



FEASIBILITY STUDY REPORT

South Branch Wild Rice River Restoration & Sediment Reduction

Wild Rice
Watershed
District

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South Branch Wild Rice River Restoration and Sediment Reduction

May 6, 2020

Fargo, ND



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1 INTRODUCTION / BACKGROUND INFORMATION

The South Branch of the Wild Rice River (South Branch) watershed encompasses approximately 260 square miles of drainage from Norman, Becker, Clay and Mahnommen Counties. The South Branch outlets in central Norman County, at its confluence with the Wild Rice River. From there, the Wild Rice River flows west to the Red River of the North. For planning and resource purposes, the channel reach under investigation has been broken into the Lake Plain, Beach Ridge and Upper Ridge portions based on easily identifiable geographical boundaries. The Lake Plain portion extends from the outlet of the river into the Wild Rice River, located approximately 8 miles southeast of the Hendrum, MN to approximately Clay County Highway 110 near the bottom of the historic Lake Agassiz Beach Ridge. The Ridge portion of the river extends from approximately Clay County Highway 110 to MN Highway 32 near Ulen, MN. A map showing the extent of the investigated South Branch Project Reach within the overall South Branch watershed is shown as **Exhibit 1**. The investigated reach consists of following Assessment Unit IDs (AUID): 09020108-662, 09020108-658 and 09020108-659 according to the Minnesota Pollution Control Agency's *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List*. [1]

1.1 BACKGROUND AND STUDY PURPOSE

The Wild Rice Watershed District (WRWD) applied for assistance from the Red River Retention Authority (RRRA) for Watershed Planning under the Regional Conservation Partnership Program (RCPP), administered by the Natural Resources Conservation Service (NRCS). The RRRA authorized the WRWD to proceed in a Cooperative Agreement with NRCS to perform Watershed Planning in the Wild Rice Watershed for the South Branch Sub-Watershed Plan. Watershed Planning funded through NRCS RCPP is required to follow Public Law 83-566 requirements.

Channel erosion and degradation were identified by various stakeholders during the problem identification phase for the South Branch of the Wild Rice RCPP. Erosion through the Beach Ridge area and resultant deposition in the Lake Plain results in both natural resource degradation and increased flooding potential.

The purpose of this channel restoration study was to define the problems and underlying causes for the current channel conditions and to develop a general rehabilitation plan for instream improvements that could be implemented to reduce future erosion and degradation of the channel. The factors contributing to the current problems are diverse. This study focuses on hydrologic, geomorphic, and ecological issues. While the improvement strategy is presented as a singular plan, it is expected that the project will be implemented in phases. Higher priority will be given to phases that either provide the greatest benefit or provide an opportunity to monitor and evaluate the effectiveness of project features prior to implementation of additional phases. The recommended phasing plan is provided in **Section 6**. Additionally, the proposed restoration measures identified in this study could be combined with other watershed improvements to provide a subwatershed plan that would achieve both flood damage reduction and natural resource enhancement for this subwatershed.

1.2 WATERSHED HISTORY

1.2.1 USACE PROJECT

In February of 1974, the US Army Corps of Engineers (USACE) published the first General Design Memorandum that detailed flood control improvements to the South Branch with the goal of increasing the capacity of the existing river channel through the flood plain. This work was subsequently authorized under the Flood Control Act of 13 August 1968 under Public Law 90-483. Work on the project was completed in the early 1980s with the Record Drawings being completed in October of 1983. This project included approximately 1.75 miles of debris removal, 5.25 miles of one bank channel sloping and enlargement, and 9.15 miles of both bank channel sloping and enlargement.

The improvements generally extended from the confluence with the Wild Rice River to approximately Clay County Road No. 110 (near the base of the Beach Ridge). The channel improvements were designed to convey flood discharge rates of 1,340 to 1,700 cfs. Since completion, operation and maintenance of the project has been the responsibility of the WWRD as the local sponsor. The USACE flood control project is described in more detail in the USACE's *Flood Control Wild Rice River - South Branch and Felton Ditch Design Memorandum No. I, Phase II* [1].

1.2.2 IMPLICATIONS OF RIVER STRAIGHTENING AND ALTERED HYDROLOGY

According to geomorphology principles developed by Emory Lane in *Design of Stable Channels* [4], natural streams are constantly evolving to balance the system's sediment and water loads without either aggrading or degrading. This process occurs by way of a direct relationship between four system parameters, namely, the system flow, sediment load, average sediment size (D50), and stream slope. This relationship is known as Lane's balance. When one or more of the four system parameters is altered, the system becomes unstable.

Straightening and widening a river reach was, and continues to be, a common engineering practice to improve drainage capacity. The level of flood protection can be increased by increasing the conveyance capacity of a drainage pathway and shortening the travel time through the system. However, riverine straightening can also have negative consequences for stream geomorphology, water quality, and subsequently riverine ecology. The USACE's early 1980's flood control project increased the capacity of the South Branch in the Lake Plain by widening and deepening the channel, but inadvertently reduced the channel's ability to effectively transport sediment. Under natural conditions, streams form a meandering bankfull channel and a floodplain. Self-formed channels are significantly narrower and more sinuous than the constructed channel through the Lake Plain. In comparison to overwide and straight constructed channels, the channel width and sinuosity of natural channels produce higher bankfull velocities, secondary helical flows and increased shear stress that provide a greater ability to transport sediment. The channel within the Lake Plain is slowly attempting to form a more natural geometry. Aggradation through the straightened constructed channel is a natural grade stabilizing process. Maintenance to remove sediment (aggradation) through the reach has the potential to reinitiate incision, and further increase the sediment supply from the Beach Ridge.

Since the completion of the early 1980's flood control project in the lower reaches of the South Branch, considerable erosion through the Beach Ridge area and resultant downstream deposition has occurred. As a result of increased conveyance capacity in the Lake Plain, conveyance, slope, and ultimately shear stress increased in the Beach Ridge. This has led to severe incision, and ultimately an increased sediment supply, through the Beach Ridge. This erosion was significantly heightened during and immediately following the record-breaking summer floods of 2002. Among other issues, the channel through the Beach Ridge has become unstable, and is disconnected from its floodplain. Although many areas of the channel are attempting to restore themselves naturally through erosional and depositional processes; considerable erosion, channel head-cutting, and resultant deposition is still evident. Complete natural restoration will take significant time and will result in large amounts of sediment continually delivered to the Lake Plain.

In addition to straightening the river, significant changes in the landscape have also occurred since the 1990s. Changes include conversion of land use from grain crops to row crops and increased tile drainage, both of which have led to increased runoff volume from the watershed. Altered hydrology disturbs the balance of the river system and leads to further instability. Higher flows increase shear stress in the channel and cause entrenchment and disconnection from the floodplain. The Beach Ridge experienced significant damage during the 2002 flood because the river was unable to access its floodplain due to this entrenchment. Extremely high flows were confined to the channel, causing higher velocities and shear stress which resulted in severe bank failure during the flood throughout the Beach Ridge Area.

1.3 OVERVIEW OF CONCEPT PLAN

Restoration of the South Branch will attempt to reestablish stable stream profile, dimension, and pattern. This will reduce erosion and sedimentation problems and provide resilience to the system during future flood events. The Project Reach is approximately 23 river miles starting near Ulen, MN and ending just downstream of Norman County Road 138. The Project Reach is split into three sub-reaches which are referred to as the Lake Plain Reach, the Beach Ridge Reach, and the Upper Ridge Reach in this report. A map showing the locations of the sub-reaches is provided as **Exhibit 2**. The Beach Ridge and Upper Ridge are experiencing excessive erosion and entrenchment whereas the channelized reach in the Lake Plain is experiencing excessive sedimentation. The proposed solution generally involves two components. The first will slow erosion and trap sediment in the upper reaches. This will be achieved by installing rock arch rapids for grade control. The second component will involve channel restoration that will facilitate improved sediment transport in the Lake Plain Reach through re-meandering of the river. By implementing these two components, the river will regain access to its floodplain throughout the Project Reach which will add resiliency to the system and reduce the risk of major damage during flood events.

2 EXISTING CONDITIONS

One of the first objectives of the feasibility study was to define existing conditions and identify known problems within the Project Reach. During this process, data not previously obtained, but necessary to complete the feasibility study was also collected. Specific tasks undertaken included:

- Review of anecdotal condition assessments and known problems as noted by potential project partners, including the WRWD and Minnesota Department of Natural Resources (MN DNR).

- Review of previous studies and construction projects within the Project Reach, including the USACE's channel modification project (designed in 1975 and constructed in the early 1980's) and sediment studies more recently completed by the USACE and United States Geological Survey (USGS).
- Review of topographical survey data collected from 1974 through 2006, and collection of additional topographical survey data in 2017 through 2019.
- Site reconnaissance, including an evaluation of existing stream geomorphology for the purpose of stream classification.
- Review of existing Right of Way limits.

Details of these tasks are provided in **Sections 2.1 – 2.8**.

2.1 DESCRIPTION OF REACHES

The Project Reach is divided into three primary sub-reaches. The sub-reaches were divided based on proposed restoration strategies within their boundaries. The sub-reaches are described in **Sections 2.1.1 – 2.1.3** and shown on **Exhibit 2**. A secondary sub-reach, referred to as the "Reference Reach" is also shown on **Exhibit 2**, and is contained within the Upper Ridge Reach boundary. Additional information on this secondary sub-reach is provided in **Section 2.2**.

2.1.1 LAKE PLAIN REACH

The Lake Plain Reach is located at the downstream end of the Project Reach beginning at Clay County Road 110 and ending just downstream of Norman County Road 138. The profile of the river in this reach is relatively flat with slopes ranging from 0.07% to 0.10%. Soils consist of lacustrine deposits [1]. The drainage area is approximately 200 square miles. Prior to any channelization and ditching of the Lake Plain area, the South Branch would flow off the Beach Ridge and spread out into the Lake Plain without a defined flow path. In the early 1980's, the USACE completed a flood control project in this reach to increase capacity of the channel and provide flood protection for a 6% chance flood. Since then, this sub-reach has seen significant sedimentation which has required maintenance and repair.

2.1.2 BEACH RIDGE REACH

The Beach Ridge Reach begins upstream of Clay County Road 110 and continues upstream to 220th Street N. The profile of the river in this reach is very steep with slopes ranging from 0.3% to 0.5%. The Beach Ridge separates the flat Lake Plain in the west from the Drift Prairie region in the east. Soils consist of fine clayey and silty sands and sometimes gravel [1]. The drainage area at the upstream end of this sub-reach is approximately 185 square miles. The most severe erosion damage, including bank failure, was observed in the Beach Ridge after the 2002 flood event.

2.1.3 UPPER RIDGE REACH

The Upper Ridge begins upstream of 220th Street and continues upstream to MN Highway 32. The profile of the river begins to flatten out again in this reach, with slopes ranging from 0.10% to 0.16%. The Beach Ridge transitions to the Drift Prairie region through this reach and contains soils composed of clay or silty clayey sand [1]. The drainage area is approximately 155 square miles. The Upper Ridge saw less noticeable damage during the 2002 flood event, however survey of the cross sections in this reach indicates severe entrenchment and disconnection between the river and its floodplain.

Channel entrenchment becomes more severe as the channel runs from east (upstream) to west (downstream) through this reach.

2.2 SURVEY REVIEW AND COLLECTION

A significant amount of survey data collection has occurred within the Project Reach of the South Branch. The survey data considered in this study begins in 1974 when the USACE collected data prior to designing their channel modification project in the Lake Plain. A technical memorandum was completed by HEI in 2019 that summarizes survey data collection by various entities since 1984. This technical memorandum is provided in **Appendix A**.

In 2006 the Wild Rice Watershed District collected survey cross-sections along the South Branch as part of the ongoing Wild Rice River Feasibility Study. More recent survey data was collected in the summer of 2019 to evaluate the evolution of the river since 2006. Cross sections were surveyed in the same locations as 2006 so a direct comparison could be made. Cross section comparisons can be found in the Existing Conditions Plan, Profile and Cross Sections attached as **Appendix B**.

A Reference Reach on the South Branch was identified based on aerial photography and prior knowledge of the area. The Reference Reach is located within the upstream end of the Project Reach and has similar hydrology, geology, soils and appropriate riparian vegetation to the rest of the Project Reach. It is relatively unaltered and had limited damage during the 2002 flood event. This points to stability and resilience within the reach. The Reference Reach extends from 240th Street N upstream to MN Highway 32 near Ulen, MN. Ideally a reference reach is used to guide the design of a proposed river restoration. Cross sections were surveyed at pool and riffle locations within the Reference Reach. Additionally, bankfull indicators were surveyed at several of the cross sections to help determine the bankfull discharge during design. A map of the Reference Reach survey data is provided as **Exhibit 3**.

Initial review of the cross sections indicated that additional profile information was needed to properly evaluate the changes that have occurred in the channel since 2006 and to identify areas where possible head cuts may be forming. Longitudinal profile survey was collected beginning at the low water crossing located in Section 36 of Winchester Township and continuing upstream to 220th Street N. A map of all the survey data that was collected for the project is provided as **Exhibit 4**.

Where required, topographical survey data was supplemented by LiDAR collected as part of the International Water Institute's *Red River Basin LiDAR Mapping Initiative* (IWI LiDAR) [2]. Data from blocks "C" and "K" of the collection were used in the study, which were collected in 2008 and 2010, respectively.

All elevations documented in this report and appendices are North American Vertical Datum (NAVD) 1988. The vertical datum of the USACE's 1975 design report, and 1983 construction plans is unknown. However, a conversion factor was developed by HEI. Detail of the datum conversion is provided in **Appendix A**.

2.3 SITE RECONNAISSANCE

Along with survey data collection, Houston Engineering and the Minnesota Department of Natural Resources River Ecology Unit (MN DNR REU) made multiple visits to the Project Reach. This included paddling the river on August 5th, 2019 and collecting photos of the erosion and sedimentation that is occurring on the South Branch. These site visits provided empirical evidence that the river is unstable.

2.3.1 LAKE PLAIN SITE RECONNAISSANCE

The Lake Plain Reach is experiencing aggradation, most apparent downstream of the low water crossing. Relatively large size material is being eroded from the Beach Ridge and making its way to the Lake Plain where the river no longer has the stream power to transport the larger material. This material is settling out in the straightened channel as demonstrated in **Image 1**. Cross-sectional survey data confirms that since 2006, the straightened channel is scouring on one side and depositing the material on the other side as shown in **Image 2**. Natural meanders are forming and were visible during the site visit as shown in **Image 3**.

Image 1 – Sedimentation DS of Low Water Crossing in Lake Plain Reach (Sec. 36 Winchester Twp.)



Image 2 – Cross section survey comparison showing channel scour and deposition in Lake Plain Reach

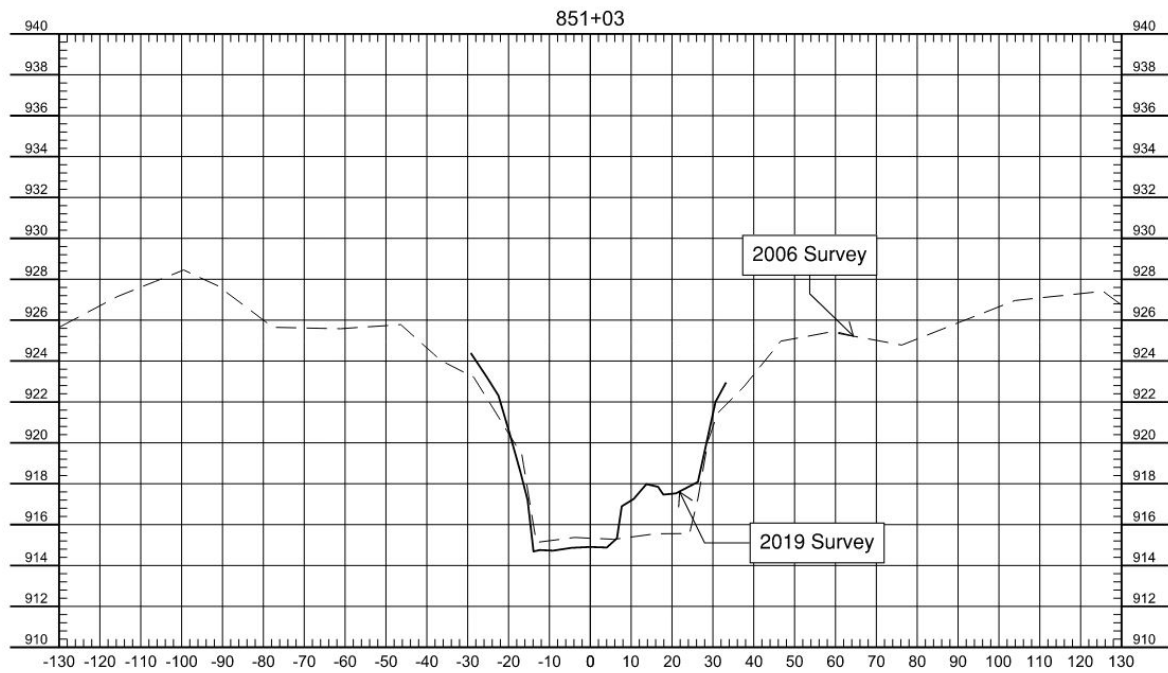


Image 3 – Natural meanders forming in Lake Plain upstream of Norman County Road 138



2.3.2 BEACH RIDGE AND UPPER RIDGE SITE RECONNAISSANCE

Survey data and site observation indicate that the channel has incised significantly based on historic floodplain elevations. This incision has consequentially caused bank erosion in the Beach Ridge since the 2006 survey was collected. Based on comparison of the surveyed cross sections, there are several locations where the river has scoured the channel bottom on the outside of the bend and deposited the material on the inside bend. An example is shown in **Image 4**. Other surveyed cross sections show evidence of bank erosion as seen in **Image 5**. Bank erosion was also evident during the site visits as shown **Image 6**.

Image 4 – Cross section survey comparison showing channel scour and deposition in the Beach Ridge

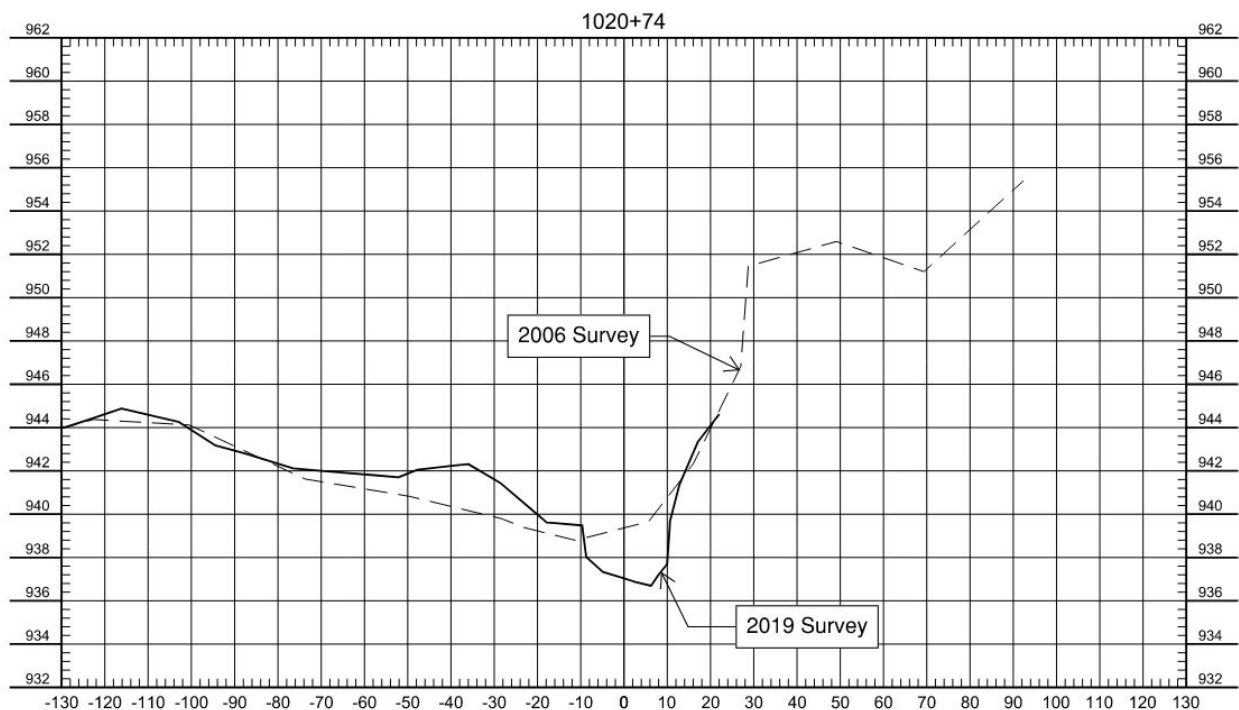


Image 5 – Cross section survey comparison demonstrating bank erosion in the Beach Ridge

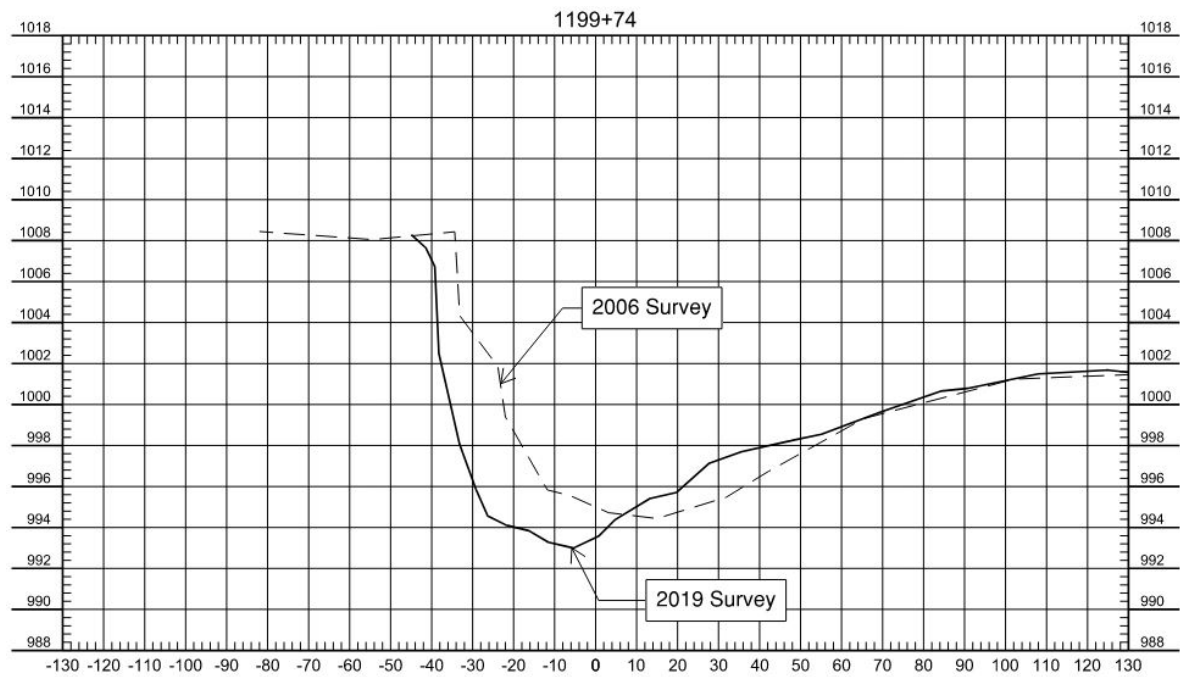


Image 6 – Photo in the Beach Ridge of unvegetated unstable bank



Upon completion of site reconnaissance, the Reference Reach, which is contained in the Upper Ridge, was found to not be as stable as originally believed. Paddling the river in this reach revealed much of the system is entrenched and disconnected from its floodplain as shown in **Image 7**. The Reference Reach is experiencing some bank erosion as well, however the grade in this reach is significantly flatter than the Beach Ridge and so erosion is less severe. Aerial imagery review shows that several meanders in the Reference Reach have also been cut off during large flood events. A map of the cut off meanders is provided as **Exhibit 5**.

Image 7 – Photo of the Reference Reach showing an unvegetated erosive bank



Information gathered during site reconnaissance was used to classify stream types. Using the techniques within Dave Rosgen's *Applied River Morphology* [3], the Upper Ridge and Beach Ridge were classified as either Type C or Type F channels. **Table 1** shows the geomorphic criteria that was used to determine the stream type.

Table 1 – Rosgen Level I Geomorphic Classification Criteria

Stream Type	A	B	C*	D	Da	E	F*	G
Entrenchment Ratio	<1.4	1.4 – 2.2	>2.2	n/a	>4.0	>2.2	<1.4	<1.4
W/D Ratio	<12	>12	>12	>40	<40	<12	>12	<12
Sinuosity	1.0 – 1.2	>1.2	>1.2	n/a	Variable	>1.5	>1.2	>1.2
Slope (%)	4 – 9.9	2.0 – 3.9	<2	<4	<0.5	<2	<2	2 – 3.9

*Stream types of the South Branch

Bankfull discharge was used to guide the stream classification. Details of the analysis and determination of bankfull discharge are provided in **Section 4.2**. Slopes in the Ridge Reaches range from 0.10% to 0.50%. Although both pool and riffle cross sections were surveyed, the riffle cross sections were used to determine bankfull dimensions as recommended by Rosgen. Width to depth ratios of the cross sections were consistently greater than 12, however, there were several cross sections with entrenchment ratios less than 1.4. The entrenchment ratio is the ratio of the flood-prone width to the bankfull channel width. The flood-prone width is measured at the elevation that corresponds to twice the maximum depth of the channel at bankfull. A low entrenchment ratio is indicative of a river that is disconnected from its floodplain as shown in **Image 8**.

Image 8 – Photo showing the disconnection of the river to its historic floodplain in Reference Reach



Maps showing the locations of the cross sections that were used to classify the South Branch are provided in **Appendix C**. The geometric characteristics of the cross sections that were used for stream classification are also provided in the appendix. Type C streams have well defined meanders and an accessible floodplain. It is common for watershed changes to affect the equilibrium of a C stream leading it to deepen and then widen out to a Type F stream. Type F streams are entrenched meandering channels. They are known for their high bank erosion rates, over-widening, and significant channel aggradation and/or degradation due to their disconnection from their floodplain.

By completing a stream classification and stability assessment through the Ridge Reaches, the primary cause of impairment and continued erosion in the Beach Ridge and Upper Ridge was identified to be the disconnection of the river from its floodplain. This disconnection has led to high shear stress on the banks of the river during high flows.

2.4 REVIEW OF USACE DESIGN REPORT AND AS-BUILTS

A review was conducted of the USACE's 1975 design report for their channel modification project. Further discussion of the USACE project is in **Section 1.2.1**. Several design components from this study were used during feasibility planning of the proposed restoration project.

The primary design criteria for the USACE was to provide protection to adjacent agricultural lands from floods with probability of occurrence up to 6% (16.7-year return period). At the time, the USACE estimated that the discharge rate corresponding to a return period of 16.7 years within the channel modification project extents varied from 1,500-1,660 cfs. As a result, the proposed project features in the Lake Plain Reach were designed to provide a similar or better level of protection for the same discharge.

Components of the channel geometry from the USACE project, namely channel and spoil side slopes, were used as the basis for the same channel geometry components in the design of the proposed restoration project. The suitability of these geometry elements should be verified using additional geotechnical analysis in the future as the project design continues.

The USACE design report and as-built drawings documented the size, location, and length of side inlet culverts installed as part of their project. This was used as the basis for the quantification of new inlet pipes to be installed as part of the proposed restoration project.

Cross-sectional survey data collected in the Lake Plain Reach was used to compare existing channel geometry to the USACE "as-built" geometry. In general, the channel bottom profiles are similar. However, the thalweg of the channel downstream of MN Highway 9 appears to be mildly degraded when compared to the USACE "as-builts". This apparent degradation is due to the river's attempt to re-meander within the bottom of the USACE constructed channel. Therefore, the channel bottom elevation is not consistent across the width of the originally constructed bottom. Portions of the cross section have experienced significant deposition of material. **Images 1 – 3** illustrate this geomorphic process.

2.5 REVIEW OF PREVIOUS SEDIMENT STUDIES (USACE & USGS)

Several previous studies to evaluate sedimentation and erosion along the South Branch have been completed by the Wild Rice Watershed District in cooperation with other entities. The following provides a short summary of these past study efforts.

In July 2007, the USACE published a report entitled "*Wild Rice River Sediment Budget*" [4] as part of the Wild Rice River Feasibility Study. This study was completed to provide information on geomorphic characteristics, in-stream sources and sinks of sediment, and sediment transport capacity on the Wild Rice River as well as the South Branch and Marsh Creek. The St. Paul District Corps of Engineers led this study for the Wild Rice Watershed District with funding provided by the Watershed District. Cross section surveys were performed by HEI. Technical work was completed the St. Paul District's Hydraulics Section.

In 2014, the USGS published a report entitled “*Suspended-Sediment Concentrations, Loads, Total Suspended Solids, Turbidity, and Particle-Size Fractions for Selected Rivers in Minnesota, 2007 through 2011*”. [5] This study provided data that was intended to improve understanding of sediment transport relations, improving sediment budgets, and to document baseline data to aid in understanding the effects of future land use/land cover on water quality. This included two sediment sampling sites on the South Branch. These were at USGS Gaging Station Numbers 05063340 South Branch Wild Rice River near Ulen and 05063400 South Branch Wild Rice River near Felton. Both sites include sampling data collection from 2007-2010.

2.6 EXISTING RIGHT OF WAY

Permanent Right of Way (ROW) was purchased by the Wild Rice Watershed District in the period between the publication of the USACE’s 1975 project design report, and implementation of the project in the early 1980’s. Existing ROW is limited to the Lake Plain Reach, and the width of ROW within this reach varies. The approximate boundaries of existing ROW are shown in the Feasibility Plan Set provided in **Appendix D**.

3 HYDRAULIC MODELING

3.1 HYDRAULIC MODEL GEOMETRY

As part of the NRCS RCPP Watershed Plan, hydrologic and hydraulic modeling was completed for the South Branch sub-watershed. The riverine characteristics within the South Branch sub-watershed were simulated using the USACE *Hydrologic Engineering Center – River Analysis System* (HEC-RAS v. 5.0.3) [5] in an unsteady state 1-dimensional/2-dimensional (1D/2D) environment. 1D cross sections were used in the Ridge Reaches while the Lake Plain Reach was more adequately modeled using a 2D mesh. This model used past survey data for the South Branch to define the cross-section geometry which was supplemented with LiDAR data to define the floodplain.

For the purpose of determining bankfull discharge, the existing conditions model for the South Branch was used and was updated to the most recent version of HEC-RAS, v. 5.0.7. The 2D portion of the model representing the Lake Plain was removed from the model. The portion of the 1D model upstream of the Project Reach (upstream of Minnesota State Highway 32) was also removed. The geometry of the remaining 1D portion of the model representing the Ridge Reaches was modified to include the survey cross sectional data collected in 2019.

A map of the HEC-RAS model extents for the bankfull discharge analysis is provided as **Exhibit 6**. A manning’s “n” value of 0.1 was chosen to represent the floodplain, while a manning’s “n” value 0.04 was chosen to represent the channel. Because the HEC-RAS model was used to analyze low flows (1 – 2-year events), a more accurate representation of the length of the river was needed to better characterize the slope of the river. The river centerline was adjusted slightly from the existing model in order to better represent the current meanders of the river. The full Bankfull Discharge Analysis is discussed in further detail in **Section 4.2**.

