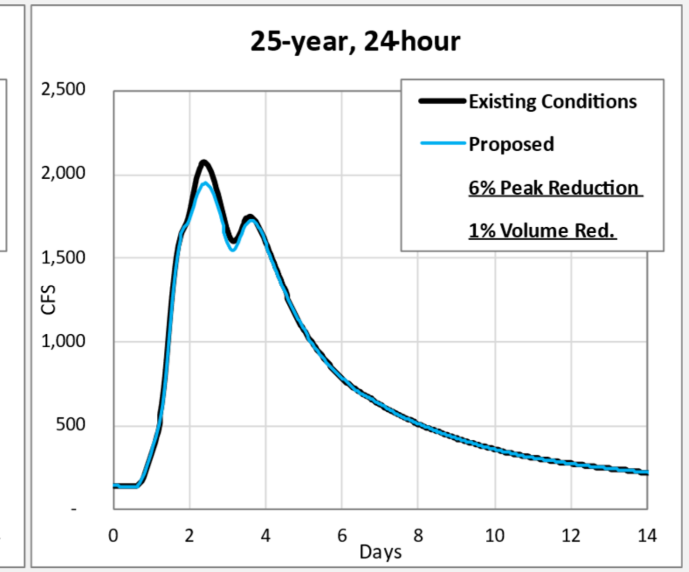
Project Alternative Area Map



Hydrologic & Hydraulic Results







Critical Area Peak Velocity Reductions

Location	2-Year 24-Hour			10-Year 24-Hour			25-Year 24-Hour		
	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction
W-14:W-17	1.9	1.4	26%	2.6	2.4	8%	3.0	2.9	4%
W-13	1.8	1.3	28%	2.8	2.5	8%	3.1	3.0	4%
W-12	0.6	0.5	9%	0.9	0.8	5%	1.0	1.0	3%
W-11	0.8	0.8	10%	1.3	1.2	5%	1.6	1.6	4%

Location names correspond to those shown in **Figure 3** of the Warroad River Watershed Storage Identification & Evaluation Report and in-channel locations within the Lake of the Woods Watershed Comprehensive Watershed Plan.

Potential Annual Sediment Transport Reduction

Existing Condition: 10,443 tons

Alternative Condition: 9,936 tons

Reduction: 508 tons

5% reduction

Cost

Assuming a regional storage cost range of $2,000 - $3,000 per acre-foot of storage, the cost range is estimated to be:

$778,000 - $1.17M

*Does not include the cost of land acquisition if necessary.

Summary

Pros

- Provides an estimated 5% reduction in annual sediment transport capacity of the Warroad River channel.
- Provides 0%-10% peak flow reduction at the downstream analysis point on the Warroad River.
- Provides 1%-4% volume reduction (depending on design storm), assuming water is retained in the subwatershed..
- Provides up to 28% reduction in peak velocities at 4 of 9 critical areas.
- Majority of the subwatershed is located on public land.