4 RESTORATION FEATURES AND DESIGN

4.1 RESTORATION GOALS

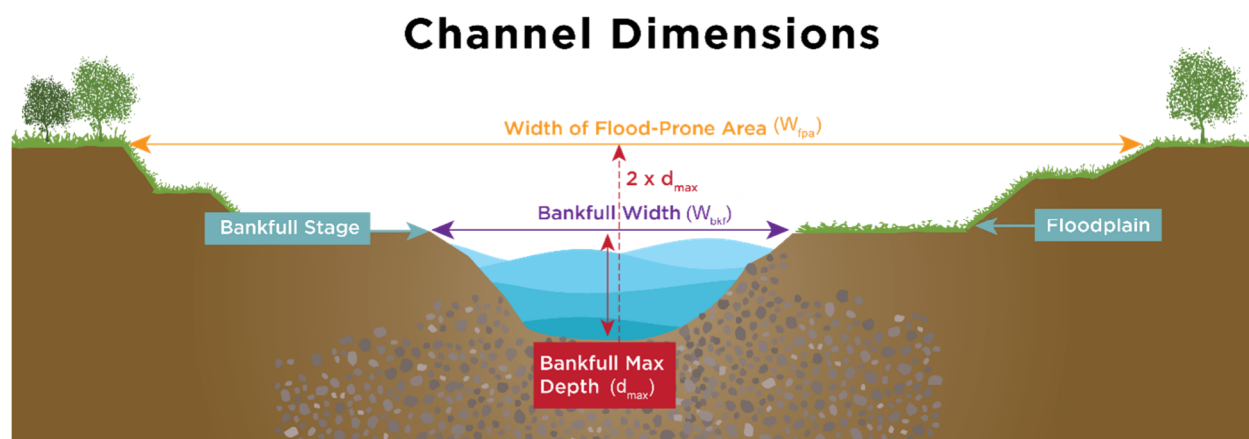
The goal of the project is to create an environment along the South Branch where stable and natural stream conditions can be reached, and natural geomorphic processes can maintain the constructed restored river. After examining the collected survey and 1983 USACE “as-built” plans, several project development meetings were held between Houston Engineering and representatives of the WRWD and the MN DNR REU, to discuss and seek concurrence on general restoration concepts and design. The main goals for restoration are reducing erosion in the Ridge Reaches and reducing sedimentation in the channelized Lake Plain Reach.

Stream stability is defined as “the ability of a stream to transport the water and sediment of its watershed in such a manner as to maintain its dimension, pattern, and profile over time, without either aggrading or degrading” [3]. Stable stream conditions are expected to provide benefits for water quality and aquatic habitat, while maintaining the flood damage reduction benefits of the early 1980’s USACE project. The proposed project is estimated to restore 23 miles of the South Branch. In the Ridge Reaches, the restoration features are intended to stabilize the grade and provide erosion reduction through installation of up to 14 total rock arch rapids. The objectives of the rock arch rapids are to trap sediment and reconnect the channel to its floodplain which is expected to provide riparian corridor habitat benefits. In the Lake Plain Reach, the restoration project features are intended to increase sediment transport capacity through the by restoring sinuosity and a stable bankfull channel geometry. The proposed project in the Lake Plain Reach would restore approximately 270 acres of riparian habitat and 60 acres of aquatic habitat.

4.2 BANKFULL DISCHARGE ANALYSIS

The bankfull discharge is the flow that is conveyed within the banks of the river just before water begins spilling into the floodplain. It has a return period probability of approximately 1 to 2 years [3]. The defining geomorphic characteristics of the river are formed during bankfull flow and it is therefore important when designing a restoration project. A bankfull channel diagram is provided as **Figure 1**.

Figure 1 – Bankfull Channel Dimensions

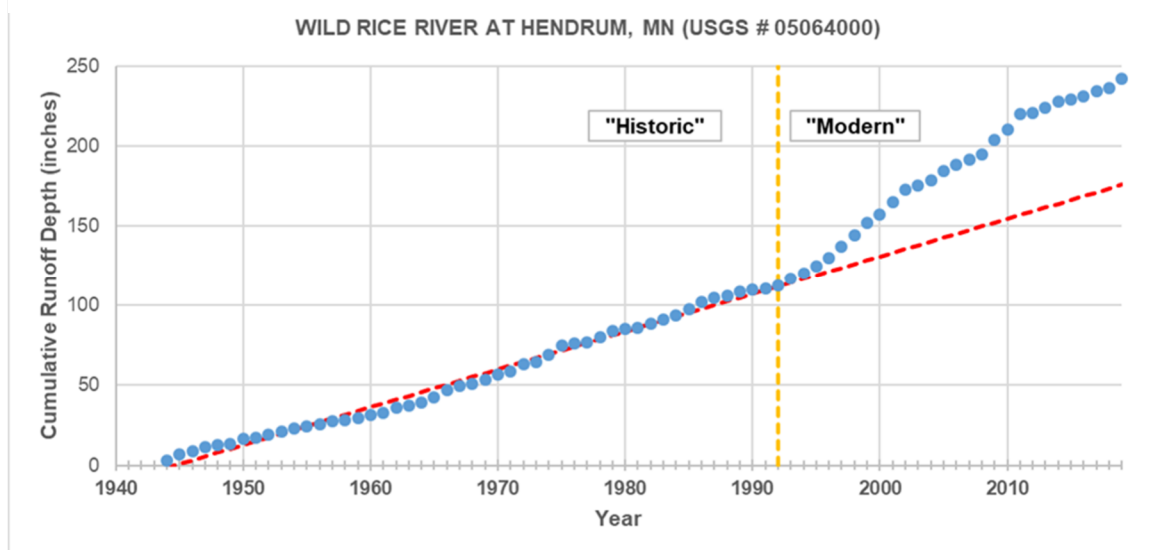


Survey data of bankfull indicators (mainly depositional point bars) were collected in the Reference Reach at several cross sections. The Reference Reach is shown on **Exhibit 3**. A modified HEC-RAS model, as defined in **Section 3**, was used to estimate bankfull discharge. Water surface profiles were created by analyzing a range of flow rates. When the water surface profile matched the surveyed bankfull indicator, the flow was recorded as the bankfull discharge for that cross section of river. After eliminating outliers, the bankfull discharge was estimated to be between 328 and 385 cfs for the Reference Reach.

A frequency analysis was also completed to verify the modeled bankfull discharge. The existing USGS Gage 05063398 is located at Clay County Road 27 near Felton on the South Branch (CR 27 Felton) [6], which is within the Project Reach. This gage was established in 2004 after the major 2002 flood event and has a period of record of 15 years. Additionally, USGS Gage 05062500 on the Wild Rice River at Twin Valley, MN [7] and USGS Gage 05061000 on the Buffalo River near Hawley, MN [8] were analyzed to expand the period of record for a more comprehensive frequency analysis. A location map of the gages is provided as **Exhibit 7**.

The methods outlined in John England's, et al. *Guidelines for Determining Flood Flow Frequency: Bulletin 17C* [9] were used in conjunction with the USACE Hydrologic Engineering Center Statistical Software Program (HEC-SSP) [10] to perform the flood frequency flow analysis. The Twin Valley and Hawley gages have longer periods of record. However, it has been documented that the Wild Rice Watershed has experienced altered hydrology in the last 28 years, with the breakpoint being approximately in 1992. HEI previously completed a technical memorandum, entitled *The Wild Rice River Watershed Altered Hydrology Analysis Technical Memorandum* [11] to document the altered hydrology. The technical memorandum is provided in **Appendix E** for reference. **Figure 2** is taken from the technical memorandum and illustrates the breakpoint at the Hendrum USGS gage.

Figure 2 – Cumulative streamflow for the Wild Rice River at Hendrum, MN (USGS Station 05064000)



Due to the breakpoint in the Wild Rice River watershed hydrology, the Twin Valley and Hawley gages were analyzed with a period of record starting in 1992. This period of record more accurately represents the “modern” hydrology that occurs today. **Exhibits 8 and 9** show the increase in discharge when the period of record is shortened to start at 1992 for the Twin Valley and Hawley gages, respectively.

A drainage area transfer equation was applied to the discharge at the USGS gages to directly compare the 1.5-year discharge at each location. Typically, a drainage area ratio is applied directly to the gaged discharge to determine the discharge at the ungaged location. A study was completed for the Red River of the North Basin to evaluate an improved drainage area ratio method for estimating stream flow rate and is outlined in Douglas Emerson's, et al., *Evaluation of Drainage-Area Ratio Method Used to Estimate Streamflow for the Red River of the North Basin, North Dakota and Minnesota* [12]. Regression equations were developed for winter, spring, and summer. The summer equation was used for this study and is given below.

$$\text{Summer: } Q_y = 1.06 \left(\frac{A_y}{A_x} \right)^{1.02} Q_x. \quad (12)$$

A comparison of the frequency analysis results is given in **Table 2**.

Table 2 – Flood Flow Frequency Analysis Results

Analysis Method	Source	Drainage Area (sq mi)	1.5-year Event at Gage (cfs)	1.5-year Event Transferred to Reference Reach (cfs)
HEC-SSP	CR 27 Felton	191	701	551
HEC-SSP	Twin Valley	934	2,042	318
HEC-SSP	Hawley	325	653	298
HEC-RAS	Reference Reach	142	328 - 385	

The CR 27 Felton gage produced the highest flow. This could be due to the short period of record skewing the frequency analysis results. Alternatively, the typical range for bankfull discharge return period is 1 to 2-years. Breaking the frequency analysis down further for this location indicates that the bankfull discharge for the South Branch may be closer to a 1.3-year event. This breakdown is summarized in **Exhibit 10**. The 1.3-year event at CR 27 Felton is estimated to be 348 cfs, which falls in the middle of the Reference Reach bankfull discharges estimated in the HEC-RAS model. The frequency analysis results indicate that the HEC-RAS model results for bankfull discharge are within a reasonable range. The bankfull discharge is used to design several restoration components, within all sub-reaches of the Project Reach. A map summarizing bankfull discharges for the entire Project Reach is provided as **Exhibit 11**. The final flow rates used for design are based on a combination of HEC-RAS modeling results and the drainage area transfer equation in areas that did not have good bankfull indicators surveyed in the cross sections.

4.3 LAKE PLAIN – CHANNEL RESTORATION

The Lake Plain Reach is located on the downstream end of the Project Reach as shown on **Exhibit 12**. The grade of the river begins to flatten out in this area. The project completed by the USACE in this reach aimed to reduce flood damages in agricultural areas adjacent to the South Branch. The project included channel enlargement, debris removal, channel bank protection at bridges, and side ditch inlet modifications. Enlarging the channel increased the hydraulic capacity, however, the channel's ability to effectively transport sediment was negatively impacted. Creating an overly wide channel reduces the shear stress on the bed and banks of the channel. This causes sediment to settle out and has led to significant aggradation in this reach.

The proposed plan for restoration in the Lake Plain includes reestablishing a meandering Type E channel [3] with an appropriate bankfull width and depth. The geometry will be a two-stage channel consisting of a low flow (bankfull) channel excavated into a wider floodplain. The belt width of the floodplain will be minimized to reduce land requirements. Flows conveyed within the low flow channel are typically more frequent events; up to the 1.5-year event. Flow above the bankfull discharge is conveyed through the floodplain. Reducing the size of the low flow channel increases the shear stress and facilitates increased sediment transport when compared to the overly wide channel that was constructed in the early 1980's. The proposed bankfull channel geometry was designed to carry the bankfull discharge, which ranges from 487 cfs to 497 cfs in the Lake Plain Reach. The bankfull cross section geometry falls within the range indicated in regional curves developed by the MN DNR REU. The preliminary design utilizes a trapezoidal cross section; however, an elliptical shape is preferred and will be used for final design.

The floodplain geometry was designed so that the design water surface profile will be equal to or below the design water surface profile from the early 1980's USACE project at the design flow rate. The design discharge rate ranged from 1500 cfs to 1660 cfs across the length of the project. A comparison of the USACE design and proposed restoration design water surface profiles for the design flow rate is provided as **Exhibit 13**. The proposed typical section for the floodplain (side slopes, berms and spoil piles) generally matches the typical section in the 1983 plan. However, the width of the spoil will be significantly wider under the proposed conditions. The USACE channel stability analysis completed in early 1980's indicates that this typical section will perform well in the geologic conditions of the Lake Plain Reach. However, additional geotechnical evaluation of the proposed geometry should be completed as part of future detailed design to confirm its stability. **Table 3** provides a summary of the proposed channel and floodplain geometry of the Lake Plain Reach. A typical section and plan and profile can be found in the Feasibility Plan Set in **Appendix D**.

Table 3 – Proposed Lake Plain Restoration Channel Geometry

River Segment (Station)	Bankfull Discharge (cfs)	Flood Discharge (cfs)	Bankfull Channel Slope	Bankfull Depth (ft)	Bankfull width (ft)	Flood Depth (ft)	Valley Width (ft)
0+00 to 35+94	497	1,660	0.05%	4.8	49	7.5	209
35+94 to 162+96	497	1,660	0.06%	4.8	45	7.7	239
162+96 to 295+45	497	1,500	0.06%	4.8	45	7.65	199
295+45 to 393+17	487	1,500	0.085%	4.8	39	7.5	173

Reestablishing sinuosity and pattern to the Lake Plain Reach is equally essential in preventing sedimentation and restoring balance. A stable river system erodes material from the outside bends of meanders and deposits material on the inside bends. Helical flows are largely responsible for this process and are only present in meandering streams. The sinuosity of the proposed channel ranges from 1.2 to 1.4. The ratio of radius of curvature to bankfull width is an important parameter in predicting the depth of the scour pool at the outside bends. A smaller ratio leads to deeper pools. The preliminary restoration design includes ratios ranging from 1.5 to 3.4. Providing adequate shear stress in the bankfull channel and creating helical flows through re-meandering the river will reduce sedimentation in the Lake Plain.

At the upstream end of the Lake Plain channel restoration, a rock arch rapid will be constructed to reconnect the floodplain just downstream of the Clay County Road 110 bridge. This location marks the end of the Lake Plain channel restoration and the beginning of the Beach Ridge Reach. The design of the rock arch rapids is explained in detail in **Section 4.4**.

4.4 BEACH RIDGE – ROCK ARCH RAPIDS IMPLEMENTATION

A map of the proposed Beach Ridge Reach restoration is provided as **Exhibit 14**. The Beach Ridge has steep slopes for the Red River Valley, ranging from 0.30% to 0.50%. This reach experienced the most severe geomorphic change as a result of the 2002 summer flood and continues to experience significant erosion and bank failure. The river's bankfull profile in this reach is severely disconnected from its historic floodplain; in some places this disconnection is up to 10-feet of separation. Portions of the Beach Ridge Reach are classified as a Type C, while other portions are classified as a Type F channel. Type C classifications are generally found in portions of the reach where the banks have failed due to flood events.

Connection to the floodplain is important during flood events because energy dissipation primarily occurs in the floodplain. Without this energy dissipation, streambanks experience high velocity and shear stress, causing them to fail. Sediment eroding from the Beach Ridge ranges in size from fine sand to gravel [1]. The loss of energy due to flatter slopes in the Lake Plain causes the eroded sand and gravel from the Beach Ridge to settle out in the Lake Plain. To achieve the goal of sediment reduction in the Beach ridge, the restoration plan proposes implementing a total of six rock arch rapids for grade stabilization as well as reconnection to the floodplain. The rock arch rapids will also act as sediment traps while still allowing for fish passage. The rapids were designed to an elevation that brings the bankfull profile back up to the historic floodplain. The heights of the rapids in the Beach Ridge range from 2.3 to 8.6 feet, the lengths range from 270 to 450 feet and the widths range from 100 to 150 feet. The rapids are relatively large structures. The size is necessary to recreate proper connection to the floodplain and provide long-term grade stabilization.

The rock arch rapids will consist of both a riprap lined ramp and a series of undulating boulder rock arches, or boulder weirs. Following guidance from the MN DNR REU, the ramp and boulder weirs are designed at a 3% longitudinal slope, which is the maximum slope suggested by the MN DNR REU. The boulder rock arches were designed with 0.5 feet of head loss per weir section. The boulder arches will be constructed to slope both downstream and toward the center of the arch section in order to concentrate low flows toward the stream center.

The rock arch rapids will consist of several types of rock aggregate designed to achieve both the hydraulic and ecological goals of the project. The base layer of rock was designed based on the USACE's Steep Slope Riprap Design outlined in *EM No. 1110-2-1601* [13], which determines the size of rock required to resist movement based on unit discharge calculations during high flows. A subbase of smaller rock was designed to be placed below the base layer in order to fill the voids left by the larger rock and prevent subsurface flow. The boulder weir sections will consist of larger boulders, ranging from 3 to 6 feet in diameter, placed above and into the base layer. The boulders will be placed in a semi-circular shape with natural curves facing downstream in order to replicate natural rapids. This will converge flow to the center of the channel, reducing near bank velocities.

The boulder configuration will also facilitate fish passage and add stability to the ramp. In addition, these rock arch rapids would provide significant spawning habitat for numerous fish species, most notably lake sturgeon. The proposed geometry, as well as details of the rock arches and ramp are included in the Feasibility Plan Set in **Appendix D**.

4.5 UPPER RIDGE – ROCK ARCH RAPIDS IMPLEMENTATION

A map of the Upper Ridge Reach restoration is provided in **Exhibit 15**. This reach is classified as a Type F channel based on Rosgen's stream classification guidelines [3]. An F-channel is entrenched and disconnected from the floodplain. Although the slopes in this sub-reach are flatter than the Beach Ridge, disconnection from the floodplain may lead to future bank failure and erosion problems. Similar to the Beach Ridge, the proposed solution in this sub-reach is to install 8 rock arch rapids, spaced approximately every ½ mile. The rock arch rapids will have the same design components as described in Section 4.4. The heights of the rapids in the Ridge Reach range from 6.1 to 8.4 feet, the lengths range from 230 to 420 feet and the widths range from 70 to 100 feet. The Upper Ridge is still relatively confined compared to the Beach Ridge, so although the heights of the proposed rapids remain high, the widths are narrower. The proposed geometry and details are included in the Feasibility Plan Set in **Appendix D**.

4.6 ADDITIONAL DESIGN COMPONENTS

4.6.1 SOD MATS

Sod mats are incorporated into the design on outside bends of the restored E-channel in the Lake Plain Reach to protect the disturbed bank from erosion. Sod mats are meant to foster dense protective vegetative growth on a bank to provide lasting erosion control and add habitat. The sod that currently exists along the existing channel of the Lake Plain Reach can be salvaged and used as sod mats. The extents of installation are shown in the Feasibility Plan Set in **Appendix D**.

4.6.2 SIDE INLET SEDIMENT BMPS

Side inlet sediment BMP's are proposed along both sides of the channel in locations where 10 acres or more drain to the South Branch in the Lake Plain Reach. A combination of terrain analysis and the 1983 as-built plan set was used to develop the locations of side inlet installation. Proposed side inlet sizes match the existing sizes where known and were estimated where unknown. Final size determination should be completed as part of the final design. Side inlet locations are shown in the Feasibility Plan Set in **Appendix D**.

4.6.3 ROCK RIFFLES

Rock riffles are grade control structures designed to ensure the design grade is maintained over time. As part of the proposed design for the Lake Plain Reach, rock riffles will be placed every ¼ mile at the inflection points of the meanders. They will be comprised of both MNDOT Class IV and Class I riprap. A base layer of MNDOT Class IV rock riprap will be installed to a depth of 2.5 feet on a subbase layer of MNDOT Class I riprap with a depth of 1 foot. Additional Class I riprap along with a well graded mix of aggregate will be spread over the Class IV riprap layer to fill voids and seal the ramp, thereby forcing water over the riffle and not through it. A detail of a rock riffle is shown in the Feasibility Plan Set in **Appendix D**. Along with constructed rock riffles, smaller rock riffles are expected to form naturally over time within the Lake Plain Reach as material is naturally scoured and deposited at the inflection points of the meanders.

4.6.4 FLOODPLAIN RESTORATION

Stream stability cannot be achieved without floodplain restoration. When a river reaches bankfull stage, water overflows into the floodplain, slowing velocities and storing floodwater during large storm events. The original floodplain in the Project Reach has been disconnected from the river as the channel has incised overtime. Without a floodplain, velocities continue to increase within the channel causing increased incision and bank failure during flood events. Reestablishing the original profile allows the river to access its floodplain more often. Energy dissipation in the floodplain during high flows reduces the size and amount of sediment that can be eroded from the banks, directly resulting in a reduction of sediment load in the river. The proposed channel restoration in the Lake Plain and rock arch rapids in the Ridge Reaches will reconnect the South Branch to its natural and historic floodplain.

4.7 COORDINATION WITH MINNESOTA DNR REU

Coordination between HEI and the MN DNR REU has been ongoing throughout the process of the restoration study. The purpose of the coordination effort was to establish communication between potential project partners. This forum was used to build consensus for the improvement concept approach based on additions, modifications, and refinements discussed during these group meetings. The coordination efforts consisted of in-person meetings, joint site reconnaissance efforts, and tele/video conferences. A brief overview of the timeline, key discussion points, and outcomes from each effort are provided in the following sections.

4.7.1 MEETING - APRIL 15, 2019

A kickoff meeting between representatives of HEI, MN DNR REU and WRWD was held in Fergus Falls at the MN DNR office.

4.7.2 SITE RECONAISSANCE - MAY 28, 2019

Participants from HEI and the MN DNR REU met on-site to observe and collect photographs of channel and sediment condition within the Lake Plain and erosion within the Ridge Reaches. Photographs can be found in **Appendix G**. An aerial imagery comparison for the years 1991, 2003, 2011 and 2018 was also discussed at this meeting and can be found in **Appendix H**.

4.7.3 MEETING - JUNE 26, 2019

A coordination meeting between representatives of HEI and MN DNR REU was held to scope out additional feasibility level field survey collection needs.

4.7.4 SITE RECONAISSANCE – AUGUST 5, 2019

Participants from HEI and the MN DNR REU paddled the Reference Reach with kayaks. The outcomes from this site reconnaissance effort are described in detail in **Section 2.3.2**. Additional photographs can be found in **Appendix I**.

4.7.5 MEETING – NOVEMBER 11, 2019

HEI presented preliminary hydrologic analysis and bankfull discharge results, along with classification of the existing channel as Type C and F. The hydrologic and stream classification analysis was completed using data collected during the August 5, 2019 site reconnaissance trip and subsequent topo survey completed by HEI prior to the meeting.

A general consensus of the bankfull discharge determination and stream classification was reached. A determination was made to proceed with a 3-pronged restoration approach. The 3-pronged approach included adding sinuosity in the Lake Plain and stabilizing banks and reconnecting the floodplain within the Beach Ridge.

4.7.6 MEETING – DECEMBER 19, 2019

HEI presented the Type E Channel design components for the improvements within the Lake Plain. A general consensus was reached regarding the concept design, with the understanding that refinement is necessary, but is predicated on additional topographical survey data needs. Significant discussion was held on the restoration approach within the Beach Ridge. Due to the severity of the incising and disconnection between channel and floodplain, it was agreed that the best approach would be the implementation of several large rock arch rapids within this reach. HEI presented new findings on the Upper Ridge Reach. It was previously thought that this reach remained fairly unimpacted in comparison to the Beach Ridge Reach. However, comparison of aerial images and review of lidar data indicate that several meanders were cutoff during the 2002 flooding. As a result, HEI would evaluate the possibility of reconnecting the historic meanders to add length to the channel.

4.7.7 MEETING – JANUARY 29, 2020

HEI presented their proposed placement and design components for rock arch rapids in the Beach Ridge. A general consensus was reached regarding the concept design, with the understanding that refinement is necessary, but is predicated on additional topographical survey data needs. HEI also presented the results of their analysis into the feasibility of reconnecting historic meanders within the Upper Ridge Reach. Due to the incision of the channel through this reach, reconnection of the meanders by use of channel blocks was found to be impractical. Instead, it was determined that the best approach to restoration within this reach would be to match the rock arch rapids concept within the Beach Ridge Reach. With the concept in place for a total restoration plan, it was determined that development of a feasibility level plan set and design report was the most logical next step.

4.7.8 TELE/VIDEO CONFERENCE – APRIL 16, 2020

Prior to this tele/video conference, HEI provided the MN DNR REU with a draft copy of the feasibility plan set for the proposed restoration project. The MN DNR REU provided some advance comments for discussion, and a number of other items were discussed during the conference. The MN DNR also provided follow-up comments after the conference that reiterated the discussions held during the conference. In general, the MN DNR REU agrees with the general rationale and justification for the project. They expressed desire to see the problems, underlying causes, and strategy for correction defined in a basis of design report. Those elements have been documented in previous sections of this feasibility study report. Specifically, the MN DNR REU noted the following concerns with the feasibility plan set

- Additional survey data is required to demonstrate the existing thalweg elevations and low bank height. USACE as-built thalweg elevations should also be shown in the profile in the Plan set.
- The downstream-most rock arch rapids (Station 582+00) is provided to offset a drop in grade caused by the proposed Lake Plain channel excavation. Deepening of the channel is likely counter-productive since the upstream channel is already incised.

- Hydraulic modeling in the Lake Plain should be conducted to compare the proposed design to existing conditions.
- The plan includes 14 large rock arch rapids. The channel within the Upper Ridge Reach is in better overall condition than the channel within the Beach Ridge Reach. Rock arch rapids within the Beach Ridge Reach should be prioritized.

As a result of the MN DNR REU's comments, the proposed grade of the channel in the Lake Plain was adjusted so that the drop in grade near Station 582+00 is eliminated. A proposed prioritization/phasing plan was also created and is provided in **Section 6**. Additional survey collection and refinement of hydraulic modeling are identified as future prioritized tasks to be completed.

Consensus was reached between HEI and the MN DNR REU regarding the need for additional data collection, including topographical survey data, bedload measurements, particle size distributions, and sediment rating curves, and refined hydraulic modeling to evaluate the suitability of the channel design in the Lake Plain, and determine the profile produced by the rock arch rapids in the Ridge Reaches. These data needs and their prioritization are discussed in **Section 6**.

5 PROJECT PLANS AND COST ESTIMATES

Cost estimating for the project was completed using practices defined in the Association for the Advancement of Cost Engineering's (AACE) *Total Cost Management Framework (TCMF)* [14].

5.1 COST ESTIMATING CLASSIFICATION SYSTEM

For all projects, the accuracy, reliability, and risk of cost estimating varies with the maturity level of project scope definition and deliverables. The AACE has developed a Cost Estimating Classification System to help define the expected accuracy range of a cost estimate based primarily on the maturity level of project definition.

The purpose of the classification system is to improve communications among stakeholders involved with preparing, evaluating, and using the project cost estimate. The system provides for 5 classes of estimate (Class 5 through Class 1). A Class 5 estimate is the most conceptual and corresponds to a project deliverable maturity level of 0% to 2%, while a Class 1 estimate is the most advanced, with a project deliverable maturity level of 65% to 100%. For each estimate class, an expected accuracy range is provided as a +/- percentage of the estimated total cost after an appropriate contingency has been added. The range of expected accuracy is driven by the degree of project definition. Projects are prone to changes in overall scope and scale as the definition of the project improves over time. The expected accuracy range predicts the extents of which the scope and scale should be expected to fluctuate with relative certainty. The expected accuracy range, however, does not preclude the use of an appropriate contingency. While the expected accuracy range predicts the risk of change to the estimate as the project becomes more well defined, a contingency accounts for known risks, uncertainties, and assumptions associated with the specific items encountered while completing the estimate that are specific to the project.

5.2 COST ESTIMATE CLASS DETERMINATION

The primary factor for determining the cost estimate class of a project is the maturity of the project scope definition and deliverables. A set of plans titled *Feasibility Study Plans for South Branch Wild Rice River Restoration & Sediment Reduction Project* were developed to accompany this report. The plan set is the primary deliverable document that was available when completing the cost estimate. The plan set is expected to change and improve as project scope definition improves and is currently considered to be approximately 25% of final project definition. The Feasibility Plan Set is provided in **Appendix D**. The overall scope definition of the project is approximately 20% of final project definition. Concurrence on the preliminary design concept has been reached with the MN DNR ERU. However, additional stakeholders, including other resource agencies and landowners have had minimal opportunity to provide input on the proposed improvement project. Additional input from these major stakeholders has the potential to significantly alter the scope definition of the project.

The maturity level of the project scope definition and deliverables best fits within Estimate Class 3 range, which is defined in RP 56R-08 as being between 10% and 40% defined. Furthermore, the “end usage” of Estimate Class 3 is defined as “Design development, budget authorization, and feasibility”, which fits the intended end usage of this cost estimate and overall design report. The expected accuracy range for Estimate Class 3 is from -15% to +20%.

5.3 RISK ANALYSIS AND CONTINGENCY

A risk analysis was completed using the principles outlined in the AACE’s RP 40R-08: *Contingency Estimating – General Principles* [16] to evaluate and estimate a construction contingency for the project. This began with identifying risk drivers, then linking them to their potential to impact project cost. For this project, the “Expert Judgement” method of evaluating risk was practiced.

The primary risk factors identified and used to estimate contingency, including an example specific to the project for each factor, are as follows:

- Errors and omissions in the estimating process:

Quantities for excavation and placement of spoil were estimated by comparing proposed design surfaces to existing ground surfaces. The existing ground surfaces primarily utilize IWI LiDAR topographical data. In the future, the LiDAR data will be supplemented by additional field survey, including cross sections of the river channel, and densely vegetated area. LiDAR is often less accurate than traditional survey in these areas. Excavation and embankment quantities are likely to change as accuracy of existing conditions data is improved by collection of survey data.

- Design that may not be complete enough to determine final quantities:

A geotechnical evaluation of the project has not been completed. Design elements such as excavation and embankment slopes, setbacks for spoil placement, and suitability of in situ material for use in construction of project features are subject to change with geotechnical recommendations

- Some items that may define precise quantification but are required to be estimated:

The quantity and lengths of side inlet culverts, as well as impacts to centerline crossing culverts and structures are estimated. These items are subject to change as the project is further defined and stakeholder input is acquired.

- Some items to be quantified that are generally computed by factoring:

Some items, including sod mat and seeding were factored stochastically. Additional detail estimating process is provided in **Section 5.4.2**. Accuracy of estimates for these items will be improved in the future by using deterministic methods.

- Material and equipment costs that may vary due to inflationary reasons and market conditions:

Unit prices were determined based on current values as observed in recent project bid tabulations. The cost to construct the project is estimated to increase over time due to inflation and market conditions. This includes both labor and material costs, as well as land acquisition costs.

- Changes in the actual quantities that may change schedules from that assumed in the estimate:

Quantities associated with stripping and placement of topsoil in disturbed areas were not computed in a dedicated schedule. Instead, these quantities are incidental to other excavation line items in the current estimate.

It is common for the majority of the risk of any given project to be directly associated to a select few critical items. This theory is sometimes referred to as Pareto's Law, which states that, for many events, roughly 80% of the effects come from 20% of the causes. For this project specifically, the cost to complete earthwork within the Lake Plain Reach is estimated to account for 76% of the overall construction cost within that reach. Similarly, the cost to furnish and install rock riprap within the Beach Ridge and Upper Beach Ridge Reaches is estimated as 80% of the overall construction cost for those reaches. Minor to moderate changes to the quantity or unit costs for these items can have major effects on total project cost. For the reasons presented in this section, the construction contingency was estimated as 30% of the construction cost.

5.4 BASIS OF ESTIMATE

A Basis of Estimate was completed as recommended in the AACE's RP 34R-05: *Basis of Estimate* RP 34R-05) [16] and is contained in **Sections 5.4.1 - 5.4.8**.

5.4.1 PURPOSE AND PROJECT SCOPE DESCRIPTION

The purpose and project scope description are as previously defined in **Sections 1-4** of this report.

5.4.2 METHODOLOGY

Unit quantities were generally estimated based on deterministic methods. All earthwork quantities, including rock riprap and boulders, were measured using comparisons between the proposed design surfaces within AutoCad Civil 3d, and existing surfaces created using available survey and IWI LiDAR data. Pipe lengths were measured, and flap gates were counted at each proposed side inlet location.

Other items were estimated stochastically. This includes sod mat, where an area of sod mat was estimated per meander then multiplied by the total number of meanders in the Lake Plain Reach. Seeding and mulching and ROW quantities were also estimated stochastically. These quantities are based on the average spoil width per half mile of channel within the Lake Plain Reach and based on a general offset of the disturbed area extents for the Ridge Reaches. Mobilization was estimated to be 5% of the sum of all other construction line items without contingency.

5.4.3 ESTIMATE CLASSIFICATION

The Estimate Classification is Class 3 is defined in **Section 5.2**.

5.4.4 DESIGN BASIS

The Design Basis for the development of the cost estimate are the *Feasibility Study Plans for South Branch Wild Rice River Restoration & Sediment Reduction Project* provided in **Appendix D**. Estimation methods for specific line items are provided as warranted in **Sections 5.4.4.1 – 5.4.4.2**.

5.4.4.1 DESIGN BASIS – LAKE PLAIN REACH

- Line Item No. 1 - Channel Excavation:

The channel excavation line item was measured based on a comparison of existing ground surface to proposed surface. The channel excavation line item consists of the following:

1. Stripping and stockpiling of materials suitable for topsoiling within the excavation and spoil placement areas.
2. Excavation required for the construction of the two-stage channel.
3. Placement of spoil material on-site as designated in the plans.
4. Placement of materials suitable for topsoiling after completion of excavation and spoil placement.
5. Removal and disposal of any miscellaneous items encountered during excavation.

- Line Item No. 7 - Sod Mat:

The sod mat line item was measured based on a 5-foot width multiplied by the length of the radius of each bend and adding 20-feet of length for a total area of sod mat. The sod mat line item consists of the following:

1. Salvaging and stockpiling 18" thick sod mats from the areas where channel excavation will take place.
2. Hauling 18" thick sod mats.
3. Placement of 18" thick sod mats adjacent to the low flow channel on the outside bends.

5.4.4.2 DESIGN BASIS – BEACH RIDGE AND UPPER RIDGE

- Line Item No. 1 – Rock Weir (36” – 72” Boulders):

The Rock Weir line item was measured in units of linear feet along the centerline of the rock weirs placed. The rock weir line item consists of the following:

1. Placement of boulders in the rock weir as shown in the Plans.
2. Movement of riprap material to allow for placement of boulders.
3. Placement of moved riprap material to fill remaining voids.

- Line Items No. 2 & 3 – Riprap Class V and II:

The Riprap line items were measured based on the 3D area covered by the riprap multiplied by the specified thickness as shown in the Plans. The Riprap line items consist of the following:

1. Foundation preparation including placement of salvaged channel excavated material and disposal of waste material.
2. Placement of riprap to the specified thickness.
3. Aggregate material used to fill voids in the riprap.

5.4.5 COST BASIS

The unit cost basis for the estimate line items was obtained from prior project bid tabs and engineer cost estimates. The projects used were of similar nature and scope to the proposed restoration for the South Branch and occurred in the last 1 – 5 years.

5.4.6 REAL ESTATE

It was determined that additional permanent and temporary ROW will be required for this project. Some existing permanent ROW exists within the Lake Plain Reach; however, it is not sufficiently wide to complete the proposed floodplain excavation and spoil placement. Additional permanent ROW will be required from the edge of existing ROW to 16.5' beyond the top of spoil. This proposed width is required to provide an adequate riparian buffer for the stream. Temporary ROW will also be required to place the remaining spoil that extends beyond the first 16.5', and to provide a temporary stockpile and construction access area during construction. The total estimated required ROW in the Lake Plain Reach is 145 acres of permanent, and 312 acres of temporary.

No existing ROW is documented within the Beach Ridge and Upper Ridge Reaches. Permanent ROW will be required to at least the boundary of the proposed rock arch rapid installation. Additionally, temporary ROW will be required for construction access, stockpiling, and working space. The total estimated required ROW for all rock arch rapid sites within the Beach Ridge and Upper Ridge Reaches is 26 acres of permanent, and 16 acres of temporary.

5.4.7 ASSUMPTIONS

Land values for permanent and temporary right of way were assumed to be \$4500 and \$500, respectively, for tillable land. Land values for permanent and temporary right of way were assumed to be \$1600 and \$250, respectively, for non-tillable/pasture/wooded land.

The cost for remaining engineering, legal, and administration work was assumed to be 15% of the total construction cost after the addition of the 30% contingency. This includes the cost required to complete additional field survey, final design, permitting, bidding services, construction staking, construction administration, property acquisition, and project closeout.

5.4.8 CONTINGENCIES

The value of contingency selected for the project is 30% of the total construction cost as defined in **Section 5.3**.

5.4.9 ESTIMATING TEAM

Hannah Rollin – Primary Estimator. Developed unit quantities and evaluated unit cost values.
 Gabe Bladow – Primary Reviewer. Assisted in development of line items and estimation methods.
 Erik Jones – Final Reviewer. Performed final Quality Assurance of unit quantities and unit cost values.
 Jerry Bents – Final Reviewer. Performed final Quality Assurance of Total Cost Management Framework.

5.5 COST ESTIMATE

A summary of expected costs is provided in **Table 4**. This analysis represents the cost to complete the full restoration project. A phased approach is recommended for this project. Details of the phased approach and the cost estimate for the phases are provided in **Section 6**. Detailed cost estimate tables containing unit costs and quantity tabulations for individual line items are provided in **Appendix F**.

Table 4 – Cost Summary

Lake Plain Reach Construction Cost	\$13,800,000
Beach Ridge Reach Construction Cost	\$4,200,000
Upper Ridge Reach Construction Cost	\$4,100,000
Total Construction Cost	\$22,100,000
Construction Contingencies (30%)	\$6,600,000
Legal, Admin, Permitting, Engineering (15%)	\$4,310,000
Land Acquisition	\$850,000
Total Estimated Project Cost	\$33,860,000
Expected Accuracy Low Range	\$28,800,000
Expected Accuracy High Range	\$40,600,000

6 PROJECT PRIORITIZATION AND PHASING PLAN

A phased implementation of the restoration project is recommended. Phased implementation allows the project costs to be spread out over time. More importantly, it allows for the opportunity to evaluate the effectiveness of each phase through data collection and evaluation prior to implementation of sequential phases. A concept for the phased approach is as follows:

6.1 PHASE 1 – BED LOAD MONITORING, DATA COLLECTION, AND PRELIMINARY ENGINEERING

Phase 1 consists of tasks required to advance the project from a feasibility concept to a preliminary design. These tasks will provide the necessary information required to refine the overall project scope and define benefit to cost comparisons for individual project features. This will allow the project partners to make educated decisions on future phase prioritization. With support from project partners, many of the items in Phase 1 could begin immediately.

6.1.1 ADDITIONAL TOPOGRAPHIC SURVEY

Additional collection of existing thalweg profile along the project corridor is still required. This information exists for most of the project reach but is absent in the lower Lake Plain Reach. Collection of this data should be prioritized.

6.1.2 BED LOAD MONITORING / SEDIMENT TRANSPORT ANALYSIS

Monitoring of bed load and other sediment sources should be completed to verify the source, size, and other physical properties of the sediment eroding within the Beach Ridge and Upper Ridge Reaches. An evaluation of this data should be completed to evaluate the degree to which the rock arch rapids are likely to trap sediment, and infill in a manner that provides habitat and a stable bed. This data should also be used to analyze the ability of the restored channel within the Lake Plain Reach to adequately transport that sediment. Ideally, a cost-share project partnership would be initiated with the USGS to assist with the monitoring. At a minimum, monitoring should take place at a location in the lower Beach Ridge, near the transition to the Lake Plain. Preferably, monitoring would take place at an additional 2-3 locations within the Ridge Reaches. This task is on the critical path to project implementation and should be prioritized.

6.1.3 RATE REDUCTION / FLOOD MITIGATION ANALYSIS

The proposed project demonstrates the feasibility to accomplish the restoration goals of reducing erosion and sedimentation, while providing resilience to the damages of flooding. However, the project does not provide any rate reduction or other flood magnitude mitigation measures. Rate reduction and flood mitigation measures should be analyzed. There is potential to enhance the restoration project by adding rate reduction measures to form a more comprehensive project. A significant reduction in stream flow rates upstream of the Lake Plain Reach has the potential to reduce the amount of floodplain excavation required, which could reduce the cost of construction within that reach.

6.1.4 WITH-PROJECT HYDRAULIC EVALUATION

A “with-project” hydraulic analysis should be completed to determine the impacts of the proposed project on water surface profiles, stream velocities, and other hydraulic factors within the Project Reach. Additionally, hydraulic modeling should be completed to determine the size of the pools that are likely to develop behind the rock arch rapids after initial construction.

6.1.5 DOWNSTREAM IMPACT EVALUATION

Excavation of floodplain in the Lake Plain Reach has the potential to improve hydraulic capacity of the channel in this reach. An evaluation should be conducted to determine if improved hydraulics in the Project Reach impacts downstream reaches of the river.

6.1.6 LEVEE HEIGHT / BREAKOUT EVALUATION

The current design requires a significant amount of spoil placement due to the magnitude of the floodplain excavation to achieve the desired restoration goals. An evaluation of existing breakout locations, elevations, and widths should be completed so that proposed features can be designed and constructed with similar breakout capacity to prevent flooding upstream that wouldn't occur under existing conditions.

6.1.7 EVALUATION OF FUNDING SOURCES

The opportunity for project partnership and funding sources should be explored. Potential State and federal funding sources that could be considered include Section 1135 Ecosystem Restoration program through the USACE, Clean Water Funds through the MN Board of Water and Soil Resources, Outdoor Heritage Fund through the Lessard-Sams Outdoor Heritage Council, Section 319 Funding through the MN Pollution Control Agency, and Farm Bill programs (such as RCPP) through the NRCS. It is likely that multiple sources will be required to fully fund the project.

6.1.8 STAKEHOLDER ENGAGEMENT AND CIVIC OUTREACH

Potential stakeholders should be engaged to determine interest in the project concept as currently defined. This includes, but is not limited to, the Wild Rice Watershed District, adjacent landowners, regulatory agencies, and the general public. Input from these entities is the most likely contributor to change in scope of the overall project.

6.2 PHASE 2 – PILOT ROCK ARCH RAPIDS

Phase 2 represents the first construction stage of the overall project. A single “pilot” rock arch rapids will be constructed on the lower end of the Beach Ridge Reach near the transition to the Lake Plain. The purpose of this “pilot” project would be to construct a relatively low cost project element and use it as a tool to monitor and evaluate the effectiveness of rock arch rapids within the Beach Ridge to achieve their goal of reconnecting floodplain, trapping sediment, and stabilizing the channel.

6.2.1 FINAL DESIGN

Final design of the “pilot” rock arch rapids would be completed after detailed evaluation of the prospective site. Factors contributing to the final design include site-specific topographical survey collection, geotechnical evaluation, landowner coordination, and project partner coordination.

6.2.1.1 ADDITIONAL SURVEY

The existing survey data within the Beach Ridge is limited to channel thalweg elevations, and sporadic cross sections. When a site is selected, a full topographic survey will need to be conducted to provide sufficient data to complete the design of the rock arch rapids.

6.2.1.2 GEOTECHNICAL EVALUATION

Prior to finalizing design, a geotechnical evaluation should be conducted at the “pilot” project site to determine the suitability of existing materials for implementation of the rock arch rapids.

6.2.2 MONITORING AND EVALUATION

When construction of Phase 2 is complete, bed load and sediment monitoring should be conducted for a defined time period to fully evaluate the effectiveness of the rock arch rapids. This information will guide the final design and timeline and of subsequent phases. If the “pilot” project proves to be successful, priority should next be given to constructing additional rock arch rapids within the Beach Ridge Reach (Phase 3).

6.3 PHASE 3 – BEACH RIDGE REACH ROCK ARCH RAPIDS

Final design of Phase 3 will be completed in a similar manner as the Phase 2, but on a larger scale. The need for site-specific topographic survey, geotechnical evaluation, and coordination with landowners and project sponsors will apply.

6.3.1 MONITORING AND EVALUATION

Similar to Phase 2, upon completion of Phase 3, bed load and sediment monitoring should be conducted for a defined period of time to evaluate the effectiveness of the work completed within the Beach Ridge Reach at slowing erosion, and reducing the amount of sediment delivered to the Lake Plain. If the work within the Beach Ridge Reach proves to be successful, priority should next be given to completing stream restoration within the Lake Plain Reach to increase the streams capacity to convey sediment.

6.4 PHASE 4 – LAKE PLAIN CHANNEL RESTORATION

The overall scope and cost for Phase 4 is larger than Phases 3 and 2. For this reason, the topographic survey data and geotechnical needs are greater. This phase also requires significantly more land acquisition. This preparatory work could be completed coincidentally with the Phase 2 and 3 work.

6.4.1 FINAL DESIGN

Final design will include refining the grade of the proposed channel, verifying that the proposed flood plain geometry adequately conveys flow for the design return period event, defining a stream cross section that functions hydraulically while remaining stable from a geotechnical standpoint, and detailing design features such as sod-mat implementation and final sinuosity.

6.4.1.1 ADDITIONAL SURVEY

To more accurately define the quantities and costs associated with earthwork on this phase, additional existing ground topographical data will need to be collected along the entire length of stream within the reach. This data will not only allow us to design the excavated channel but refine the placement of spoil along the project corridor.

6.4.1.2 GEOTECHNICAL EVALUATION

Geotechnical analysis will need to be conducted to evaluate the stability of in situ soils. This will define the required excavation slopes, spoil placement offsets, and spoil placement geometry.

6.5 PHASE 5 – UPPER RIDGE REACH ROCK ARCH RAPIDS

At this time, improvements within the Upper Ridge Reach are considered to be of lower priority. It is assumed that this reach contributes far less sediment load in comparison to the Beach Ridge Reach. However, the results of sediment load analysis and monitoring completed as part of Phases 1-3 may impact prioritization of these improvements.

6.5.1 FINAL DESIGN

Final design will be consistent with that of Phases 2 and 3.

7 SUMMARY / RECOMMENDATIONS / NEXT STEPS

The South Branch Wild Rice River Restoration and Sediment Reduction project aims to reduce erosion and sedimentation along the channel within the Project Reach, while providing resilience to the damages of flood events. The information provided in this report supports the feasibility of the project. However, in order to proceed toward full implementation of the project, further work must be completed to advance the design of project features, gather support from stakeholders, and acquire funding for construction. The steps outlined in **Section 6** are recommended if advancement of this project from feasibility to implementation is desired.

8 REFERENCES

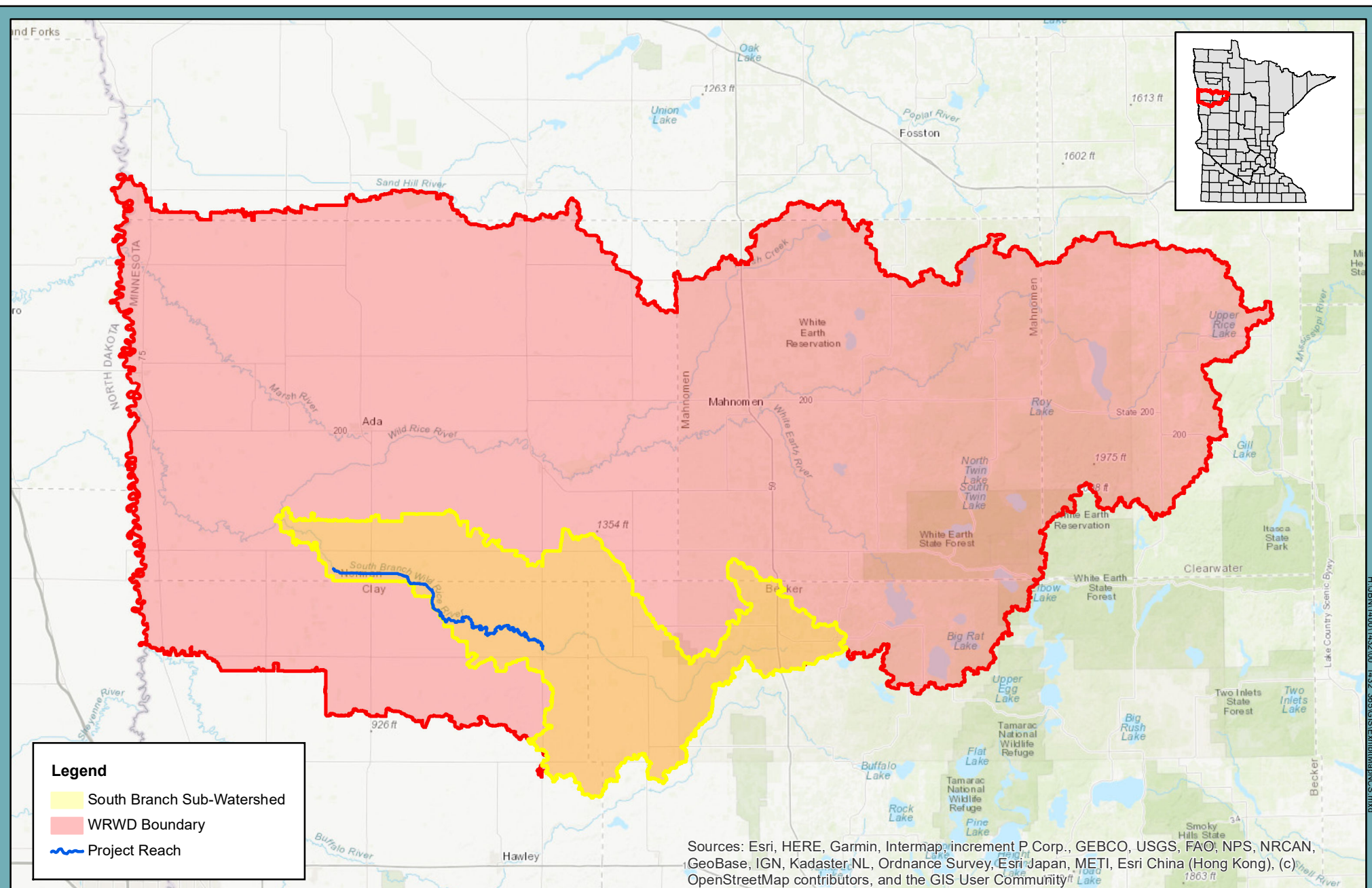
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EXHIBITS





Exh. 1

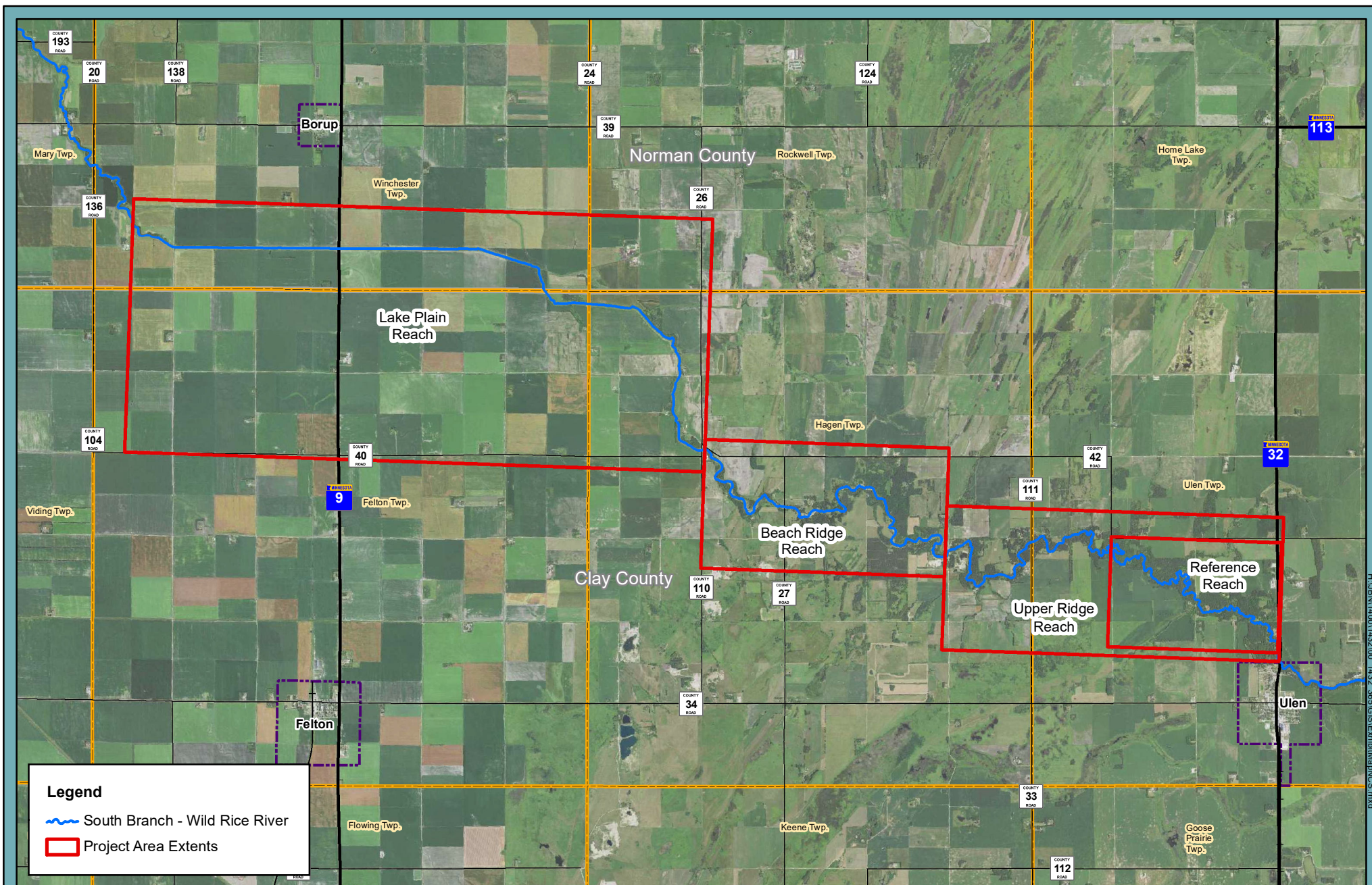
Exhibit 1: Wild Rice River Watershed and Project Location Map

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 South Branch Wild Rice River Restoration & Sediment Reduction
 Wild Rice River Watershed District



0 2.75 5.5 11 Miles





Exh. 2

Exhibit 2: Project Reach Location Map

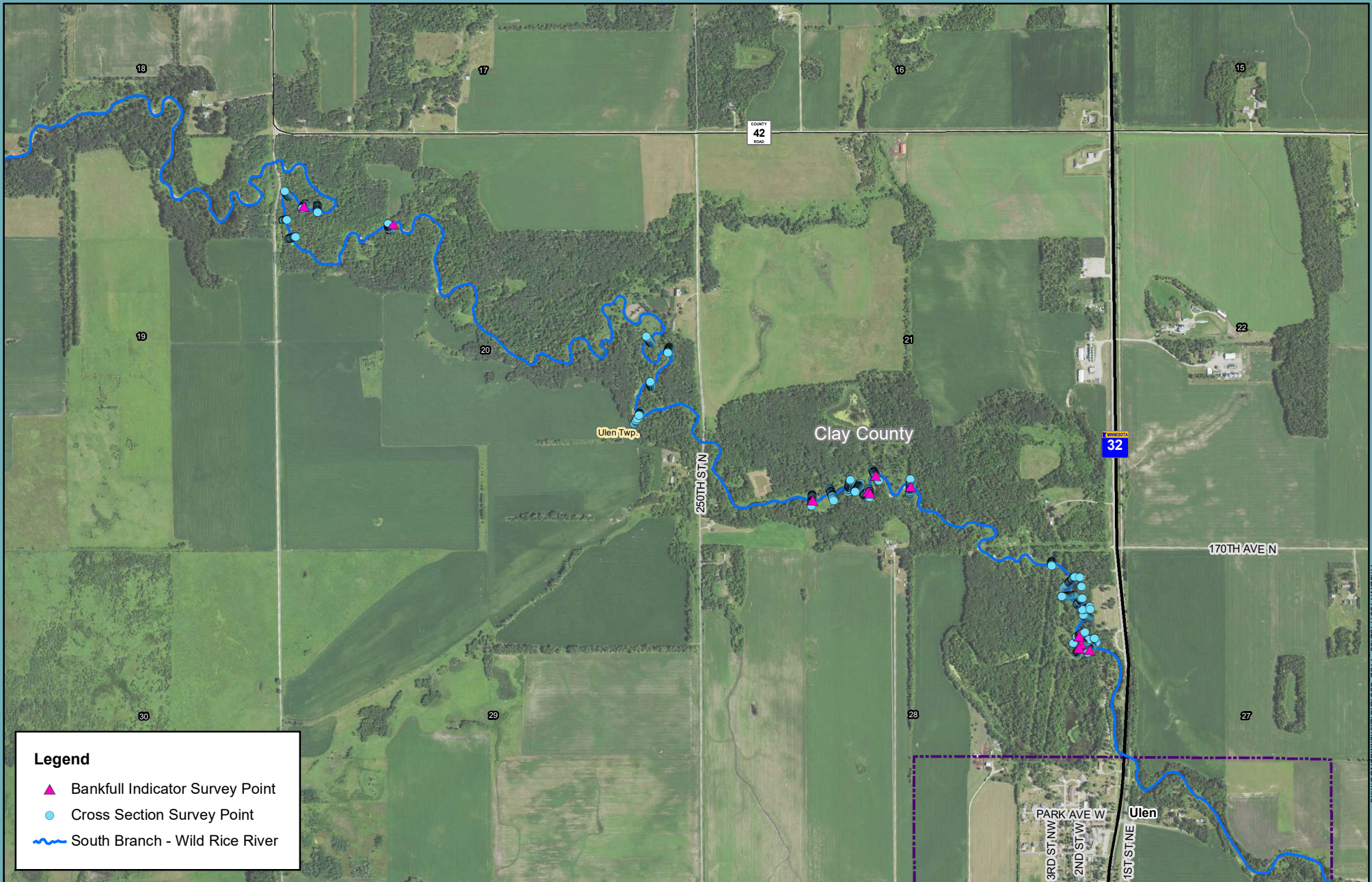
Feasibility Study Report
South Branch Wild Rice River Restoration & Sediment Reduction
Wild Rice River Watershed District



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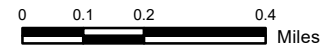


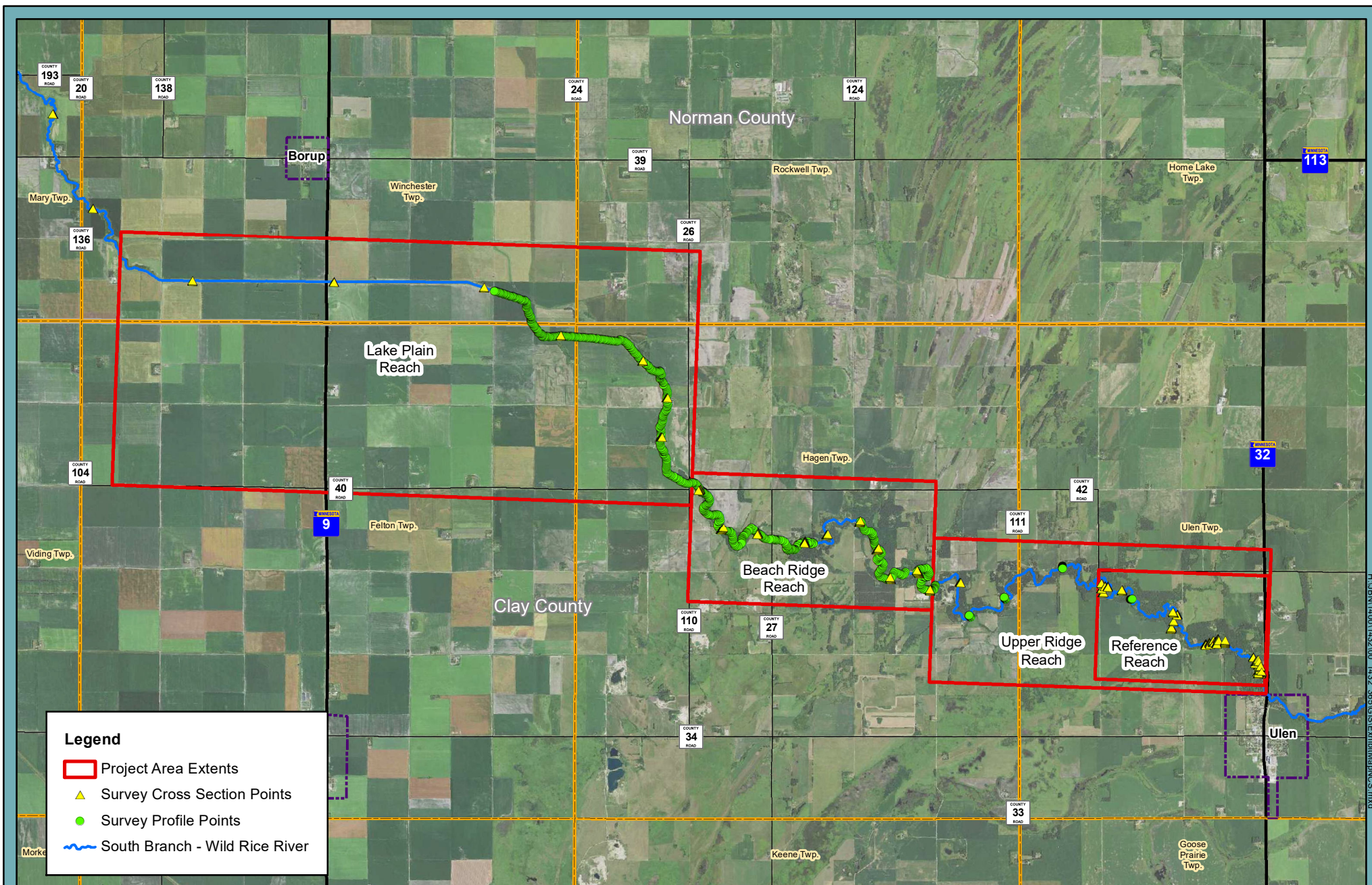
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Exh. 3

Exhibit 3: Reference Reach Survey Data Map

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 South Branch Wild Rice River Restoration & Sediment Reduction
 Wild Rice River Watershed District





Exh. 4

Exhibit 4: Project Reach Survey Data Map

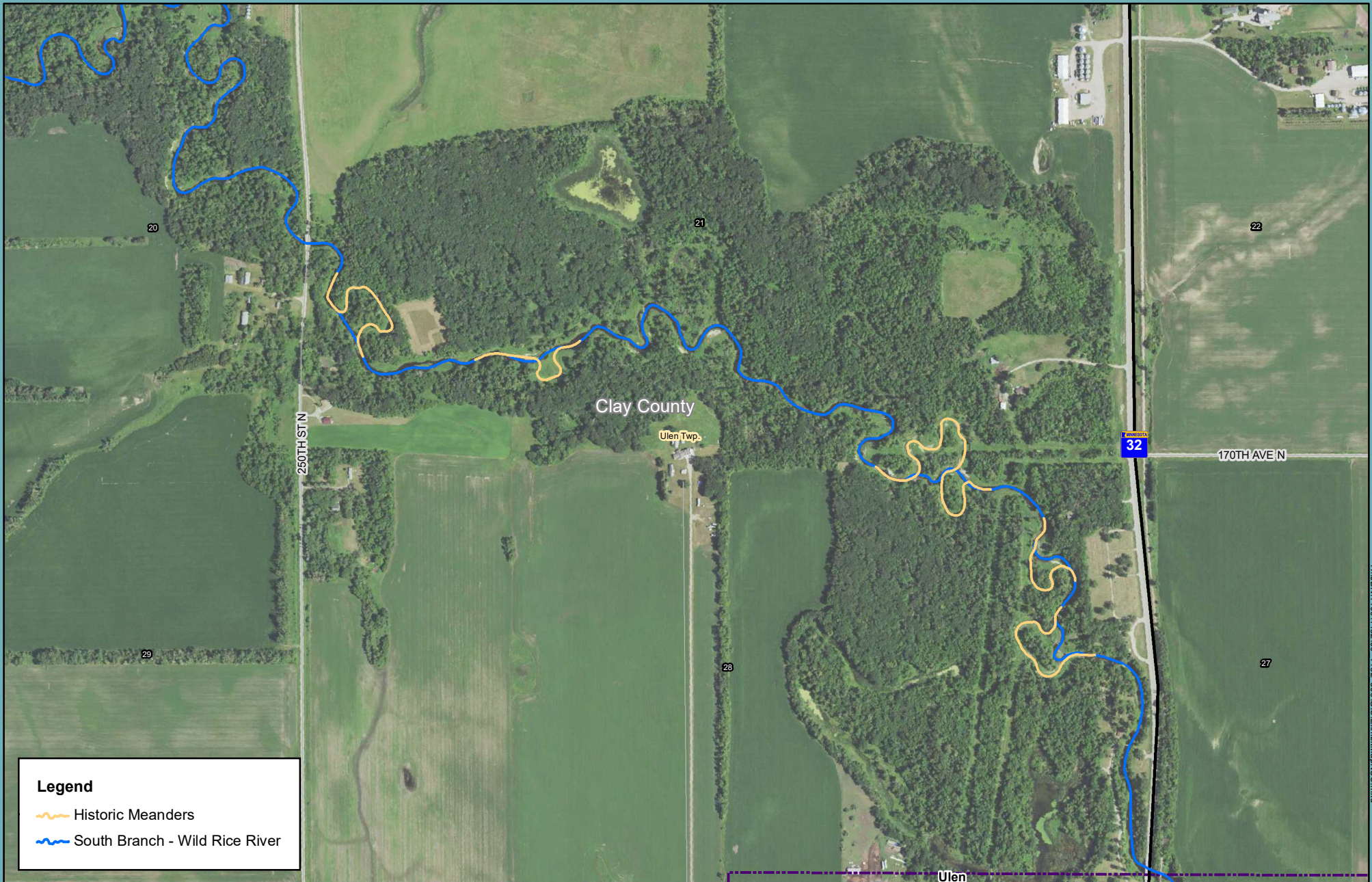
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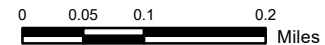
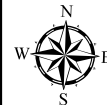