Cons

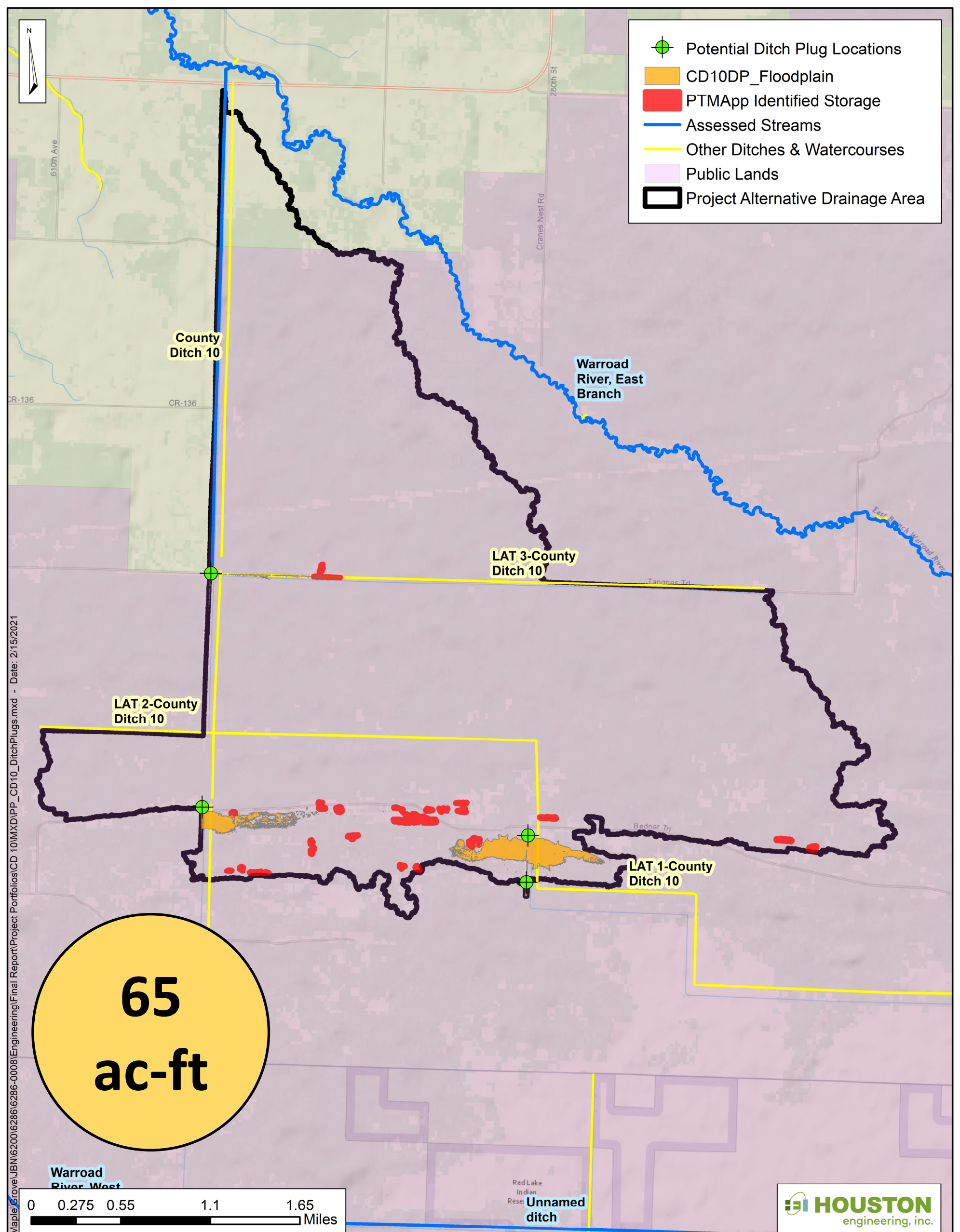
- A specific regional storage project location(s) has not yet been located.
- Large regional storage or multiple smaller storage options can be costly compared to other project alternatives.
- Requires potential coordination with private landowners and/or state agencies.