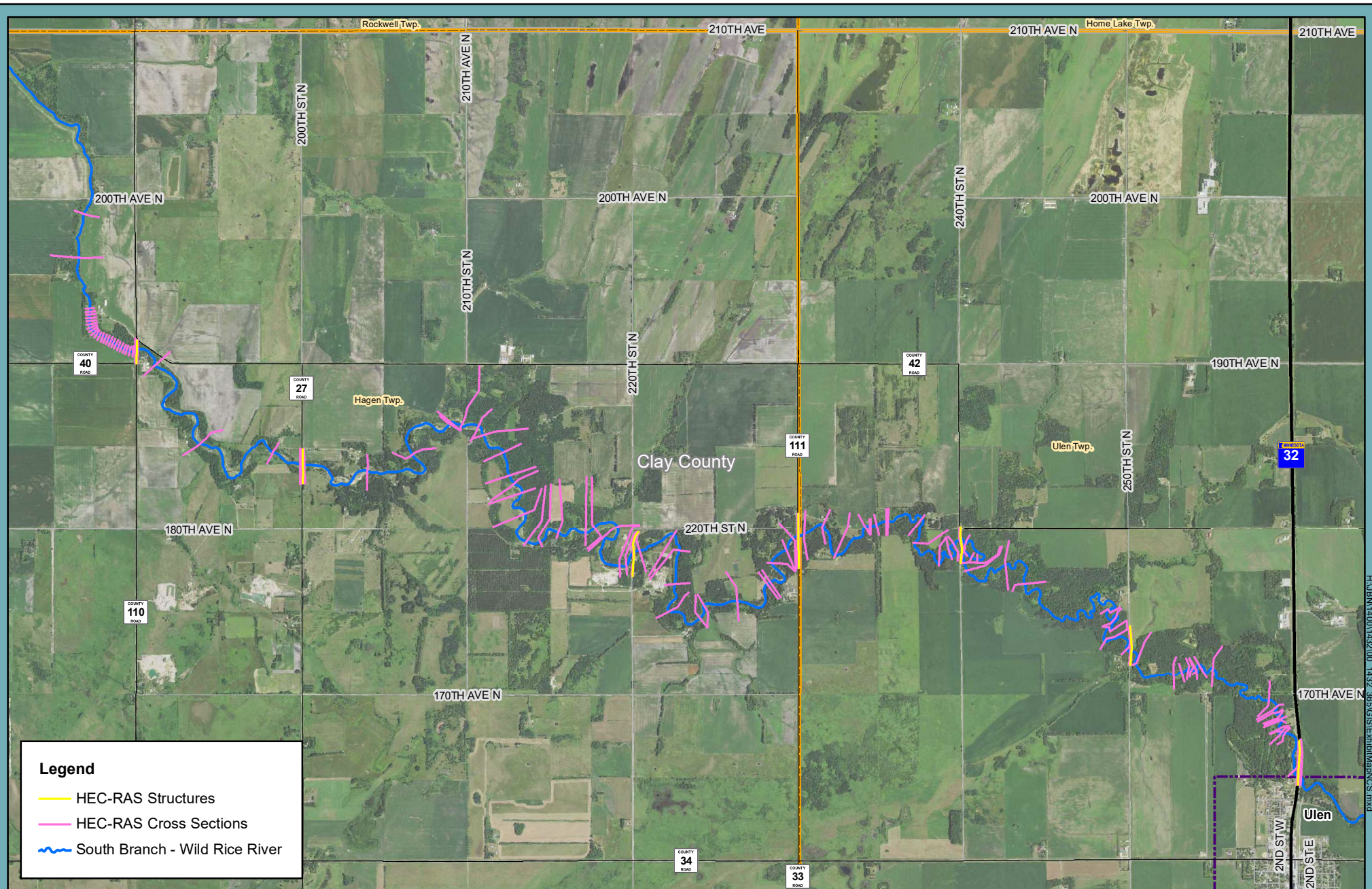
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Exh. 5

Exhibit 5: Reference Reach Historic Meanders

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Wild Rice River Watershed District

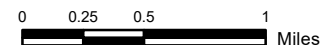




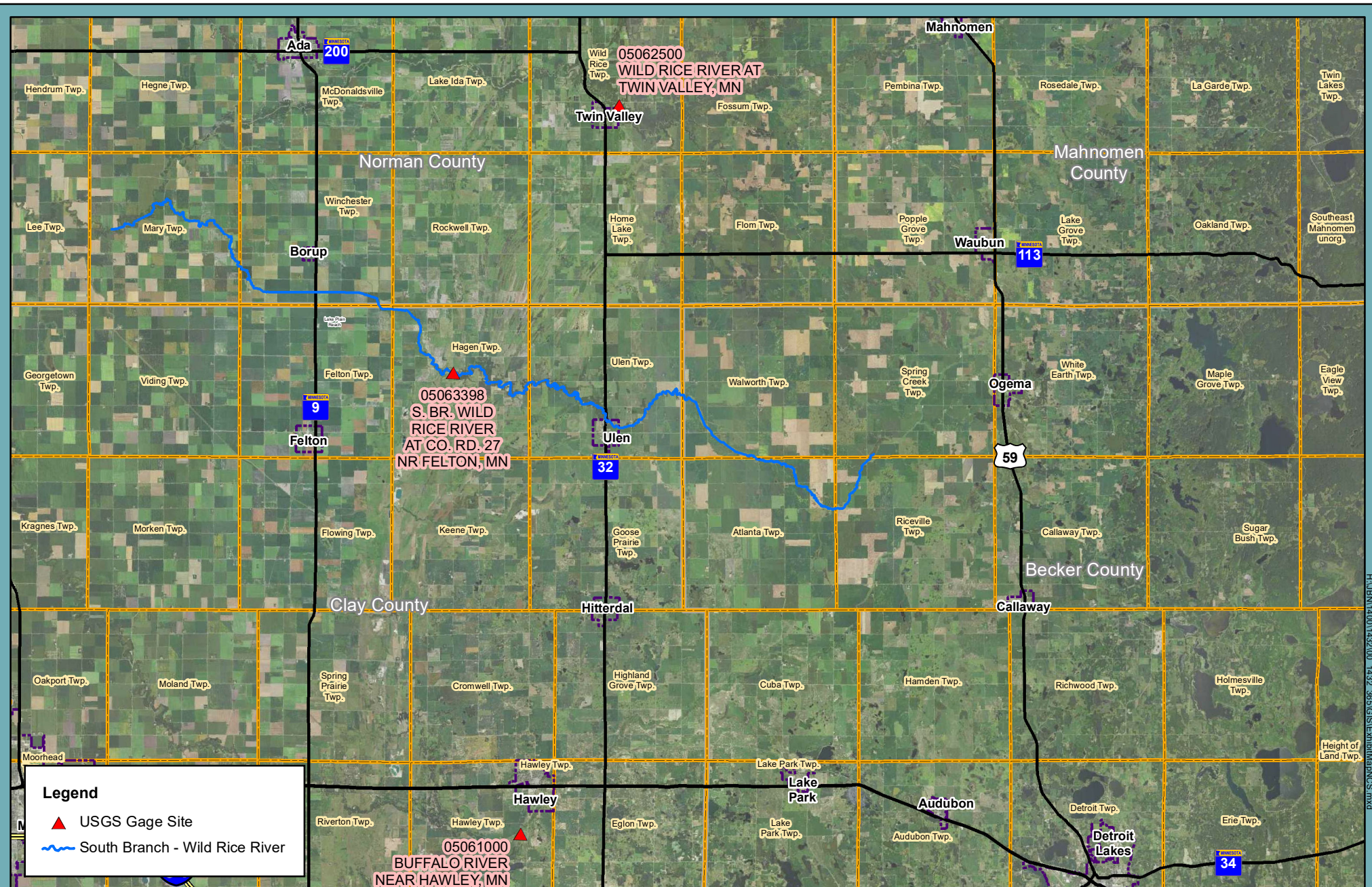
Exh. 6

Exhibit 6: Bankfull Discharge HEC-RAS Model Extents

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 South Branch Wild Rice River Restoration & Sediment Reduction
 Wild Rice River Watershed District



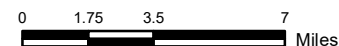
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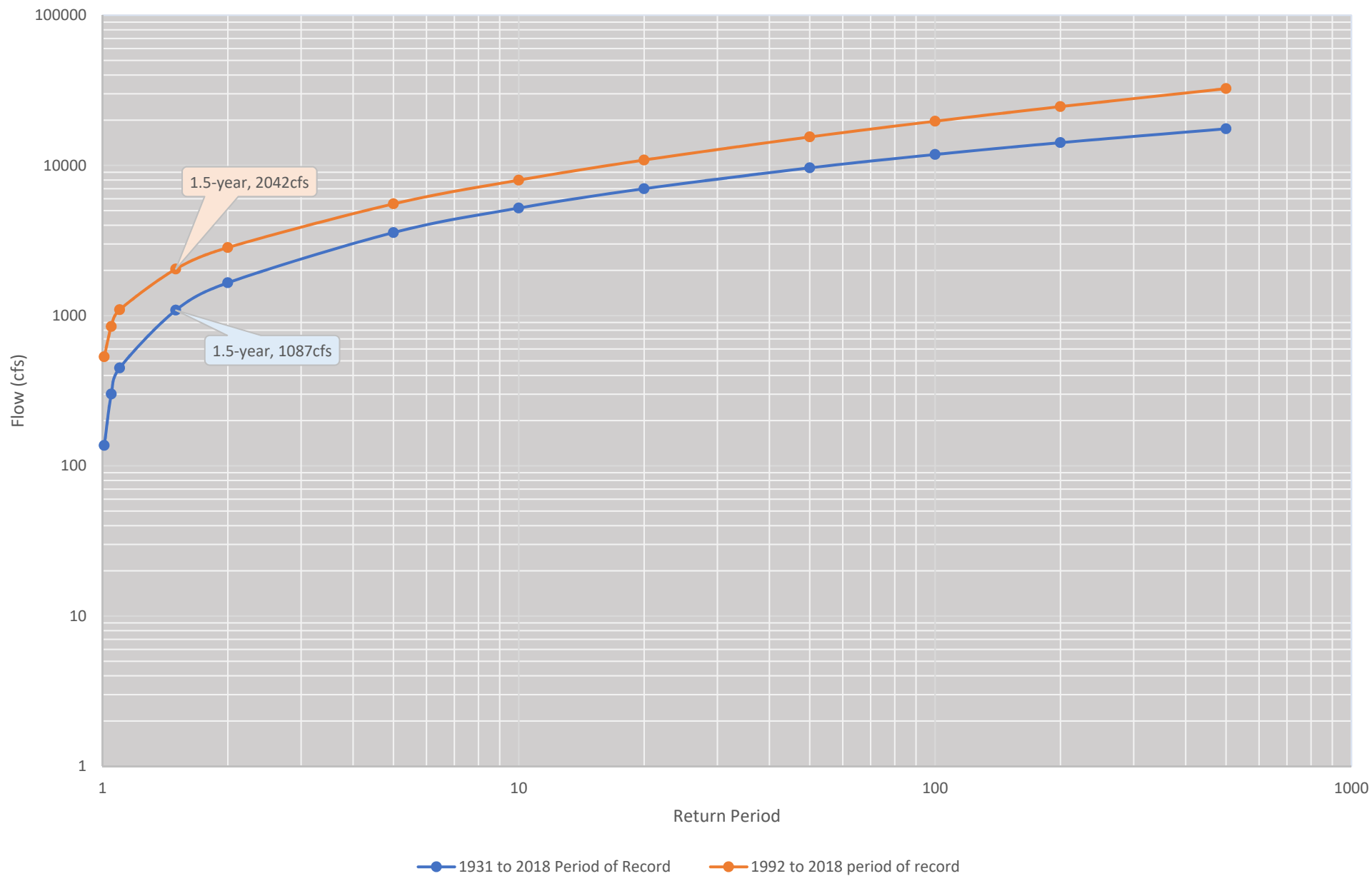
Exh. 7

Exhibit 7: USGS Gage Location Map

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South Branch Wild Rice River Restoration & Sediment Reduction
Wild Rice River Watershed District



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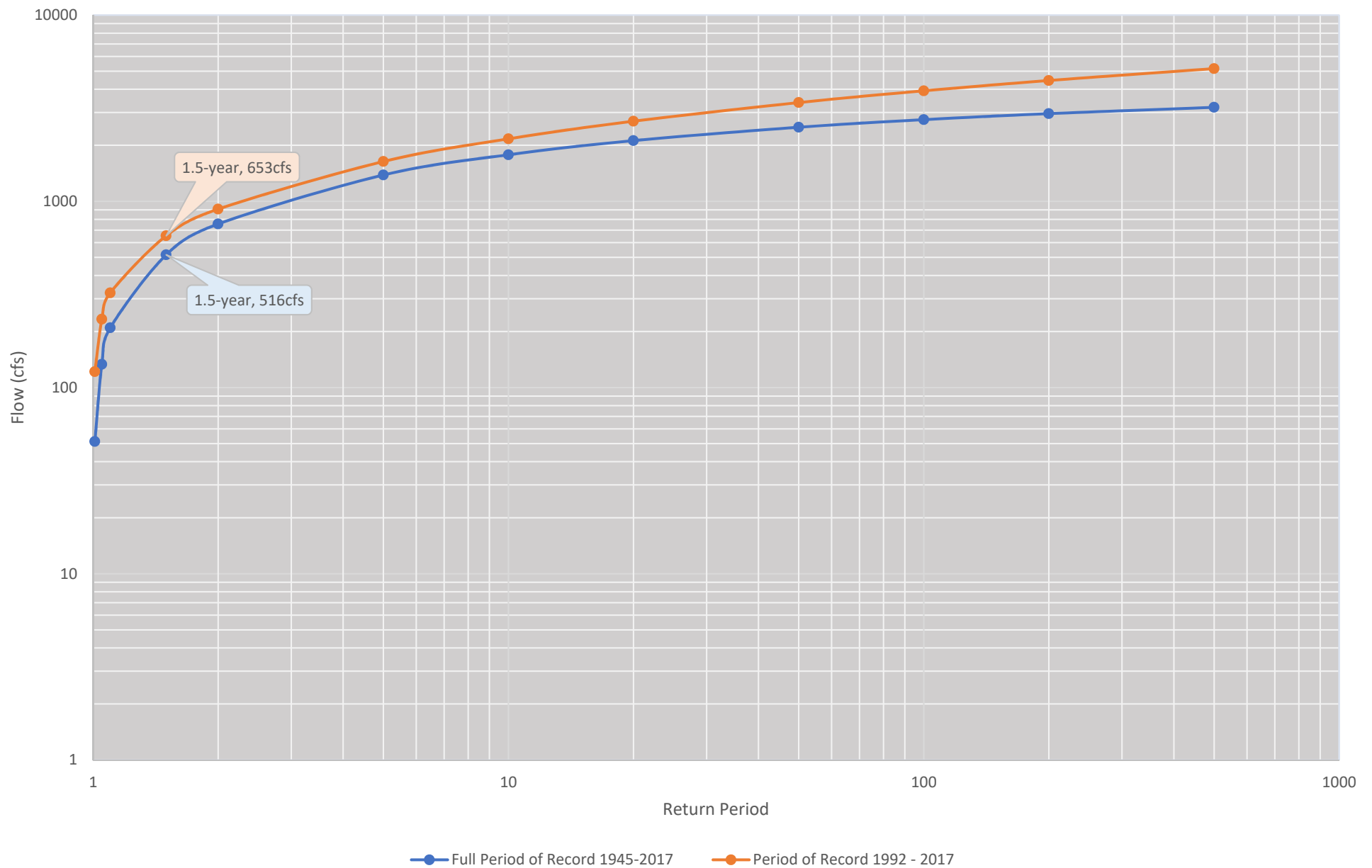


Exh. 8

Twin Valley USGS Gage (050625000) Frequency Analysis Curves

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 South Branch Wild Rice River Restoration & Sediment Reduction
 Wild Rice River Watershed District



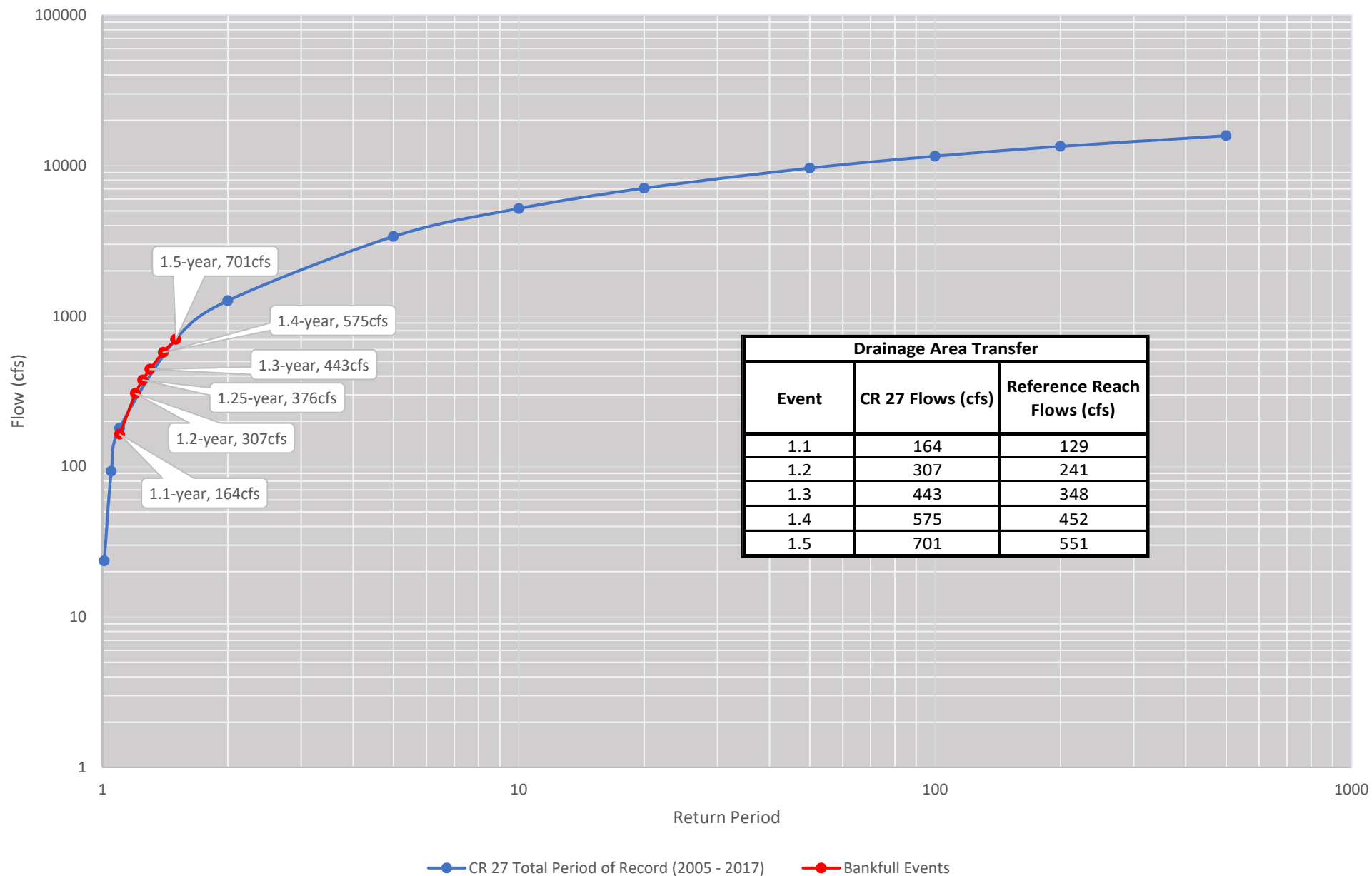


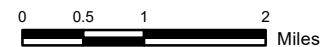
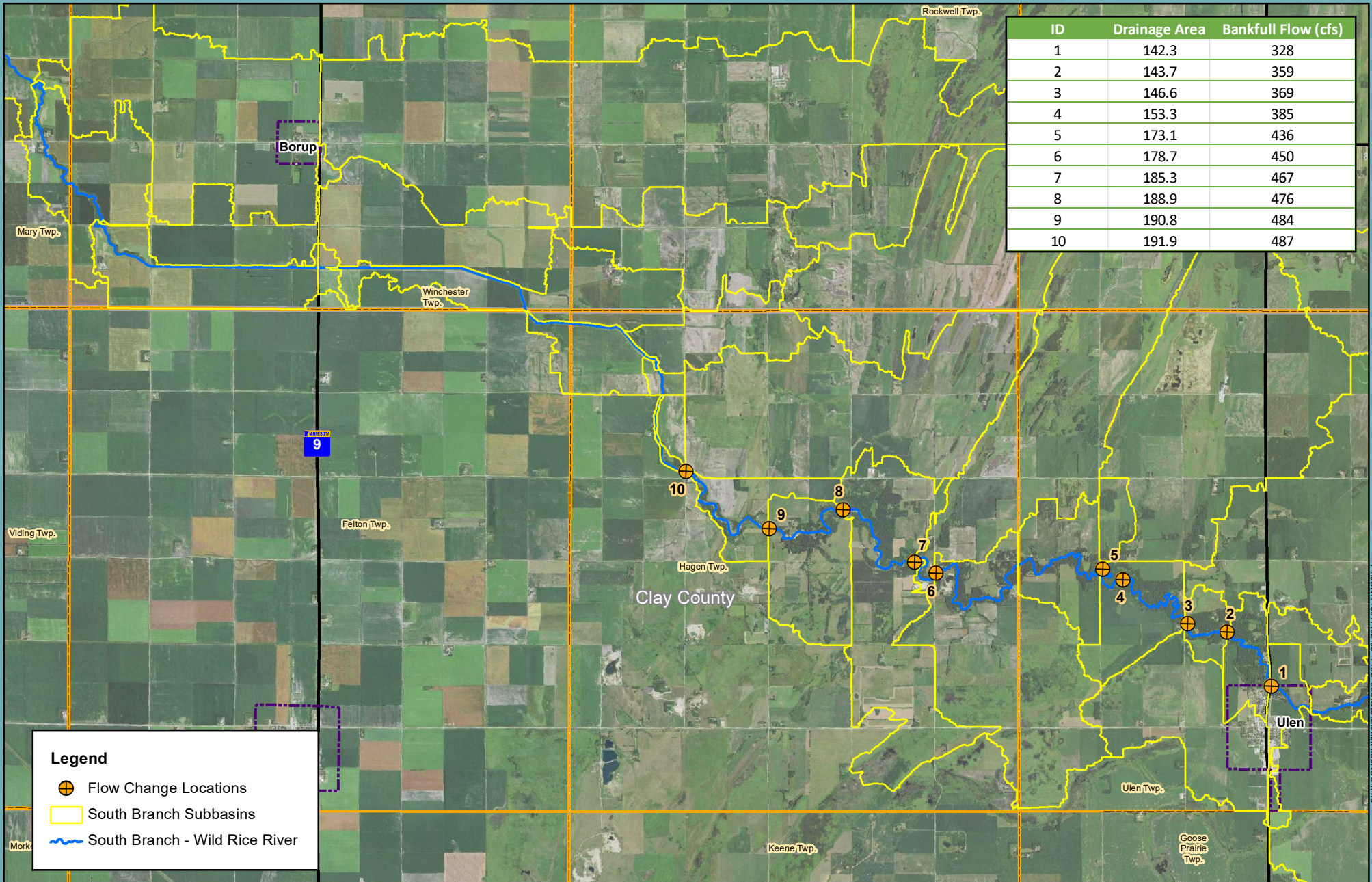
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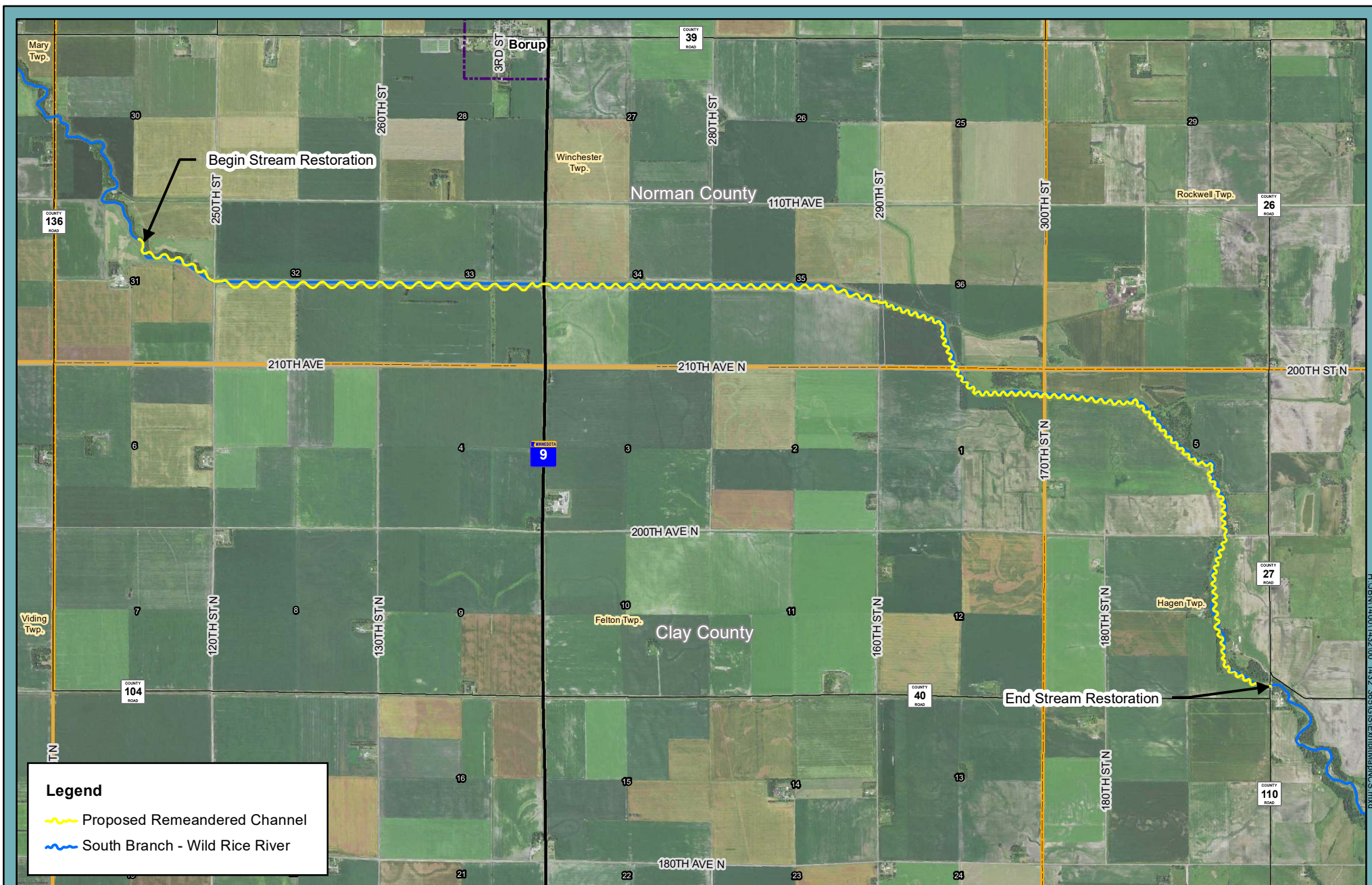
Hawley USGS Gage (05061000) Frequency Analysis Curves

Feasibility Study Report
 South Branch Wild Rice River Restoration & Sediment Reduction
 Wild Rice River Watershed District





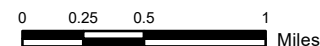


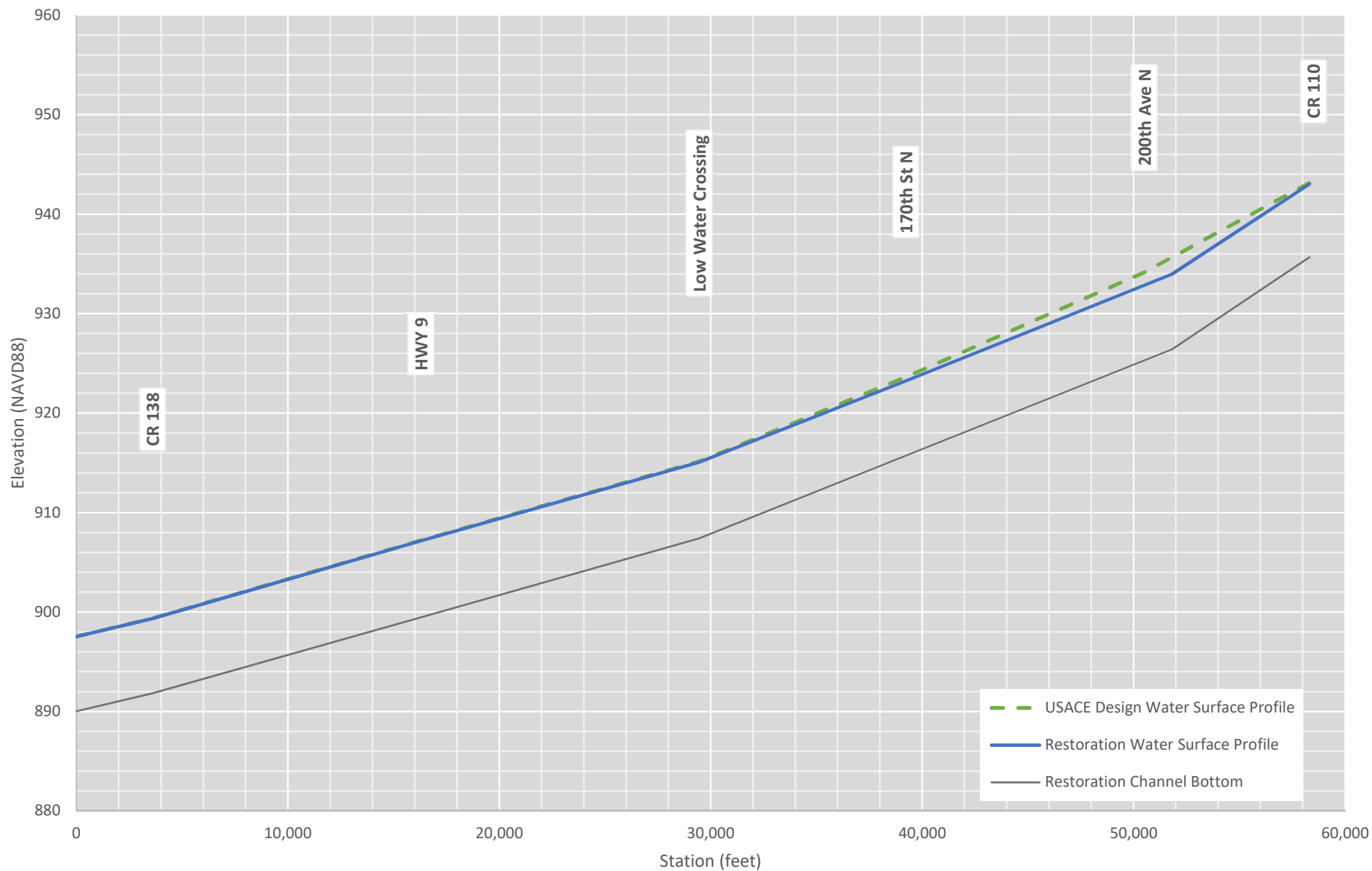


Exh. 12

Exhibit 12: Lake Plain Channel Restoration Location Map

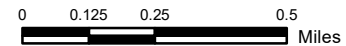
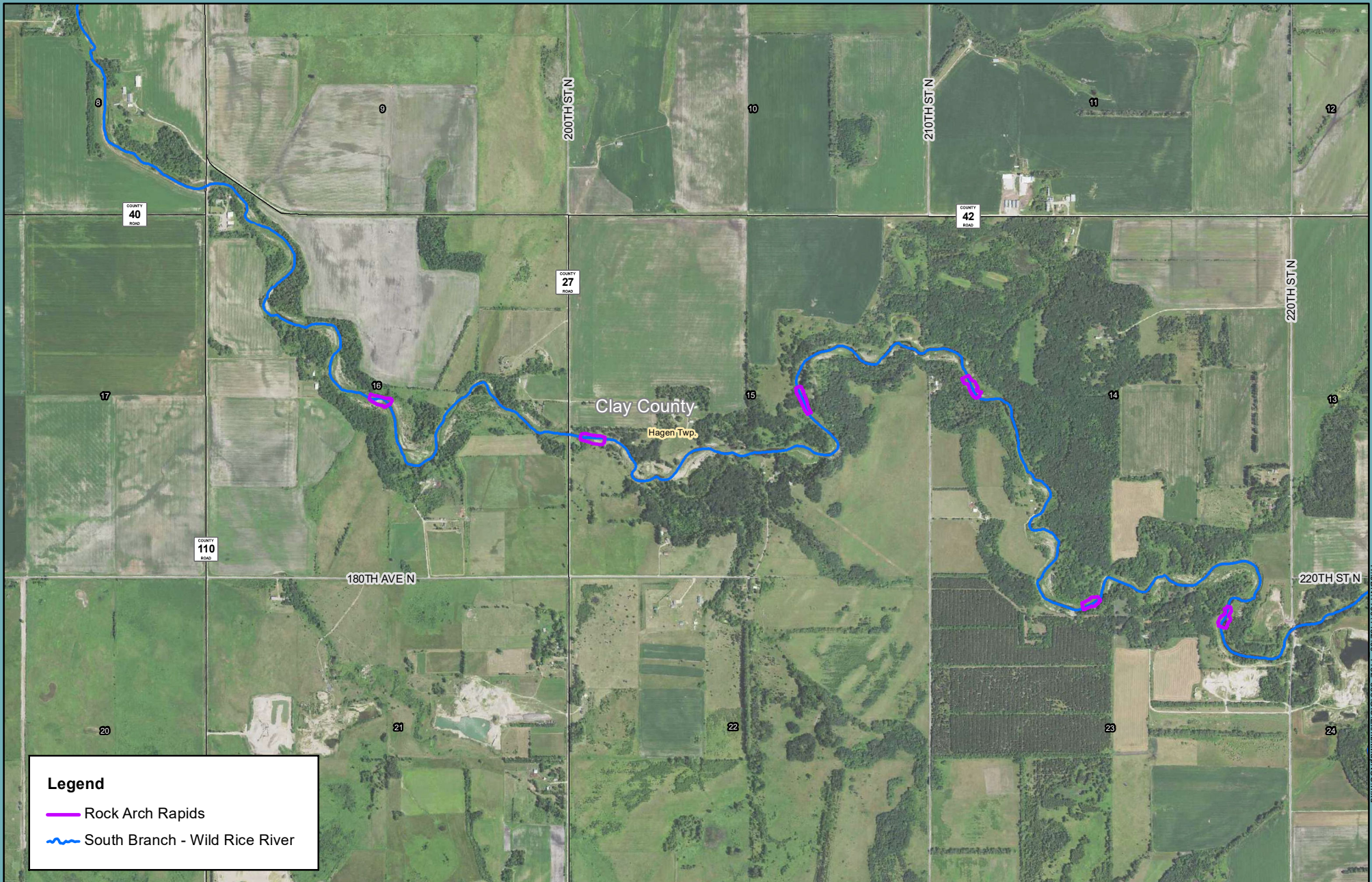
Feasibility Study Report
 South Branch Wild Rice River Restoration & Sediment Reduction
 Wild Rice River Watershed District

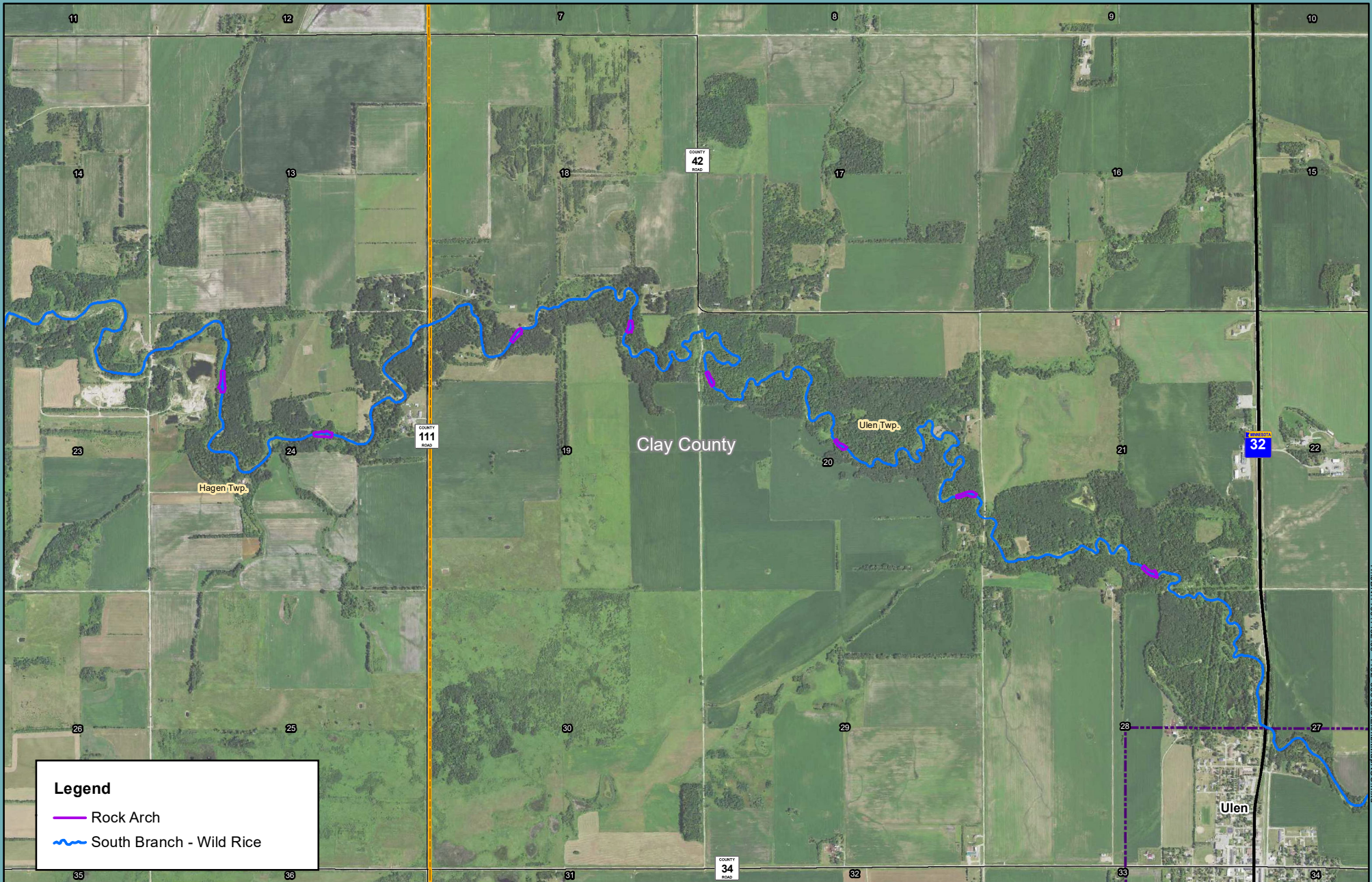




Lake Plain Reach Water Surface Profiles

Feasibility Study Report
 South Branch Wild Rice River Restoration & Sediment Reduction
 Wild Rice River Watershed District



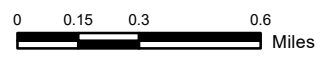


Legend

- Rock Arch
- ~ South Branch - Wild Rice

Exh. 15

Exhibit 15: Upper Ridge Rock Arch Rapids Location Map
 Feasibility Study Report
 South Branch Wild Rice River Restoration & Sediment Reduction
 Wild Rice River Watershed District



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APPENDIX A

Technical Memorandum – South Branch Channel Project/Survey History

Technical Memorandum

To: Wild Rice Watershed District
From: Gregory S. Thompson PE, CFM
Jerry Bents, PE
Houston Engineering, Inc.
Subject: South Branch Channel Project/Survey History
Date: May 7, 2019
Project: 1432-365: South Branch RCPP

INTRODUCTION

As part of the South Branch RCPP watershed planning efforts, historical and current channel bottom elevation data have been evaluated to better understand how the profile has changed over time. Understanding the extent to which the channel bottom has changed and the locations where changes are susceptible to occurring are vital when it comes to solving erosion and sedimentation issues.

Erosion throughout the beach ridge has been an ongoing issue for many years. The steep river gradient through the beach ridge creates high flow velocities resulting in channel erosion and subsequent sediment transport to downstream reaches. Then, as the South Branch reaches the Valley floor, deposition typically occurs which further reduces channel conveyance capacities resulting in increased flooding in the adjacent farmland. During RCPP planning efforts, several preliminary alternatives have been developed to increase channel conveyance and/or temporarily retain flood water. From a project sustainability and maintenance standpoint, it is important to address erosion and sedimentation issues that may later affect the project design and operation.

This Technical Memorandum (TM) documents the varying channel bottom elevations, which date back to the mid-1970s when the channel was surveyed prior to the US Army Corps of Engineers (USACE) project. The TM summarizes the channel profile and design widths including survey obtained for the RCPP planning efforts.

PROCEDURE

Channel bottom elevations from numerous prior projects and studies from 1974 to 2017 were assembled and organized into a consistent format, including the vertical datum and stationing. Vertical datums of each project were verified and adjusted if necessary, so that all elevations were in the North American Vertical Datum of 1988 (NAVD 88). As presented in **Exhibit 1**, a single channel centerline alignment was created, which extends upstream from the South Branch confluence with the Wild Rice River to Upper Becker Dam. Survey data was extracted from various sets of plans or studies, and they were associated with a specific river station along the

South Branch. The data was plotted in Microsoft Excel and multiple profile plots were created, as presented in **Exhibit 2**. Channel bottom widths were also tracked where available.

SURVEY DATA SOURCES

FLOOD CONTROL – WILD RICE RIVER – SOUTH BRANCH AND FELTON DITCH (1974-1983)

- USACE Project
- Preliminary Plans and Survey → 1974-1975
- As-Built Plans → 1983
- A 0.86 ft. datum conversion was used to convert elevations to NAVD 88.

REPAIR OF PROJECT NO. 9 - SOUTH BRANCH OF THE WILD RICE RIVER (2004)

- HEI Reference No.: 1432-037 Phase 18
- Preliminary Plans/No Construction
- Sections 24 & 25 of Mary TWP
- Sections 30 & 36 of Winchester TWP
- Section 1 of Felton TWP
- A 0.86 ft. datum conversion was used to convert elevations to NAVD 88.

REPAIR OF PROJECT NO. 9 - S. BR. OF THE WILD RICE RIVER (2004/2005)

- Construction Plans
- HEI Reference No.: 1432-037 Phase 14
- SE ¼ of Section 8 (Hagen TWP)
- Vertical Datum, NAVD 88

REPAIR OF PROJECT NO. 9 - SOUTH BRANCH OF THE WILD RICE RIVER (2004/2005)

- Construction Plans
- Sections 31-35 of Winchester TWP
- HEI Reference No.: 1432-037 Phase 15
- A 0.86 ft. datum conversion was used to convert elevations to NAVD 88.

WILD RICE RIVER FEASIBILITY STUDY (2006)

- 2006 Sedimentation Study – South Branch of the Wild Rice
- HEI Reference No.: 1432-325 Phase 1
- Vertical Datum, NAVD 88

FEASIBILITY DESIGN AND ENV. FOR SOUTH BRANCH OFF-CHANNEL (2006)

- HEI Reference No.: 1432-323
- Vertical Datum, NAVD 88

SOUTH BRANCH ON-CHANNEL STORAGE ALTERNATIVES (2007)

- HEI Reference No.: 1432-284
- Vertical Datum, NAVD 88

UPPER BECKER DAM ENHANCEMENT PROJECT (2008)

- HEI Reference No.: 1432-330
- Vertical Datum, NAVD 88

SOUTH BRANCH RCPP (2017)

- Watershed Planning Study
- HEI Reference No.: 1432-365
- Vertical Datum, NAVD 88

CONCLUSION

Numerous previously obtained survey files were compiled for this evaluation to identify if erosion and sedimentation locations can be understood. The majority of the historical survey exists downstream of the beach ridge from the 1983 USACE design, subsequent studies and construction projects. As compared to the 1983 design, much of the recent survey elevations downstream of Highway 9 appear to show erosion, degradation (channel lowering). Through the constructed channel upstream of Highway 9, slight aggradation is appearing (channel bottom increasing).

The only available survey data through the beach ridge itself originated in 2006, with limited channel survey near culverts in 2017 as part of the RCPP efforts (**Exhibit 3**). Additional survey would be required through this reach to validate the magnitude of channel profile change.

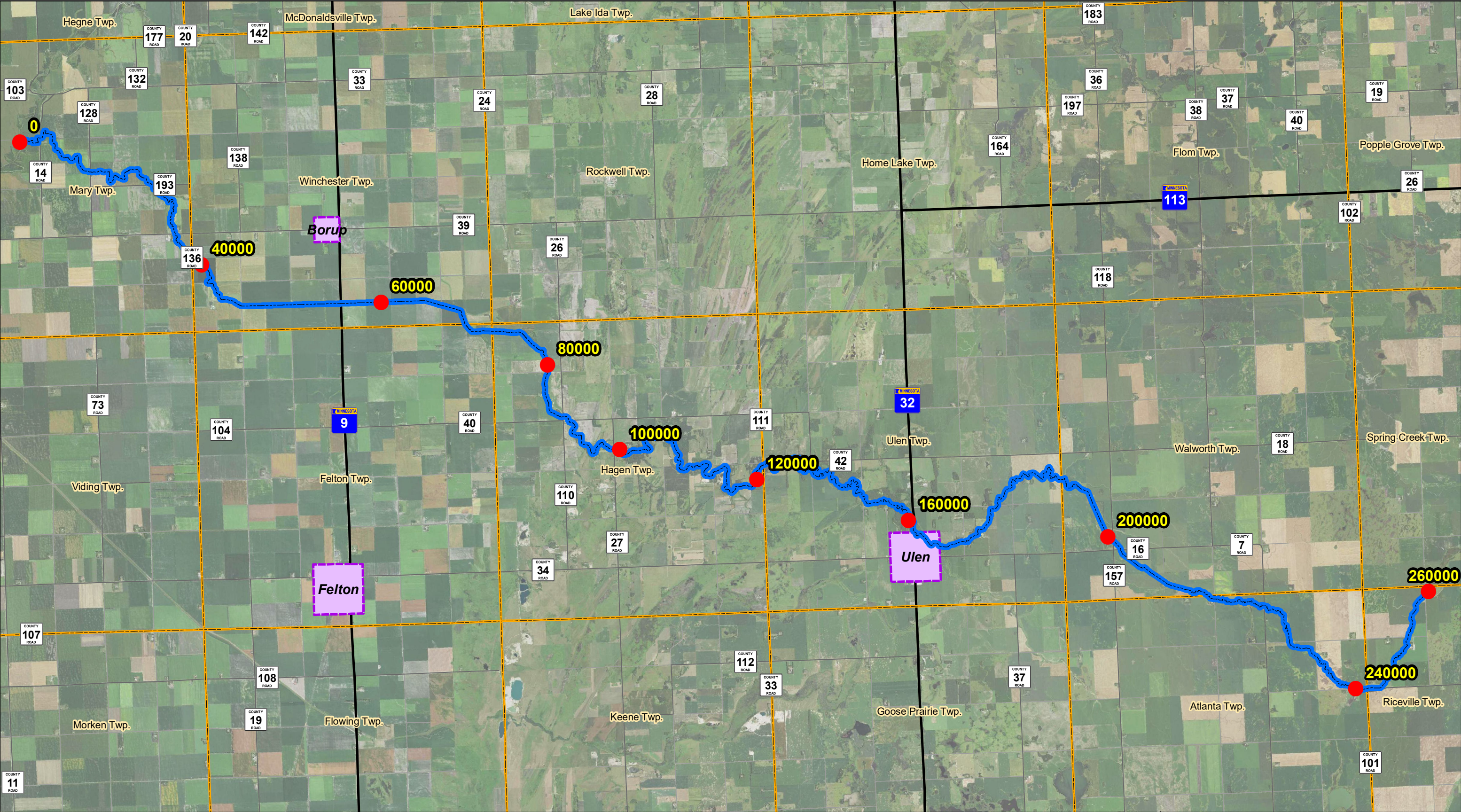


Exhibit 1: Plan View

Channel Bottom Review
NRCS RCPP Watershed Plan
Wild Rice Watershed District

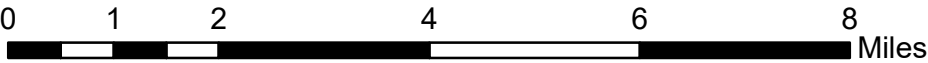
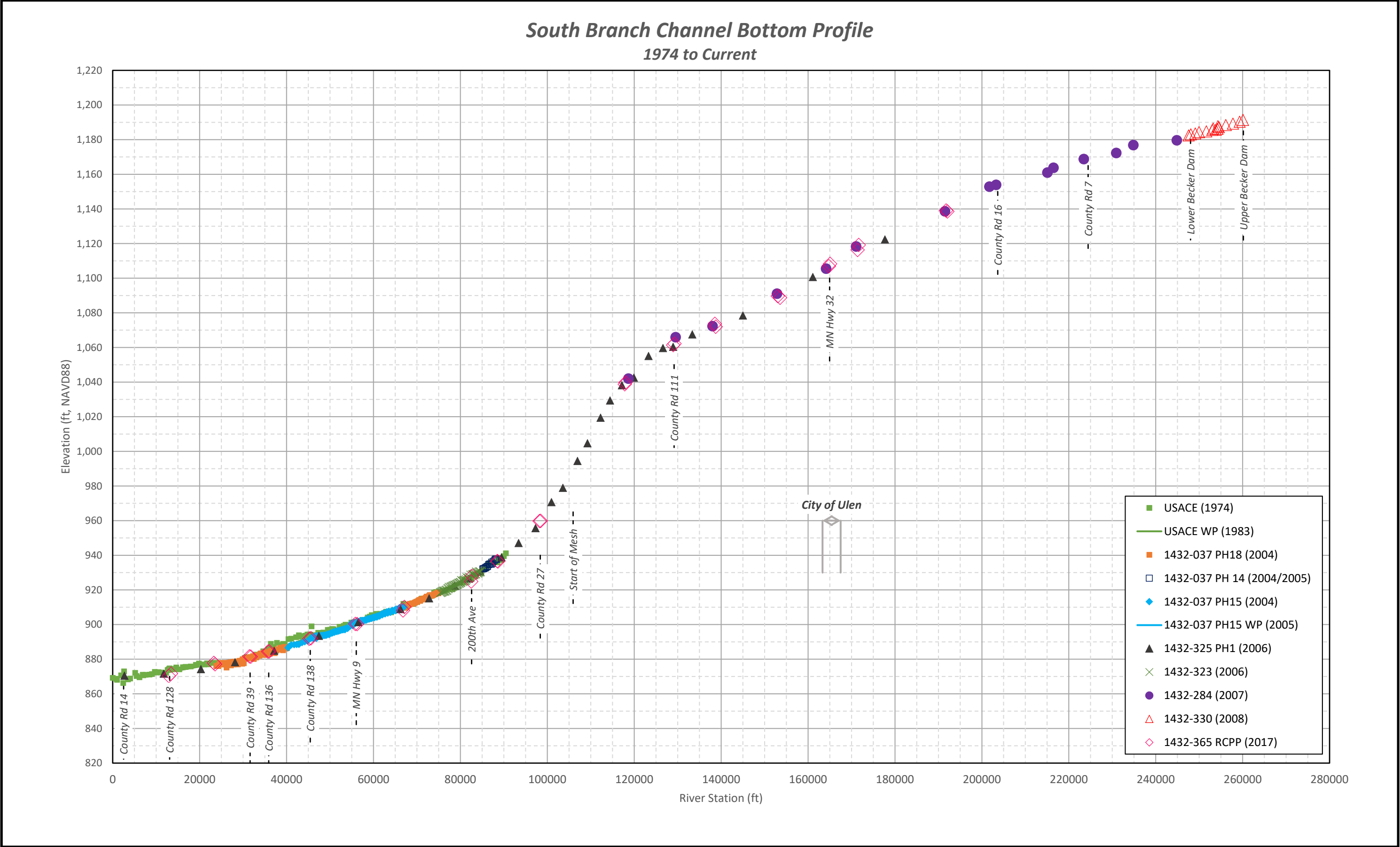
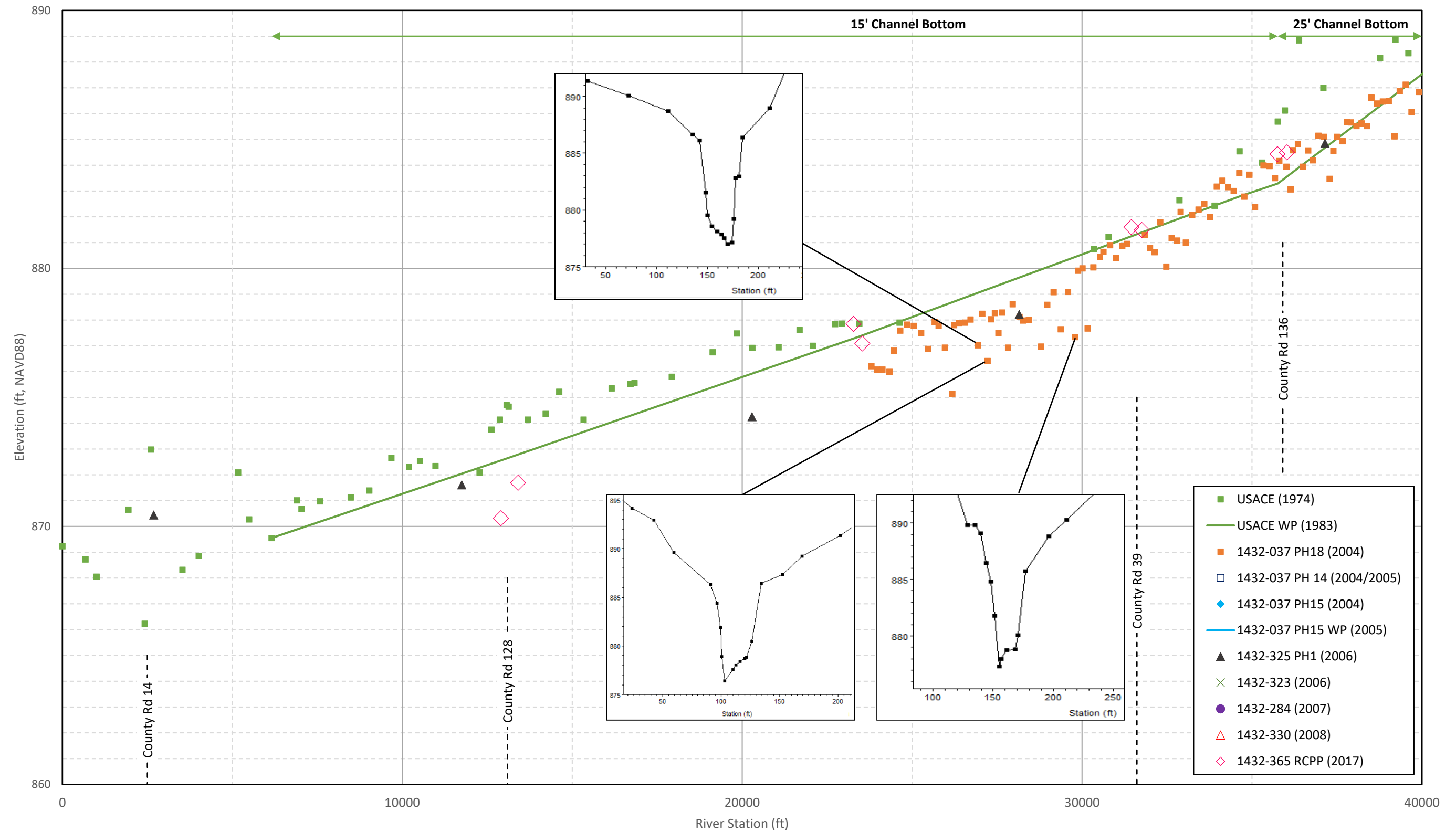