County Ditch 10 – Peatland Storage via Ditch Plugs

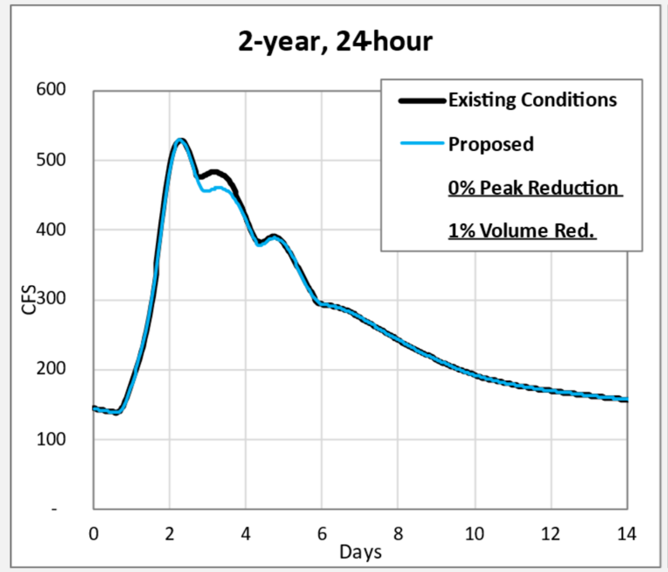
Peatland Storage via Ditch Plugs

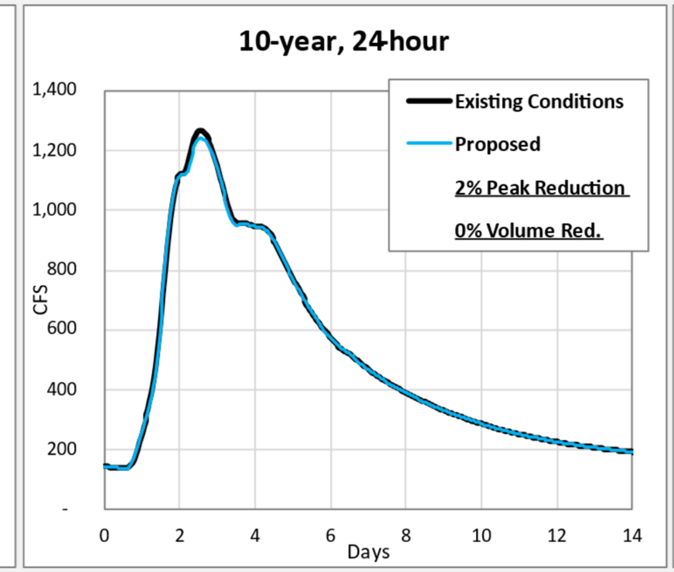
This alternative explores the potential for additional storage in the upstream peatlands using the application of ditch plugs. Ditch plug locations were strategically located to provide additional storage within the ditched wetland system. Overall, the ditch plugs shown provide approximately 65 ac-ft of additional storage. The PTMApp storage shown indicates an additional 8 ac-ft of potential storage. PTMApp storage is not included in the analysis.

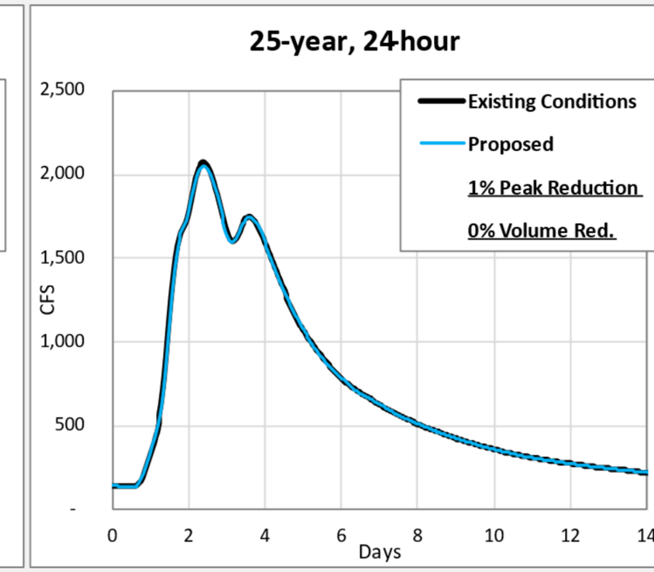
Project Alternative Area Map



Hydrologic & Hydraulic Results







Critical Area Peak Velocity Reductions

Location	2-Year 24-Hour			10-Year 24-Hour			25-Year 24-Hour		
	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction	Existing (ft/s)	Proposed (ft/s)	Percent Reduction
W-14:W-17	1.9	1.8	4%	2.6	2.6	1%	3.0	3.0	1%
W-13	1.8	1.8	4%	2.8	2.7	1%	3.1	3.1	1%
W-12	0.6	0.6	4%	0.9	0.8	1%	1.0	1.0	0%
W-11	0.8	0.8	4%	1.3	1.3	1%	1.6	1.6	1%

Location names correspond to those shown in **Figure 3** of the Warroad River Watershed Storage Identification & Evaluation Report and in-channel locations within the Lake of the Woods Watershed Comprehensive Watershed Plan.

Potential Annual Sediment Transport Reduction

Existing Condition: 10,443 tons

Alternative Condition: 10,349 tons

Reduction: 95 tons

1% reduction

Cost

Assuming a cost range of $10k-$50k per ditch plug and 4 ditch plugs, the cost range is estimated to be:

$40,000 - $200,000

*Ditch plug cost is extremely dependent on access and mobilization.

Summary

Pros

- Provides an estimated 1% reduction in annual sediment transport capacity of the watershed channel.
- Provides 0%-2% peak flow reduction at the downstream analysis point on the Warroad River.
- Provides 0%-1% volume reduction (depending on design storm), assuming water is retained in the peatlands.
- Storage located on public lands.
- Provides up to 1% reduction in peak velocities at 4 of 9 critical areas.
- Cost effective compared to other project alternatives.

Cons

- Requires significant coordination with MnDNR staff to design and install ditch plugs.
- Reductions not as significant as compare to other project alternatives.