Exhibit 2: Profile Plots

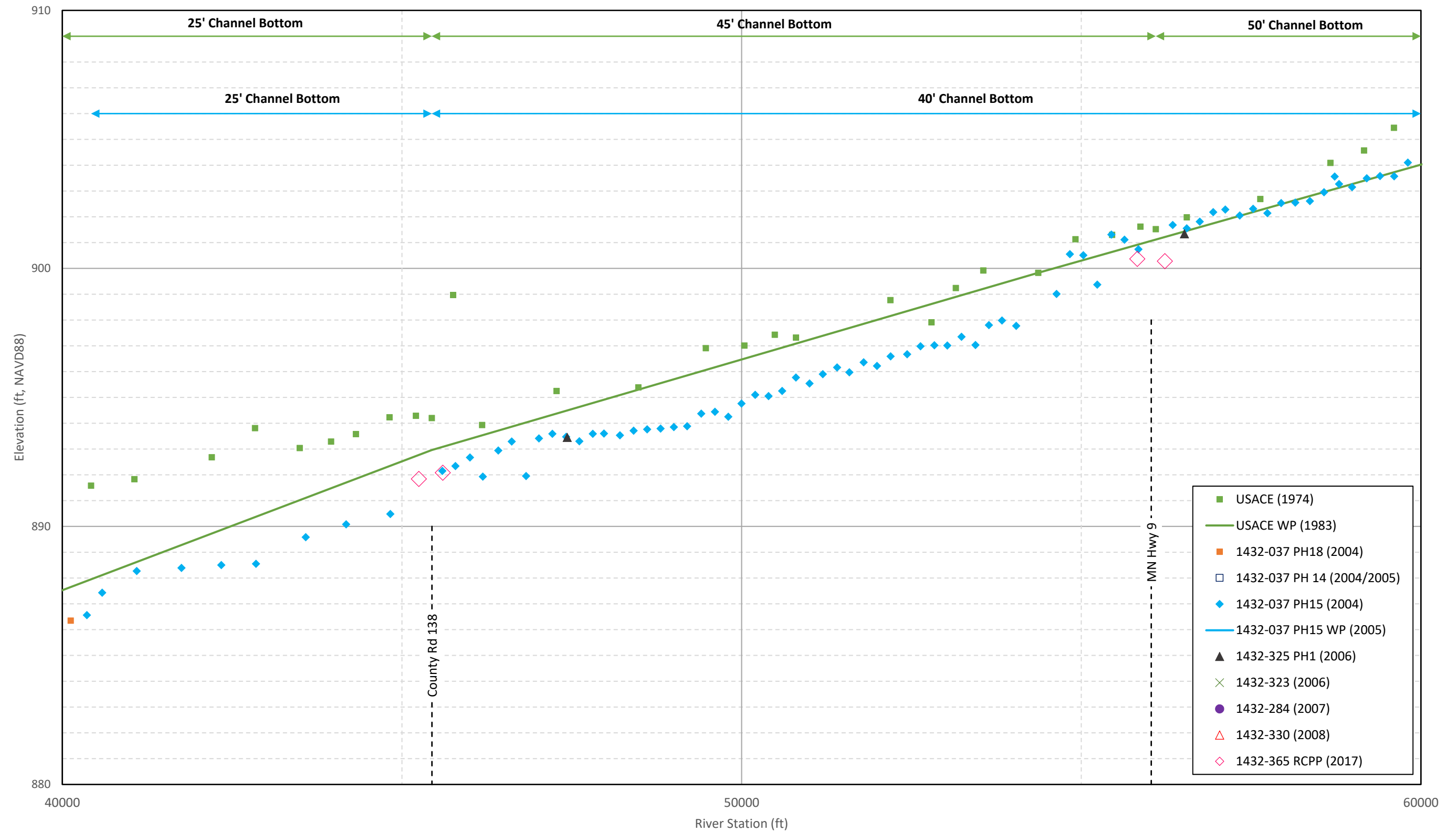


South Branch Channel Bottom Profile 1974 to Current



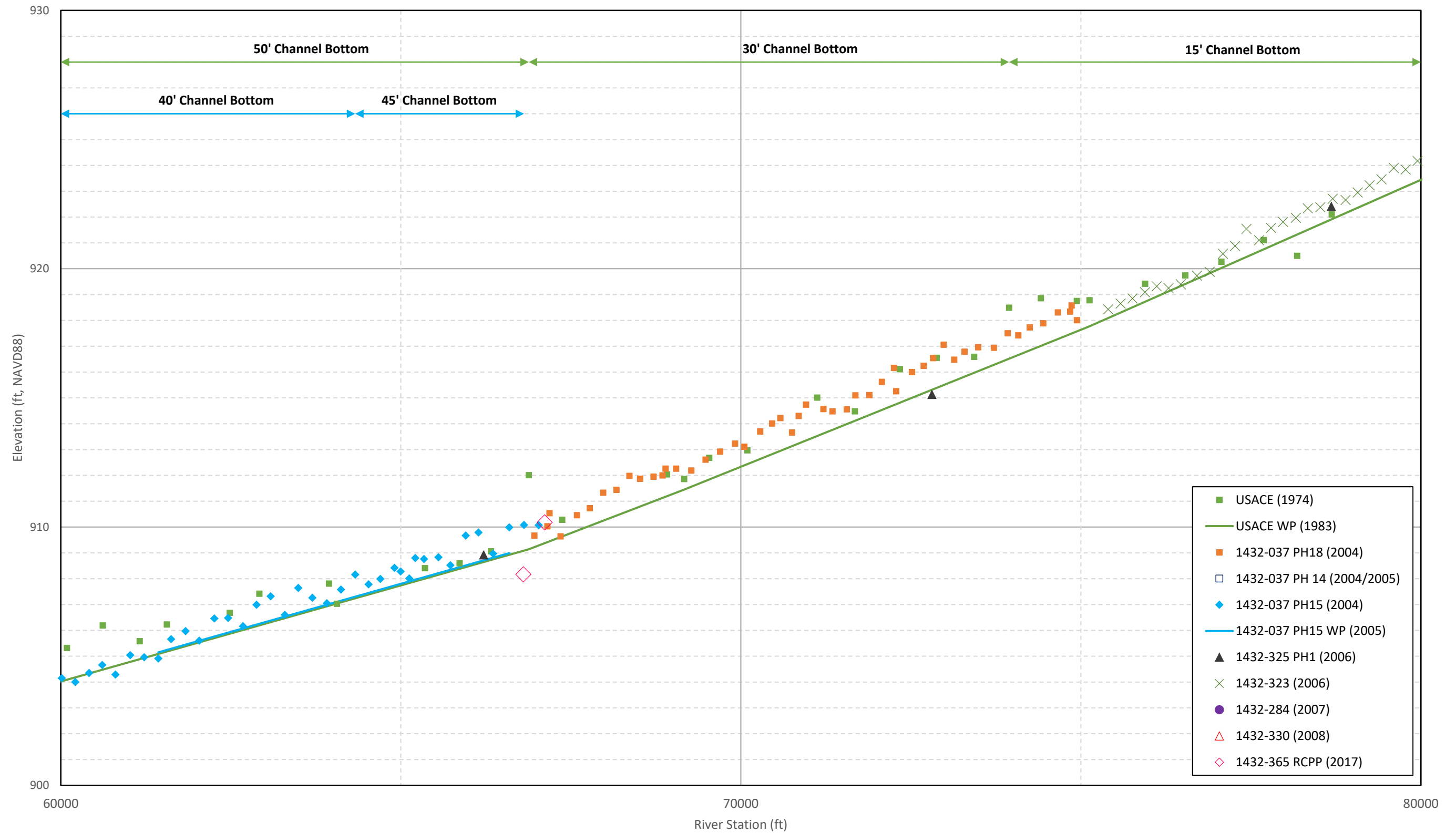
South Branch Channel Bottom Profile

1974 to Current



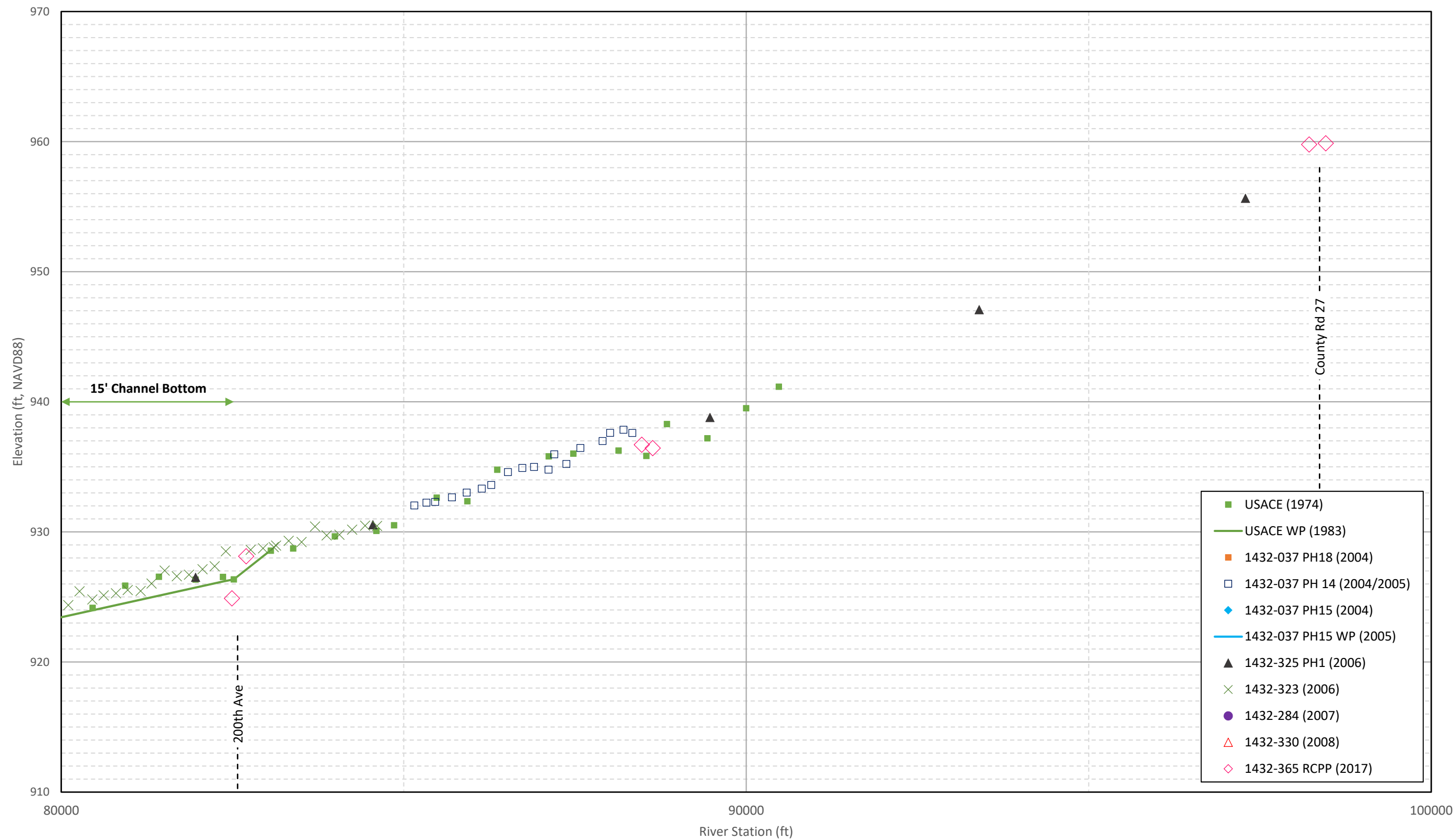
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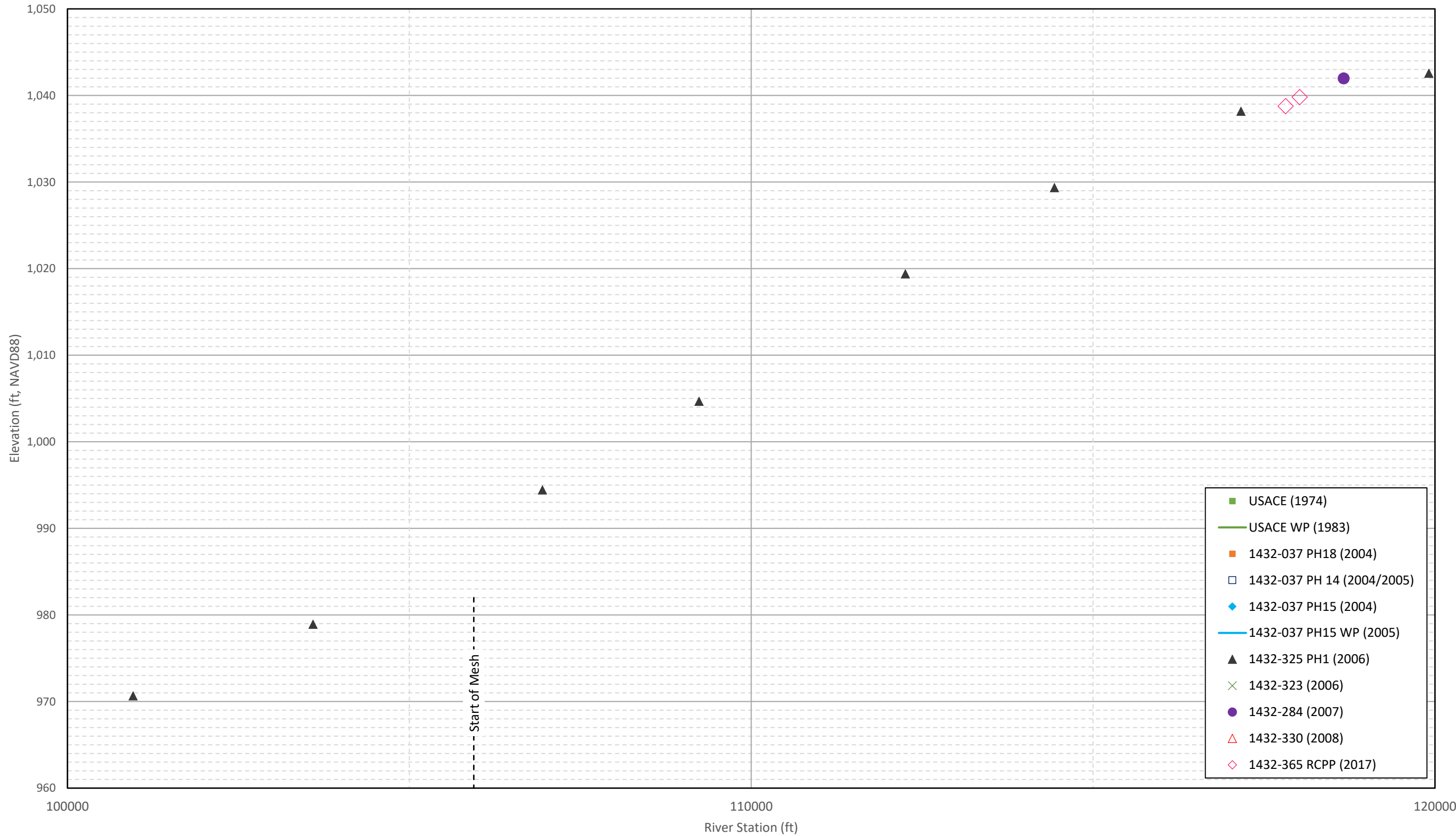


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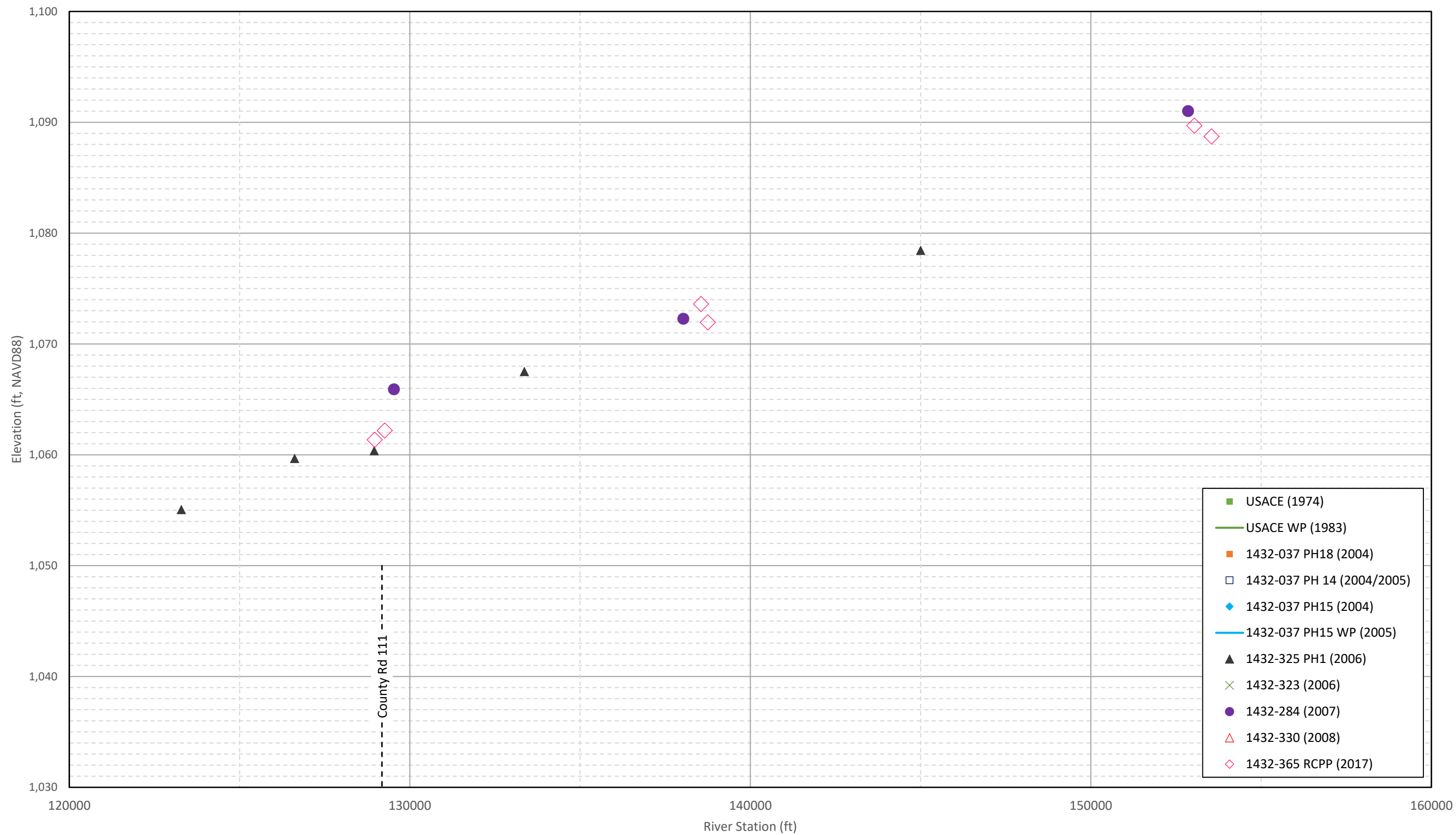


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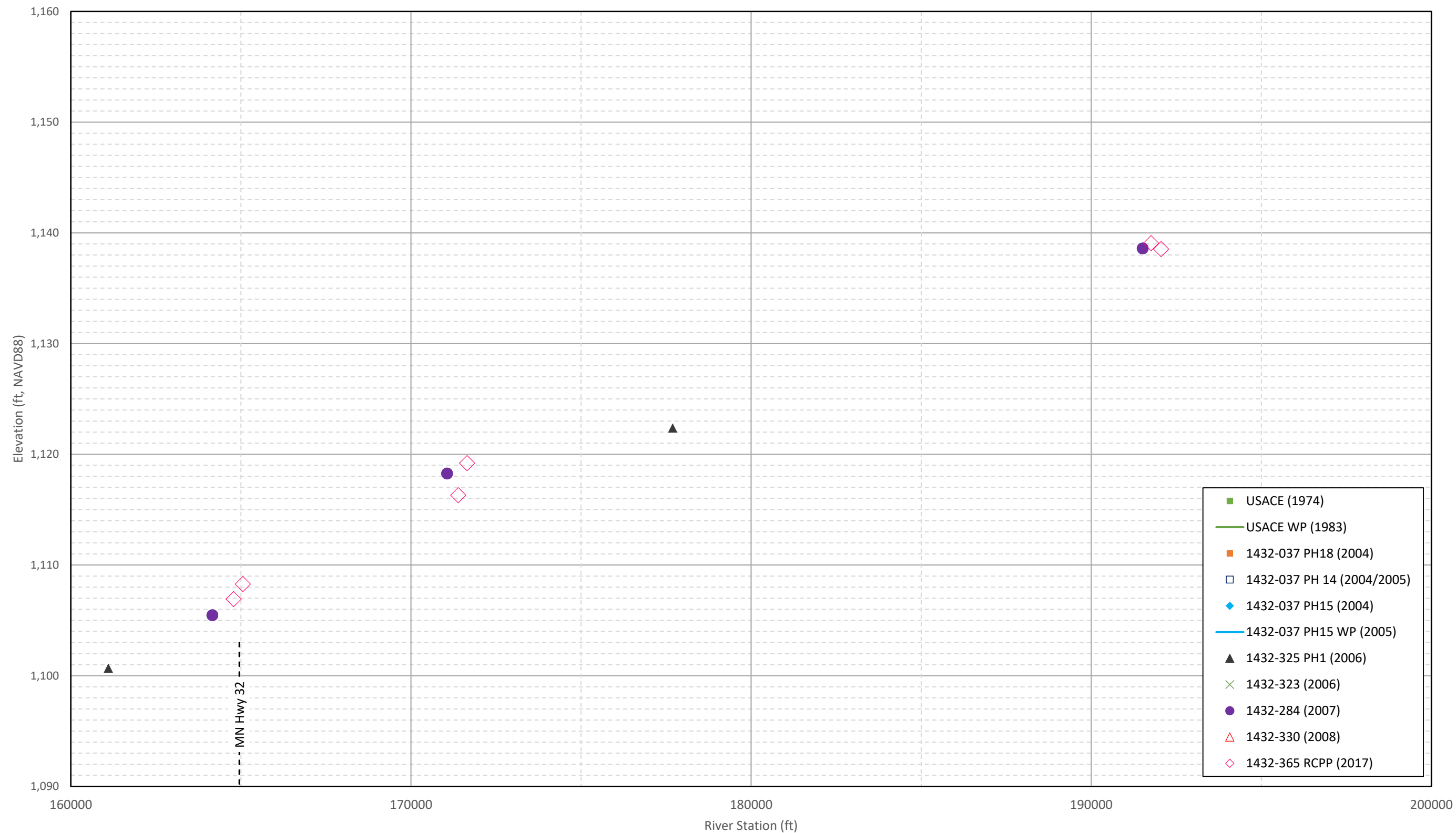
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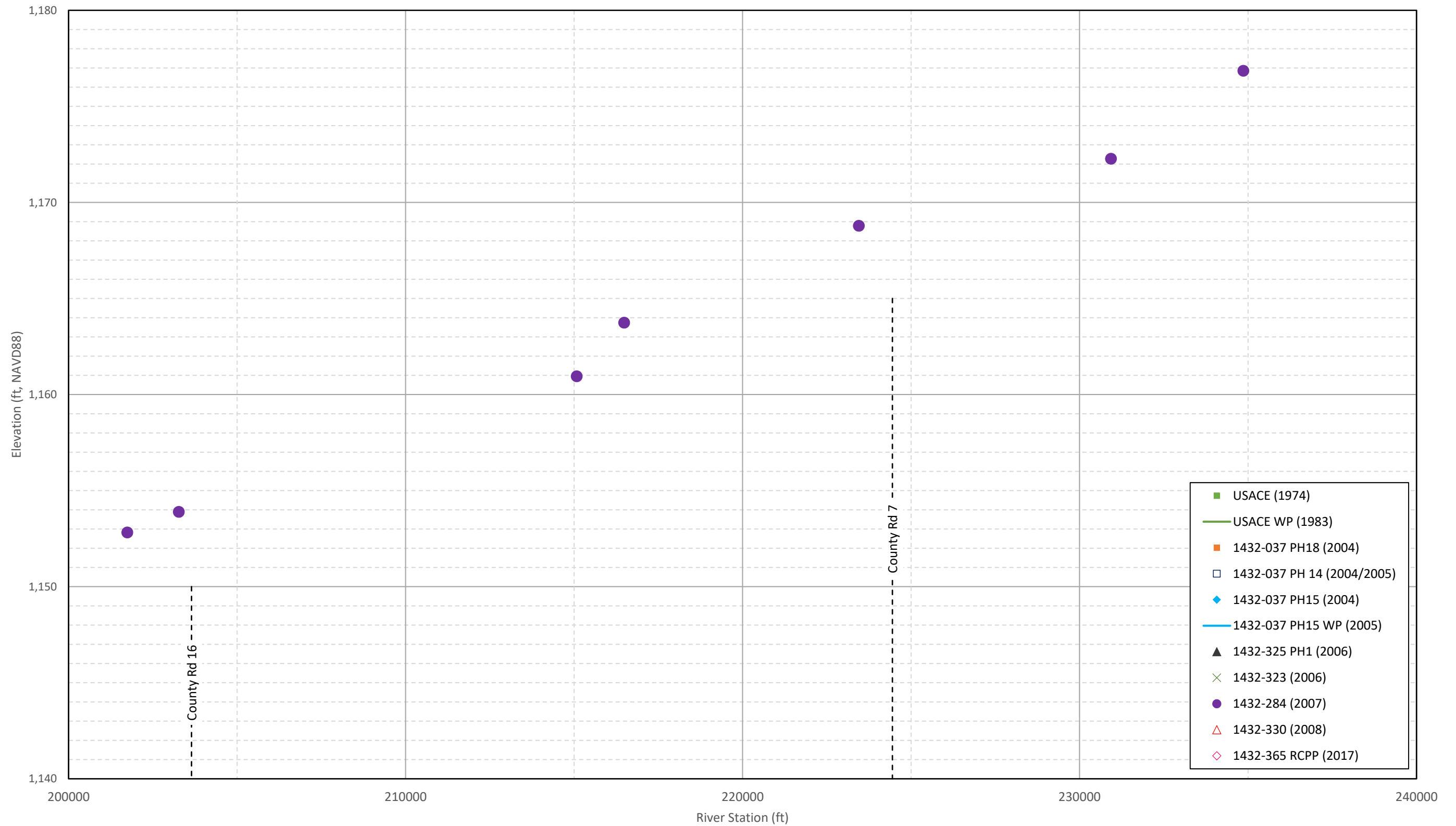
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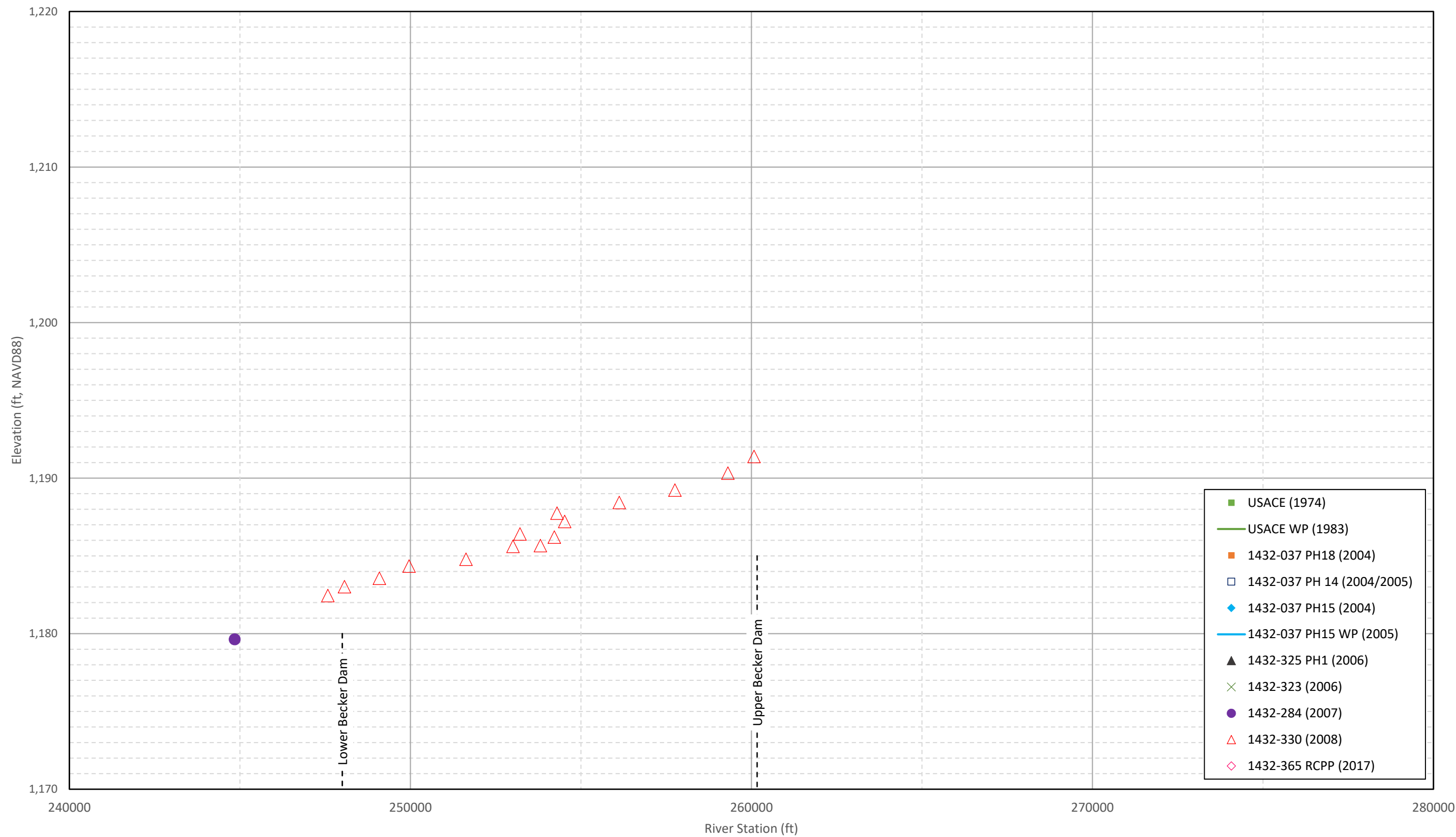
South Branch Channel Bottom Profile

1974 to Current



South Branch Channel Bottom Profile

1974 to Current



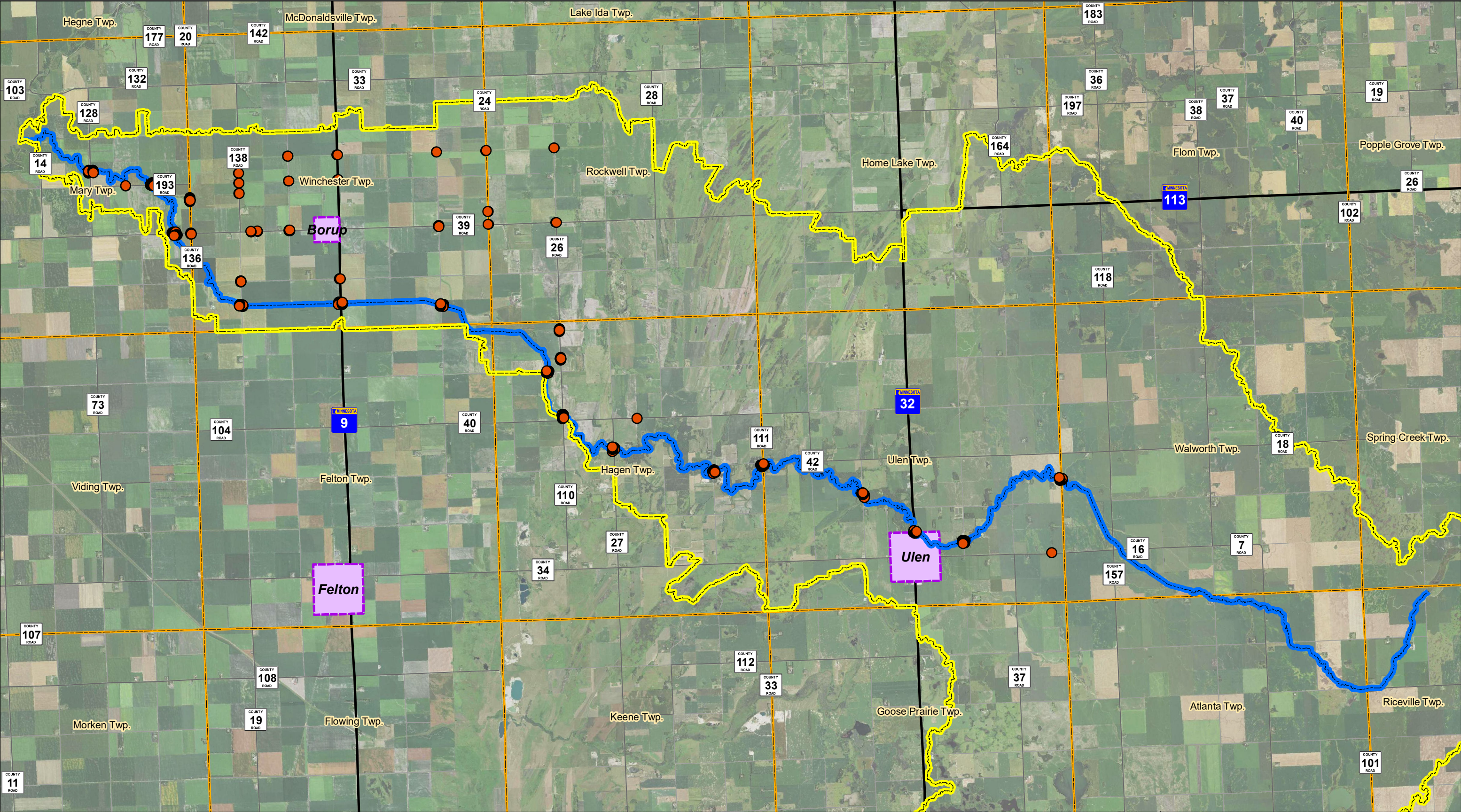
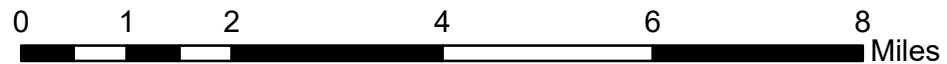


Exhibit 3: RCPP Survey
Channel Bottom Review
NRCS RCPP Watershed Plan
Wild Rice Watershed District

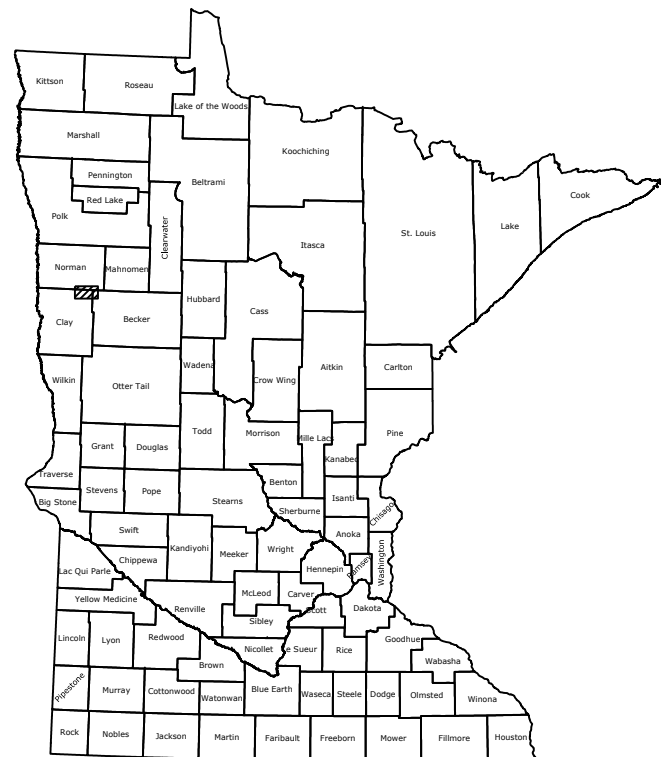




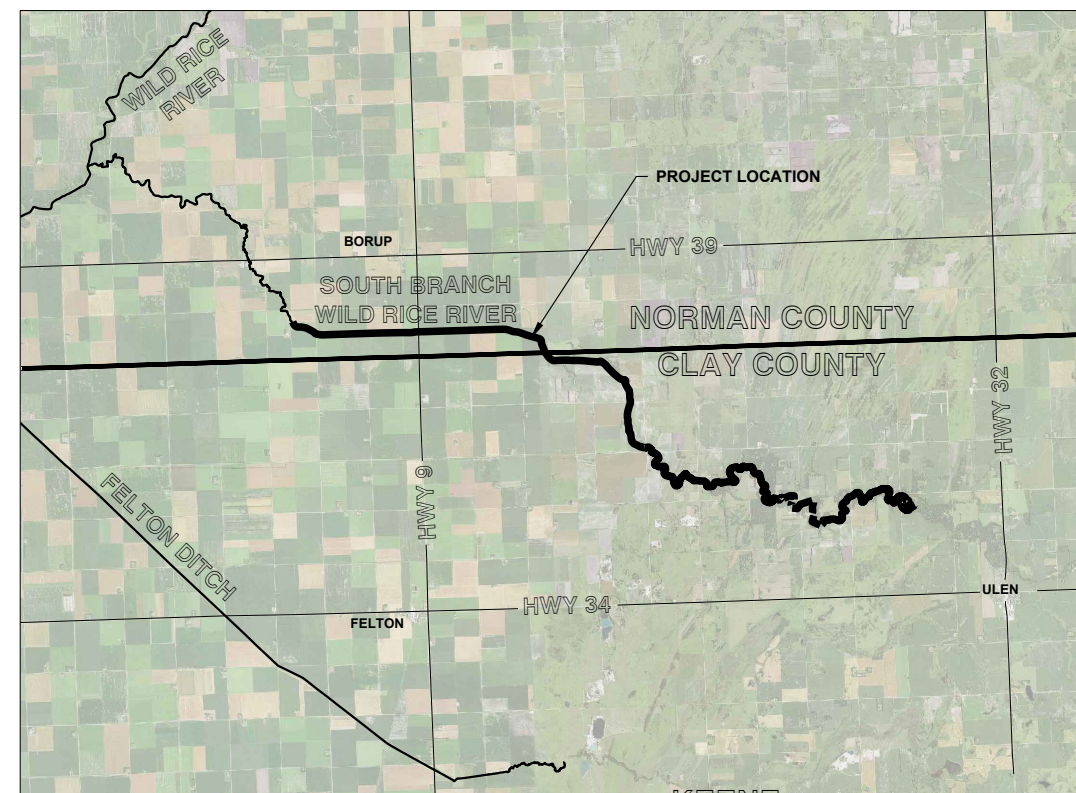
APPENDIX B

Existing Conditions Plan, Profile and Cross Sections

EXISTING CONDITIONS PLAN, PROFILE AND CROSS SECTIONS FOR SOUTH BRANCH WILD RICE RIVER RESTORATION & SEDIMENT REDUCTION PROJECT WILD RICE WATERSHED DISTRICT ADA, MINNESOTA 2020



STATE COUNTY MAP



FOR REFERENCE ONLY
Not for Construction

PREPARED BY:



Houston
Engineering Inc.

FARGO, NORTH DAKOTA

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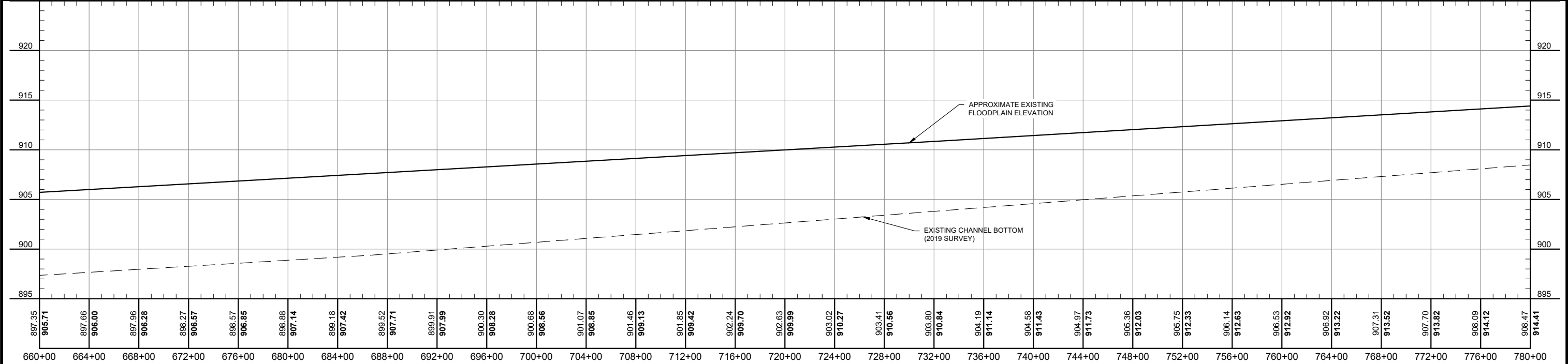
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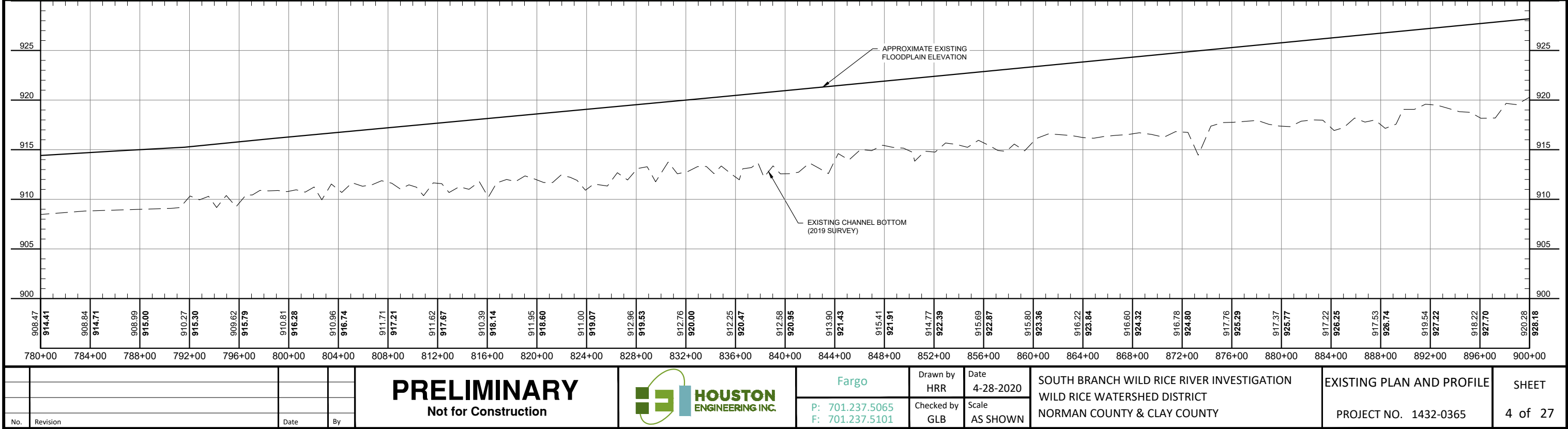
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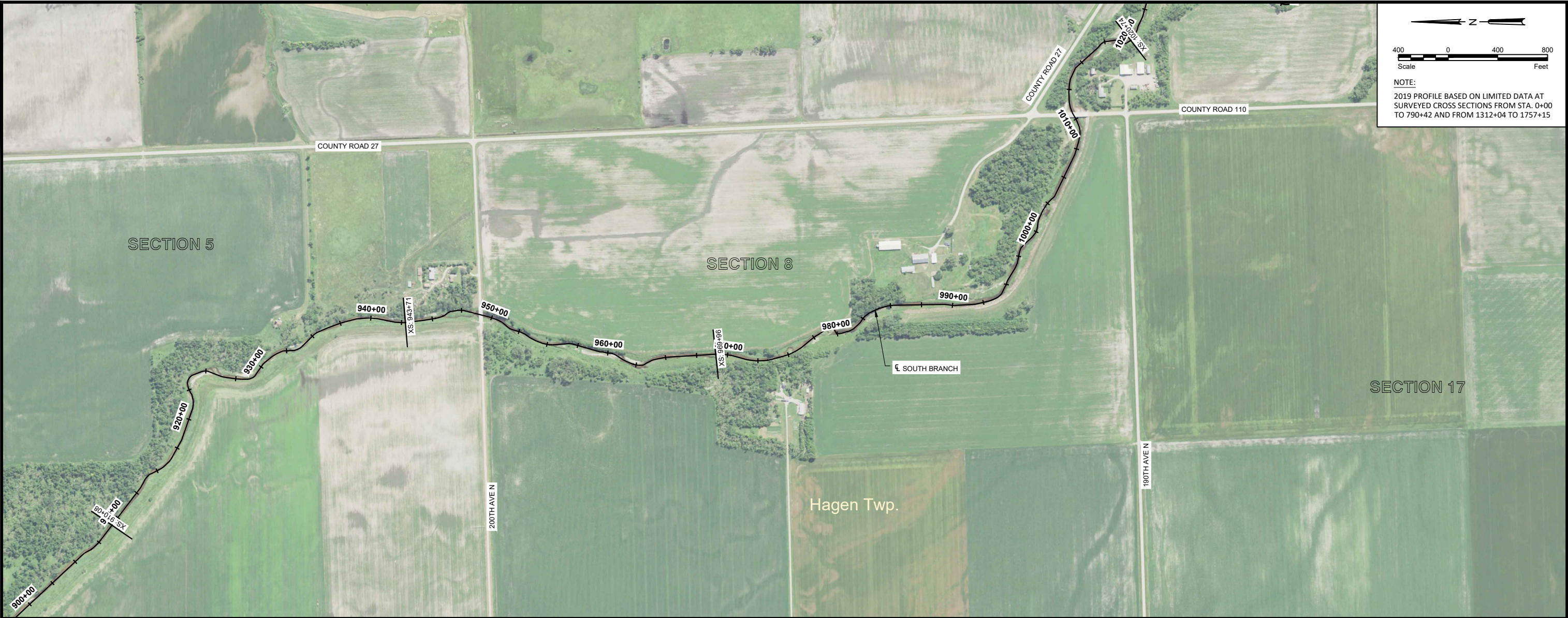
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SOUTH BRANCH WILD RICE RIVER INVESTIGATION
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NORMAN COUNTY & CLAY COUNTY

EXISTING PLAN AND PROFILE
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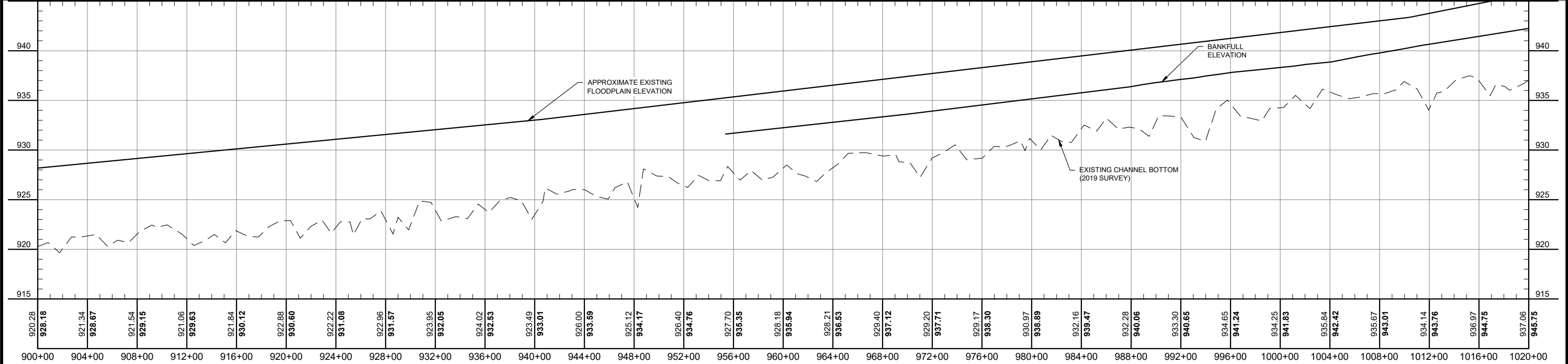
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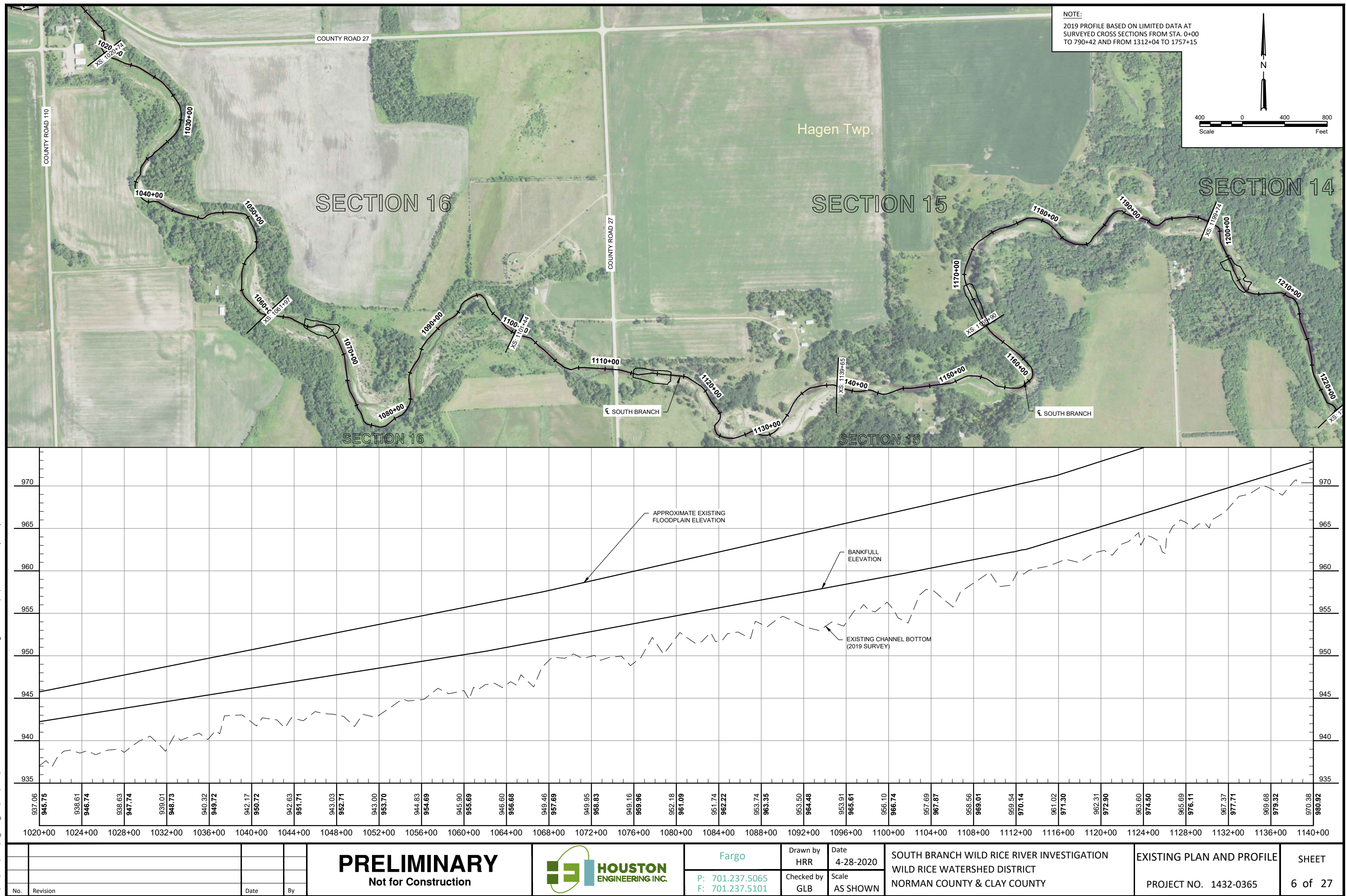


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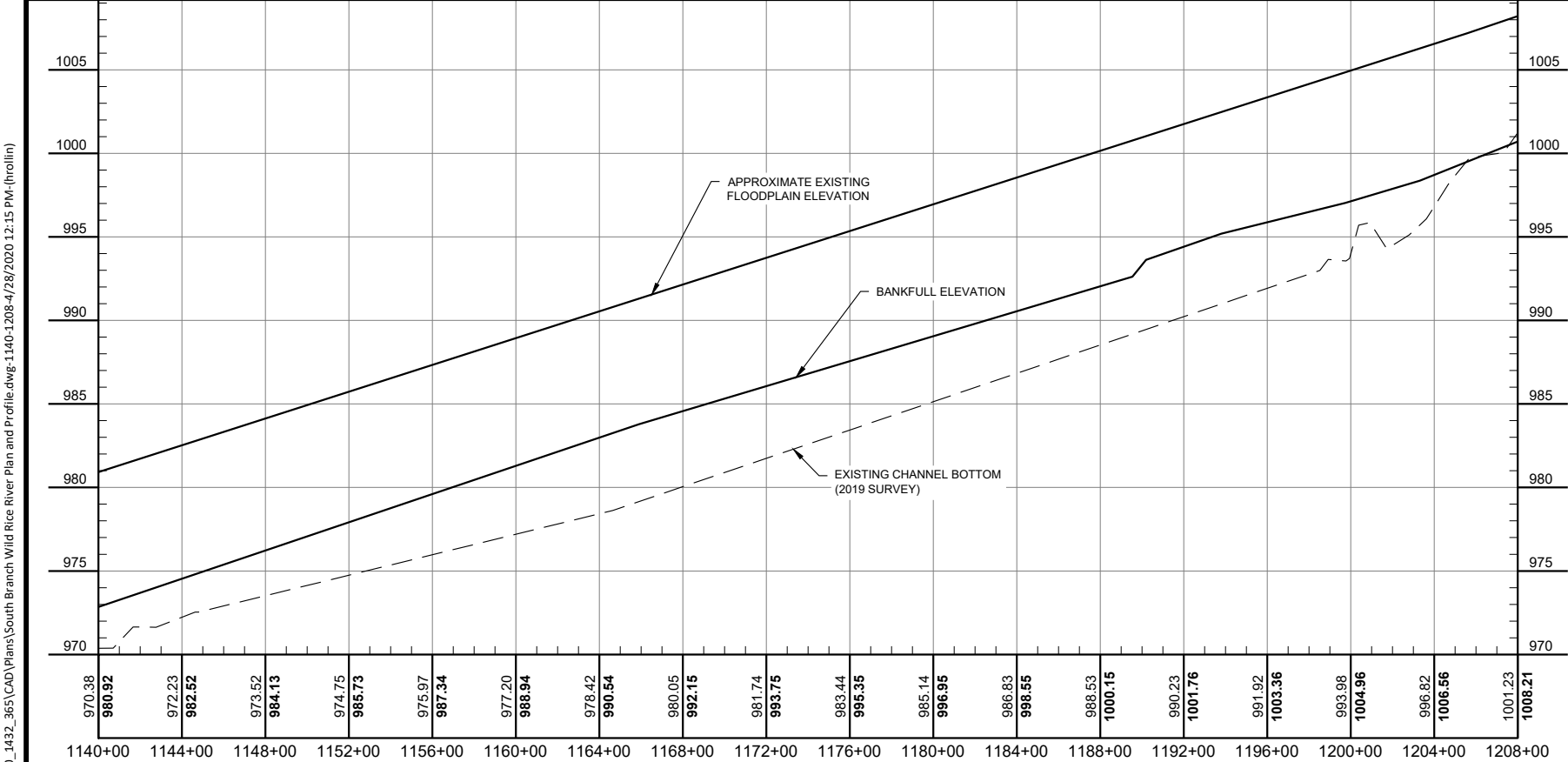
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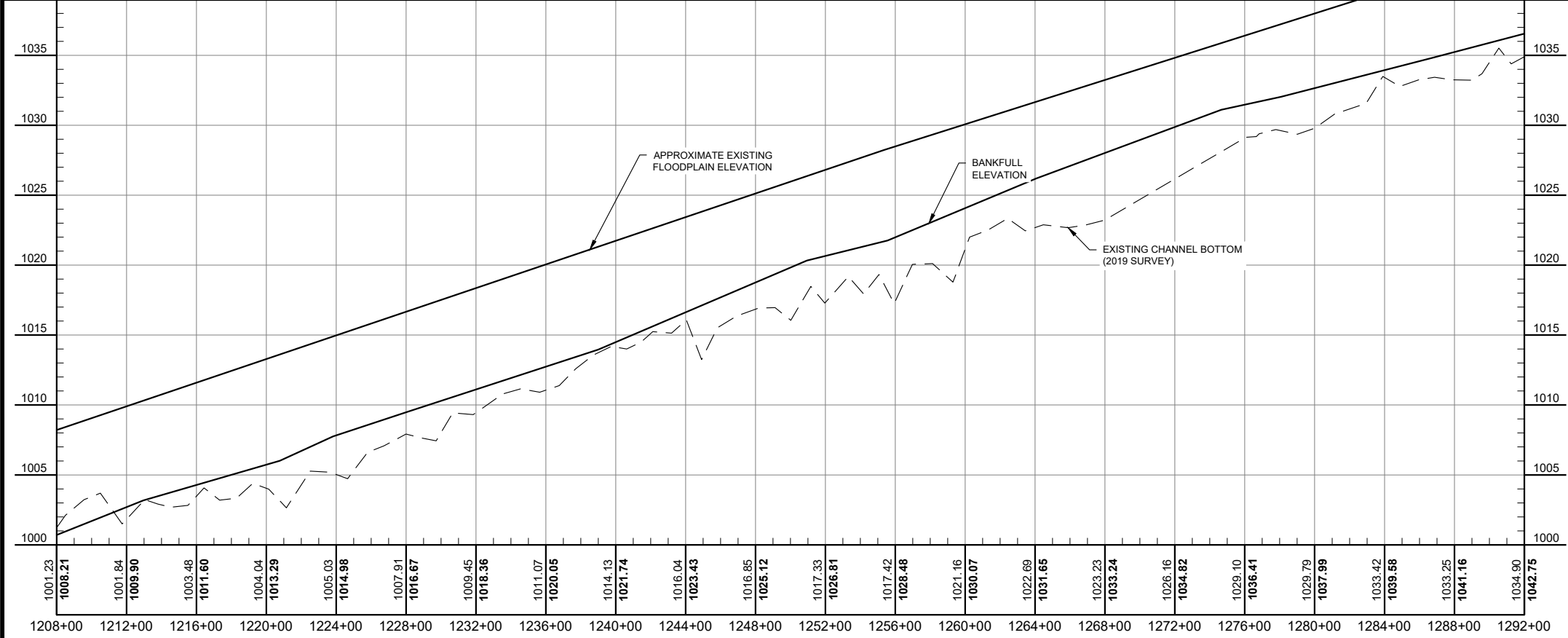


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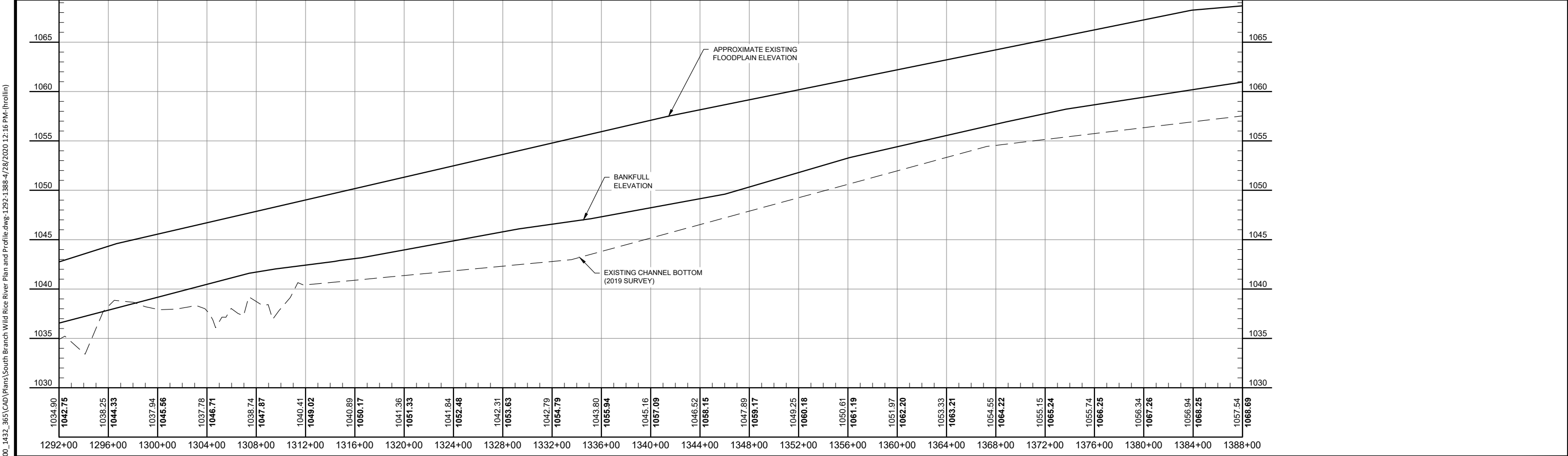
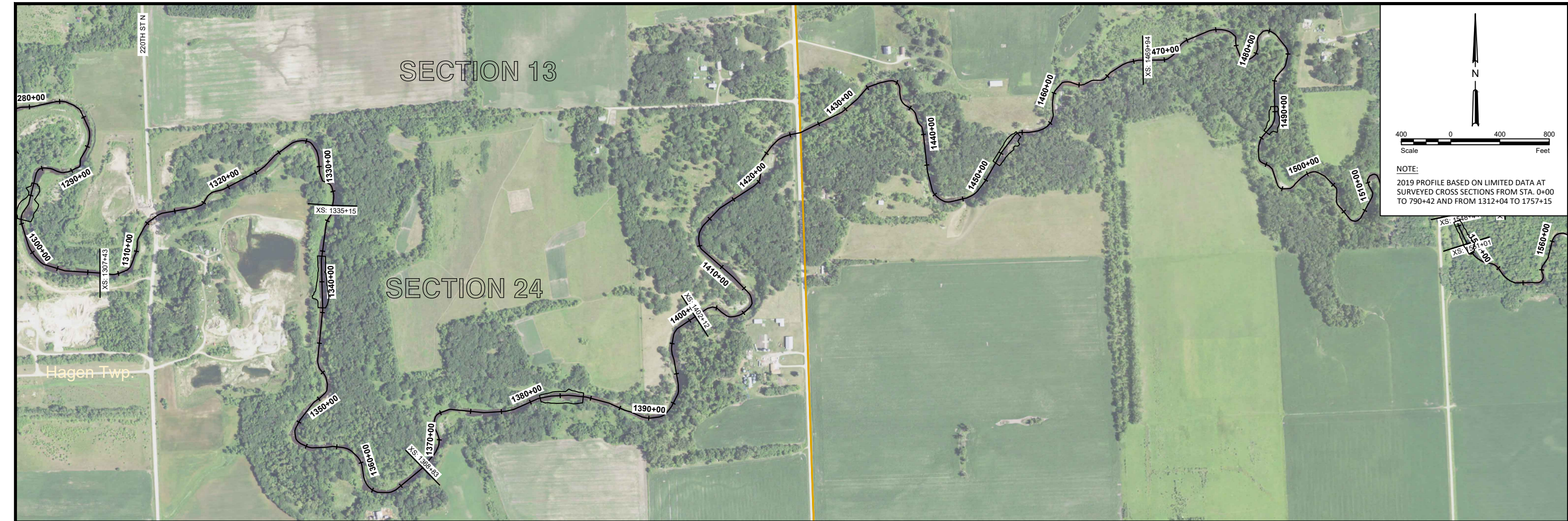
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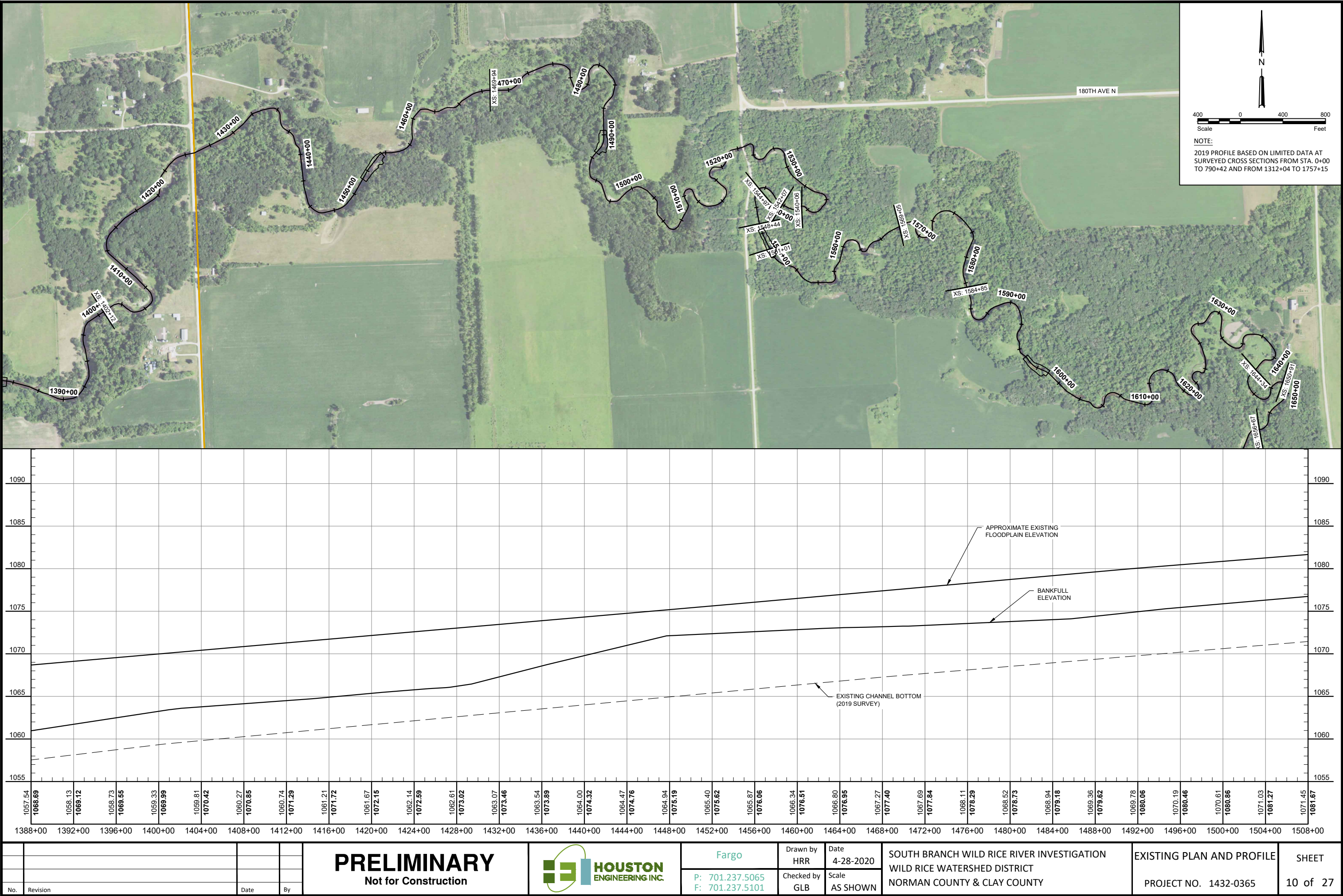
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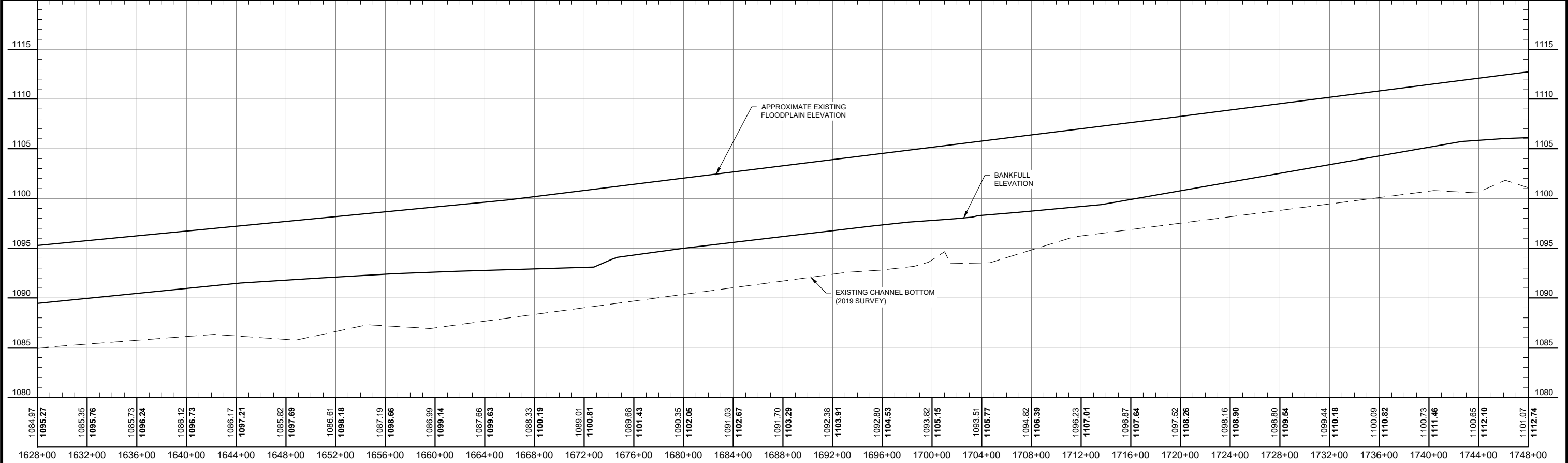
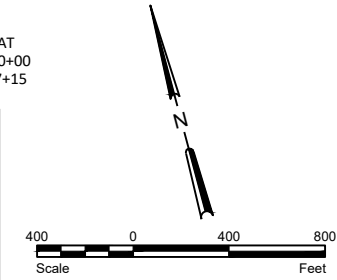
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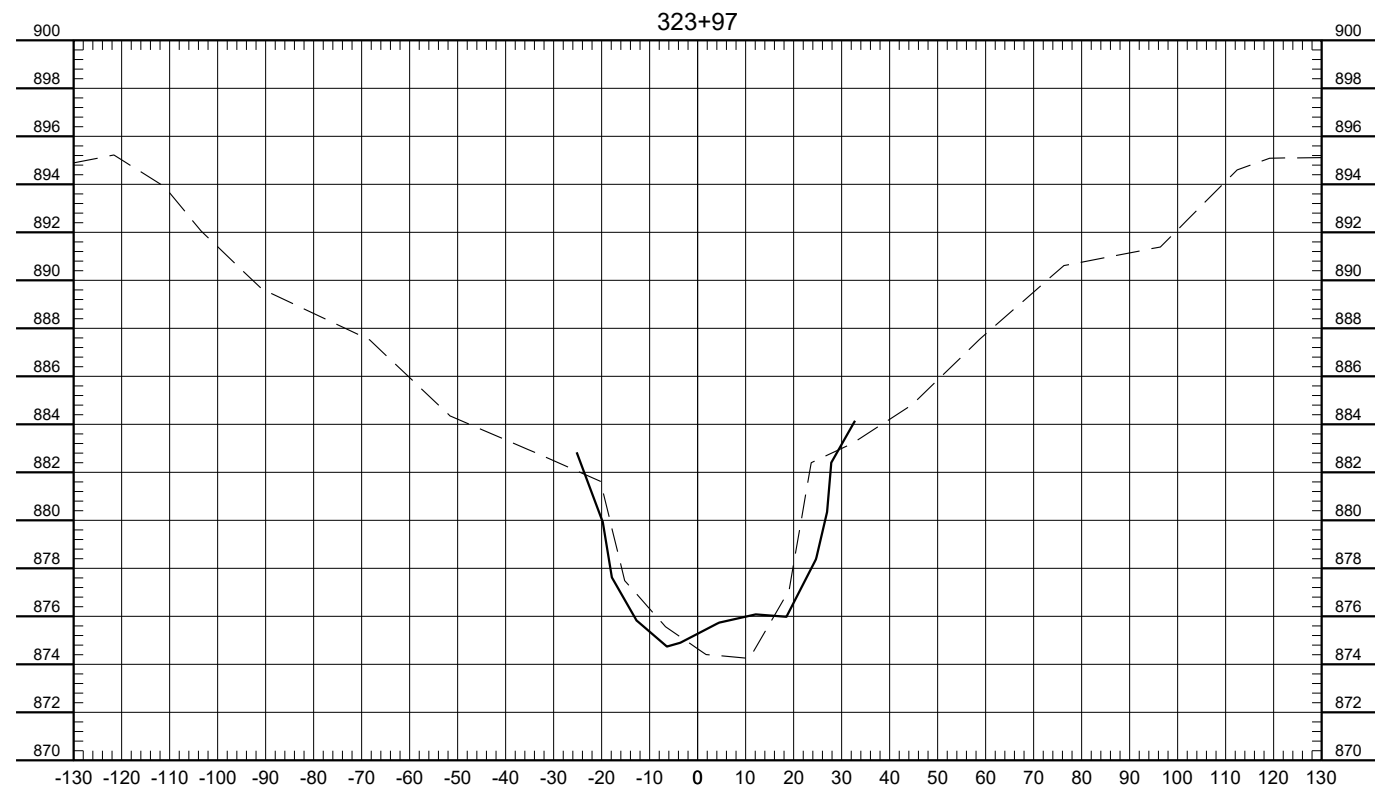
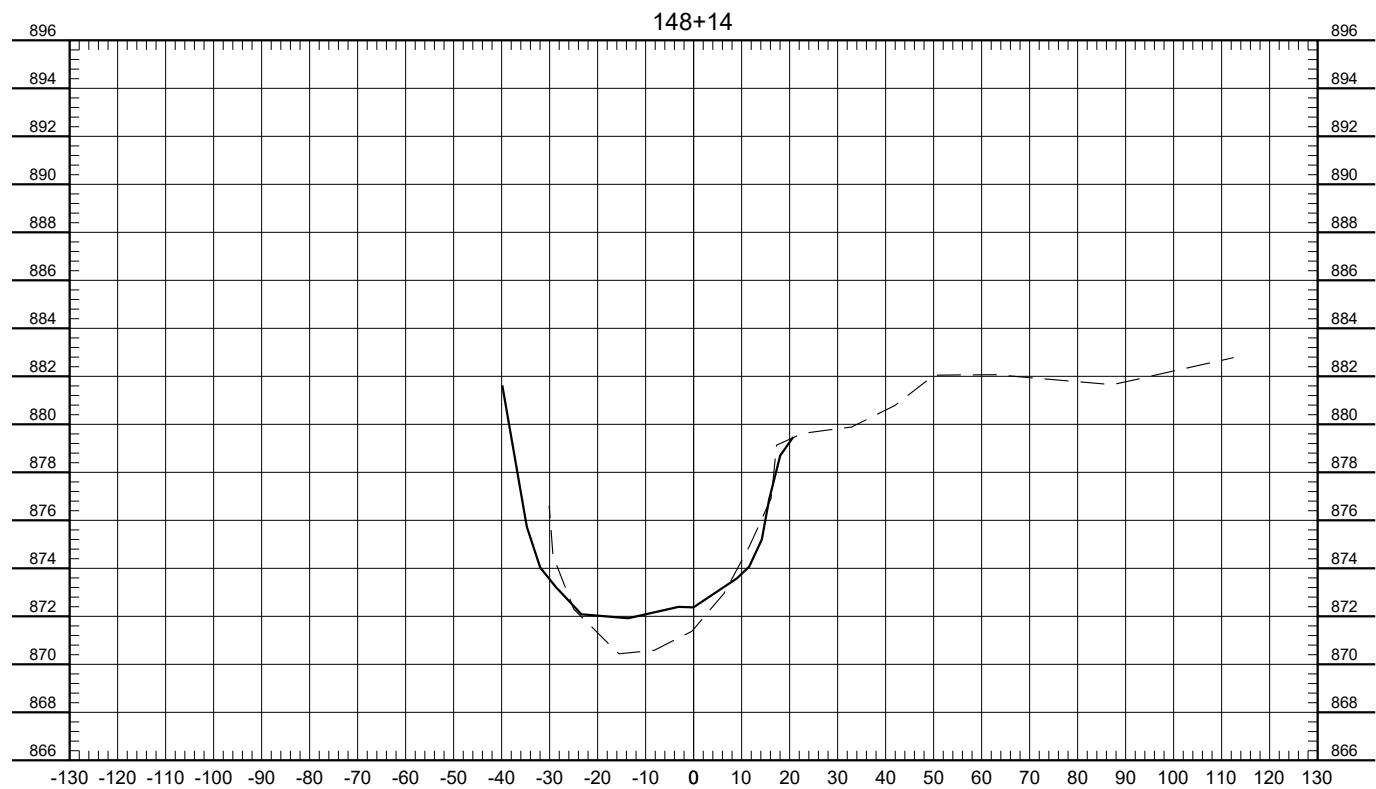
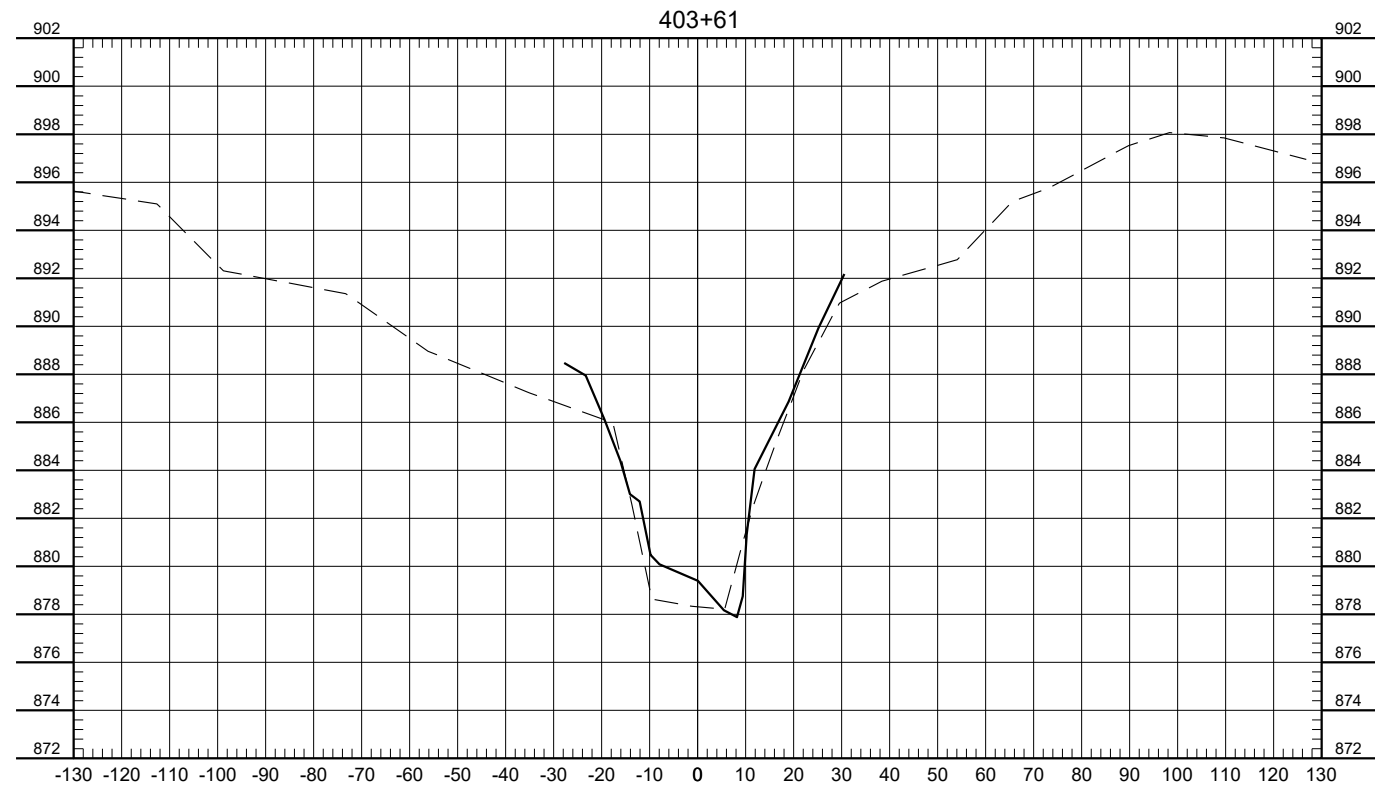
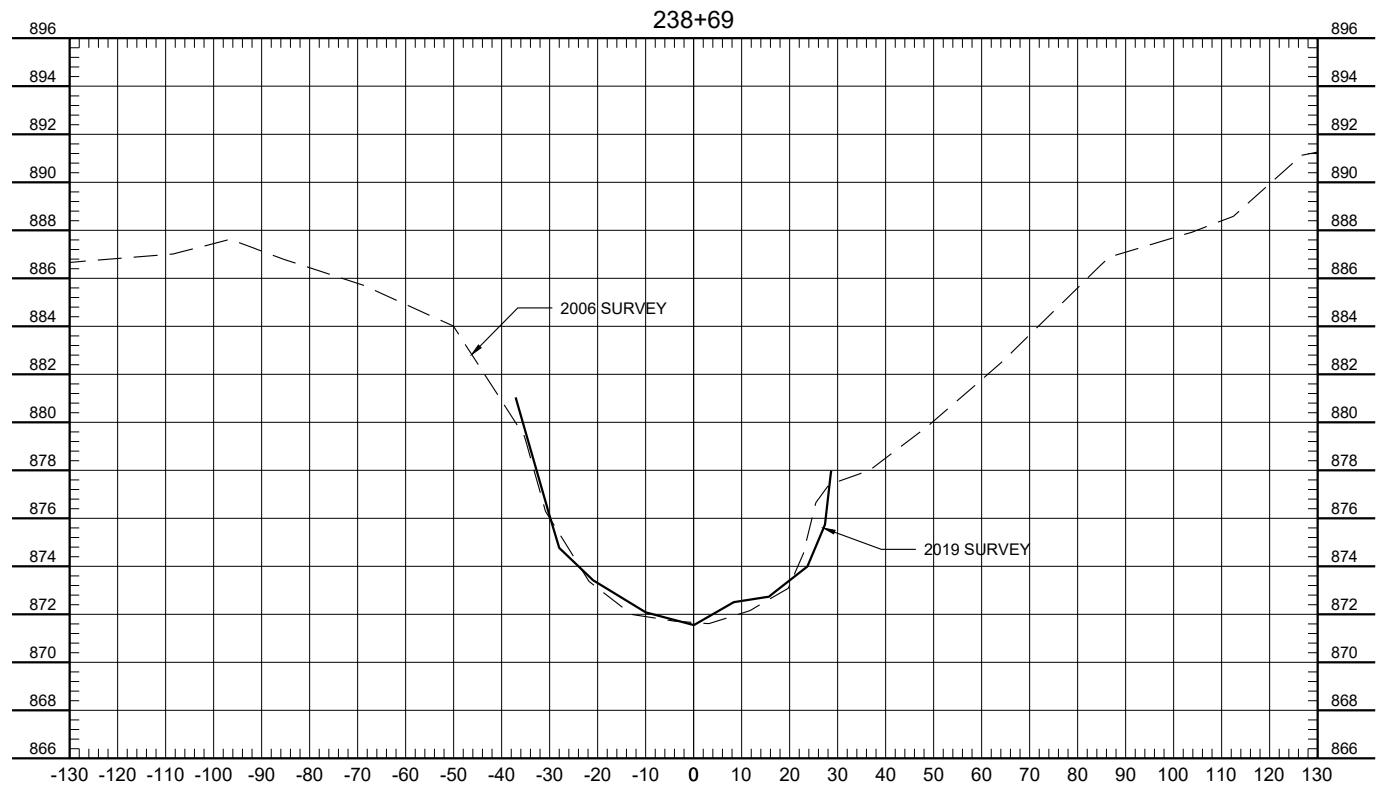
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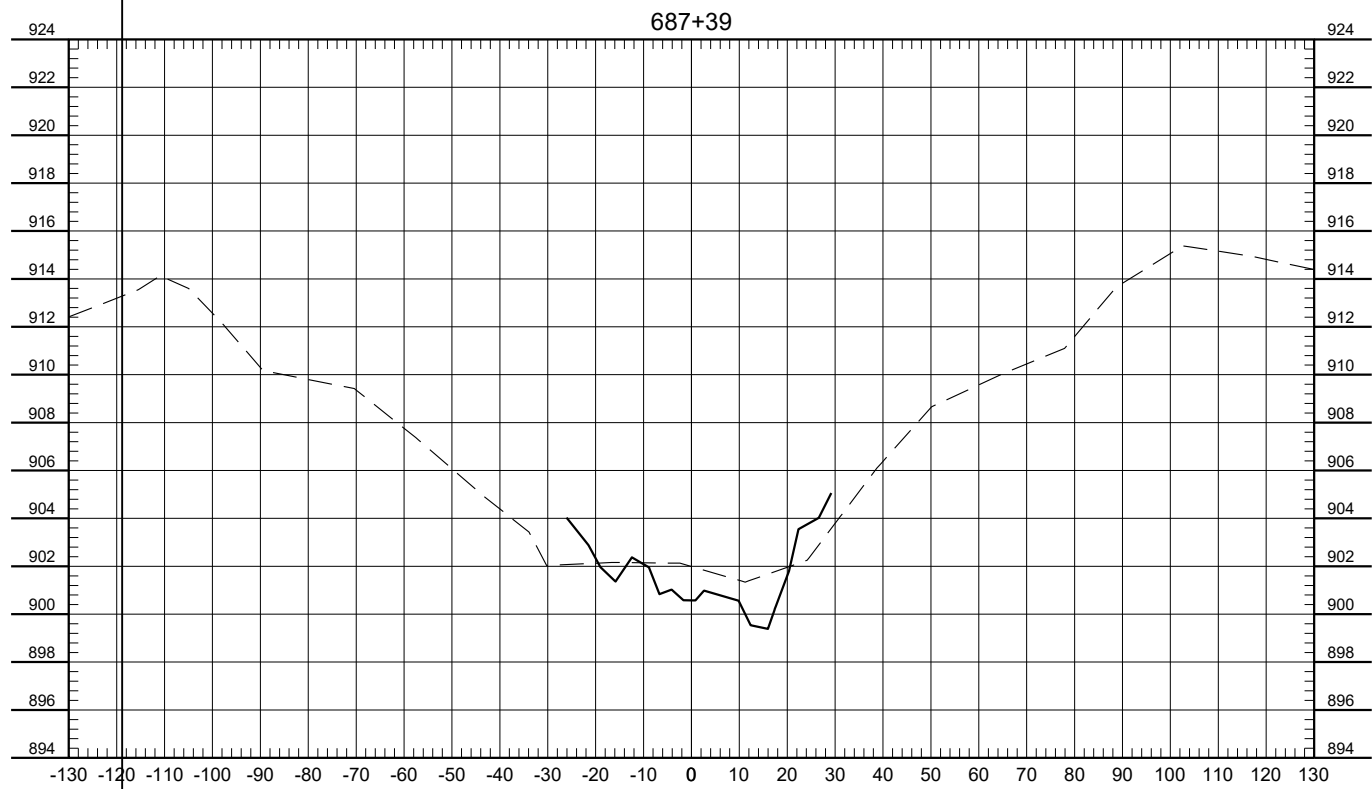
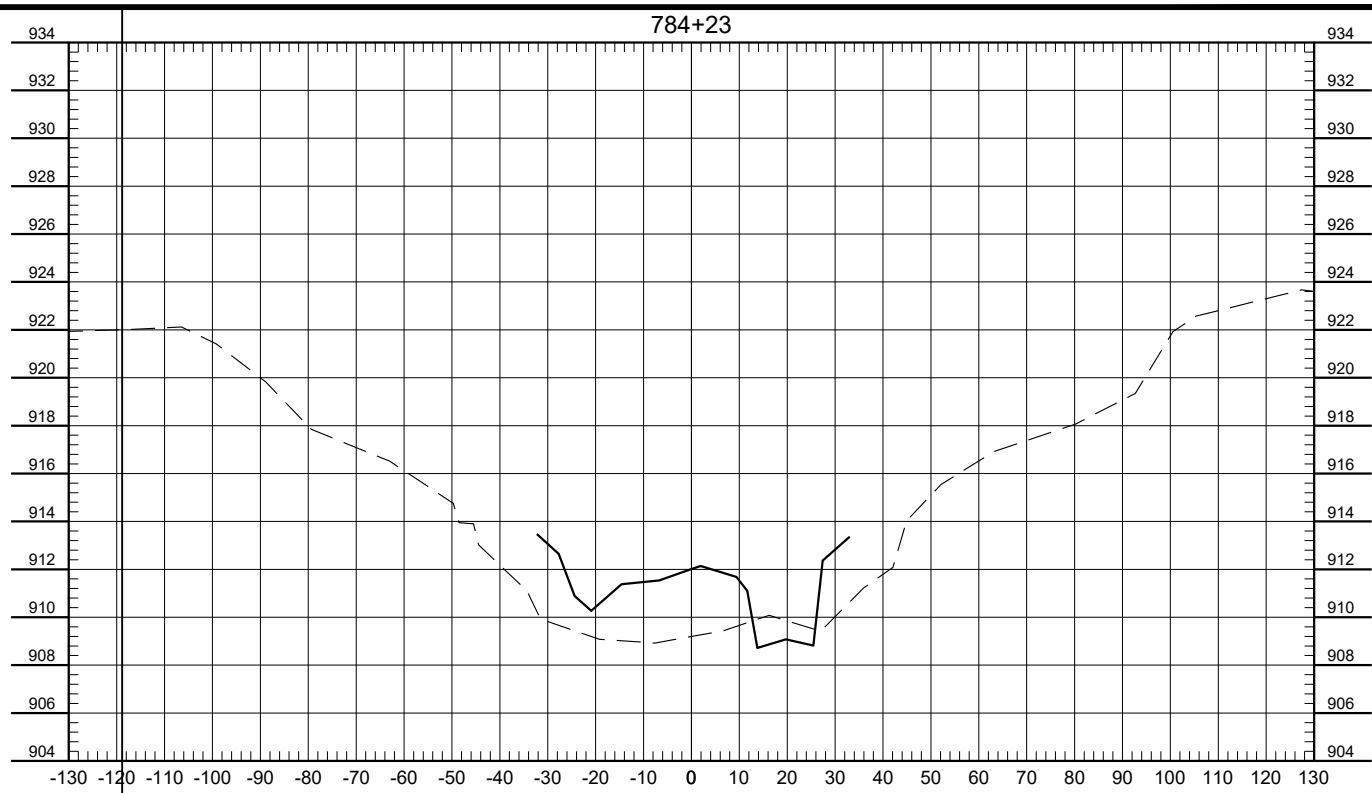
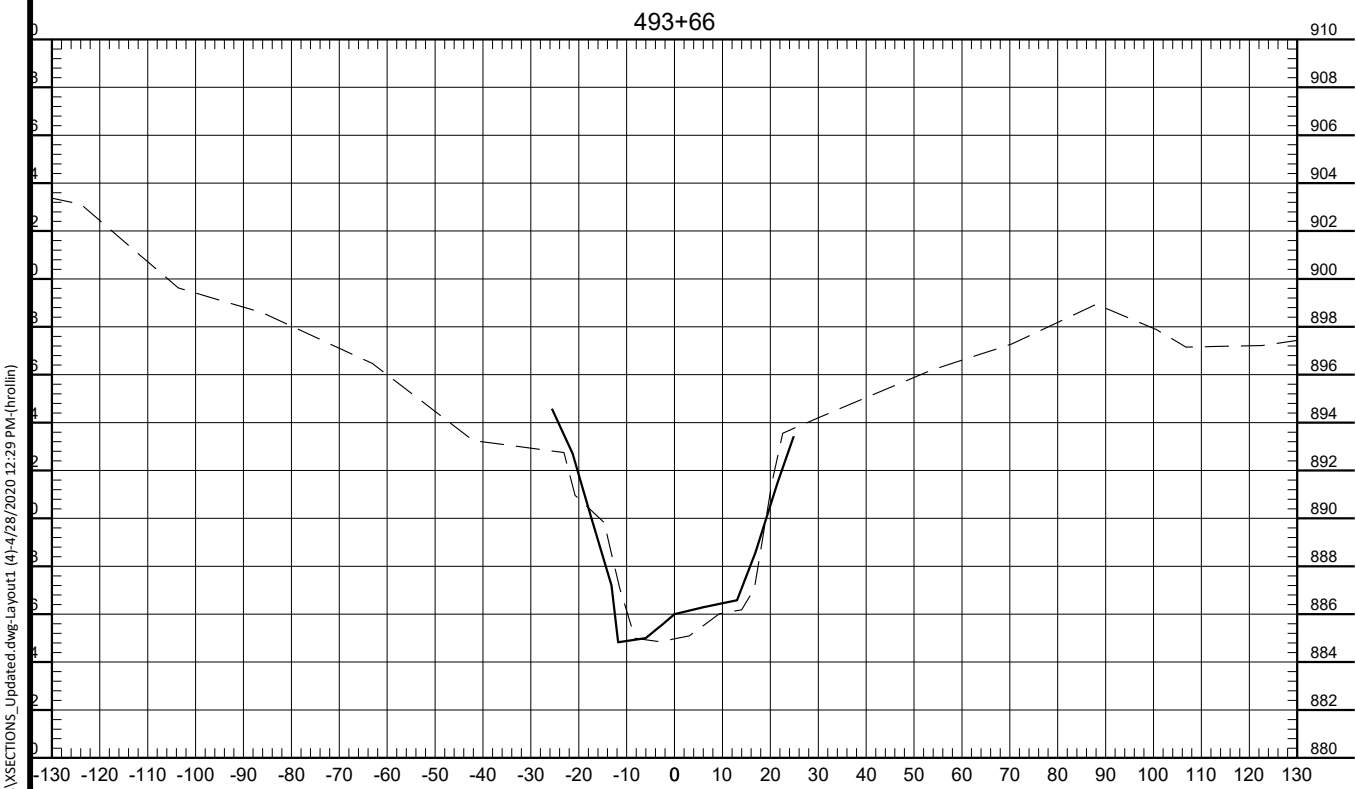
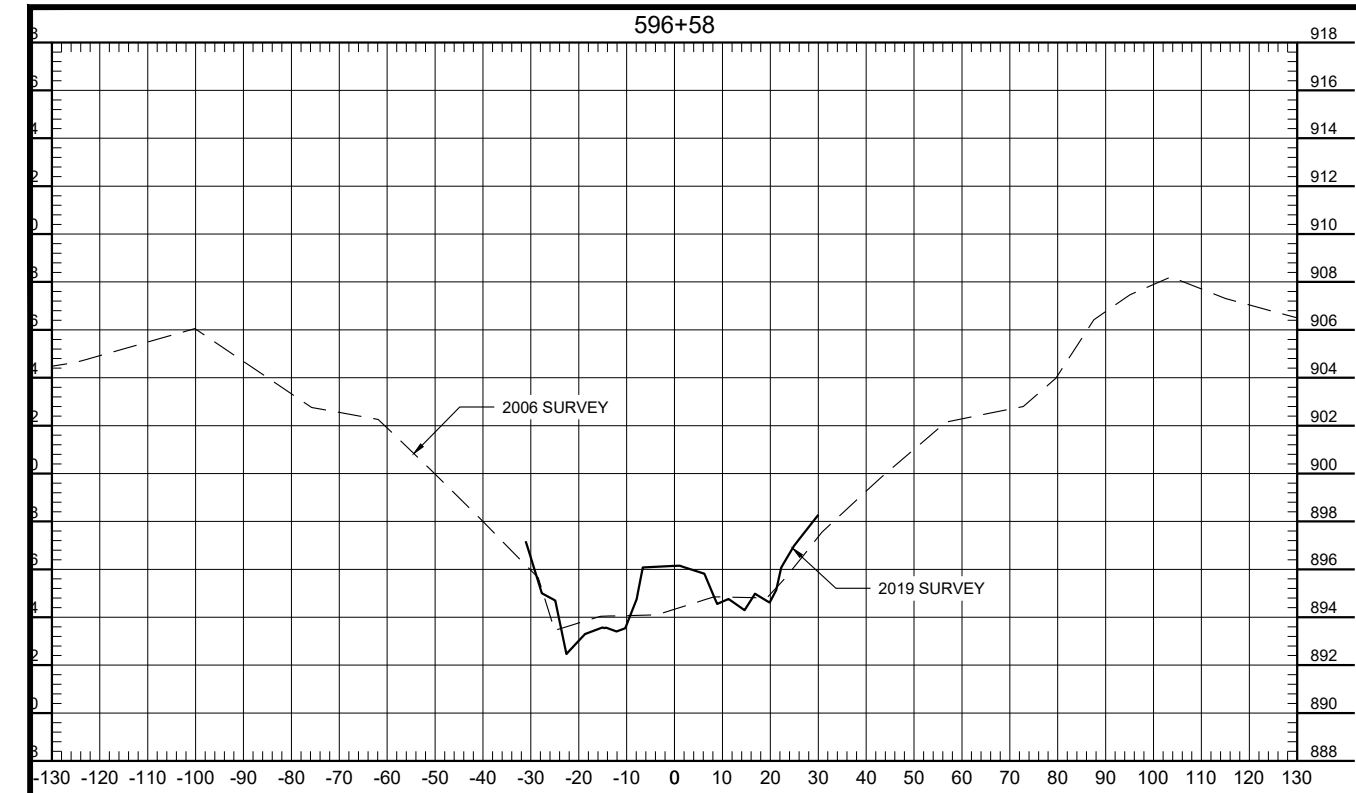
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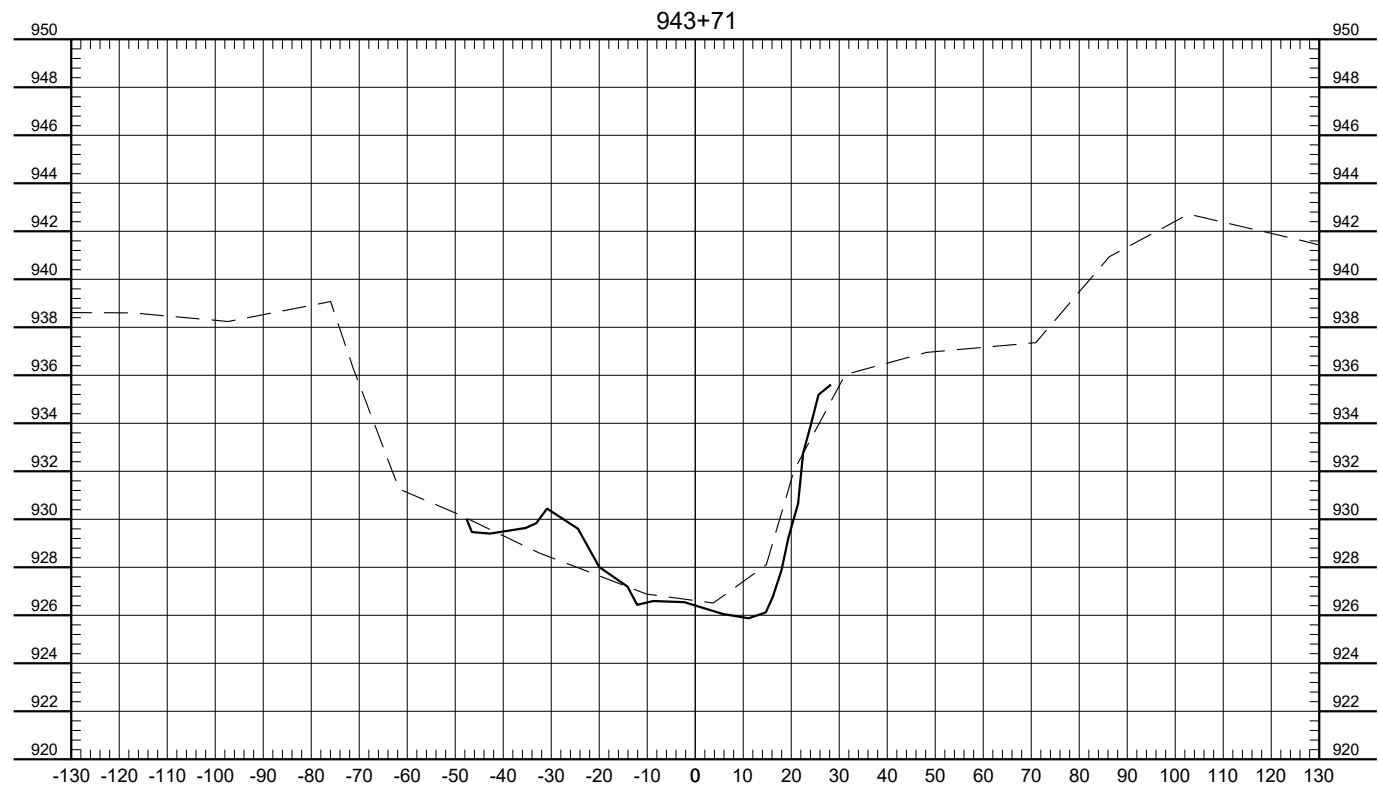
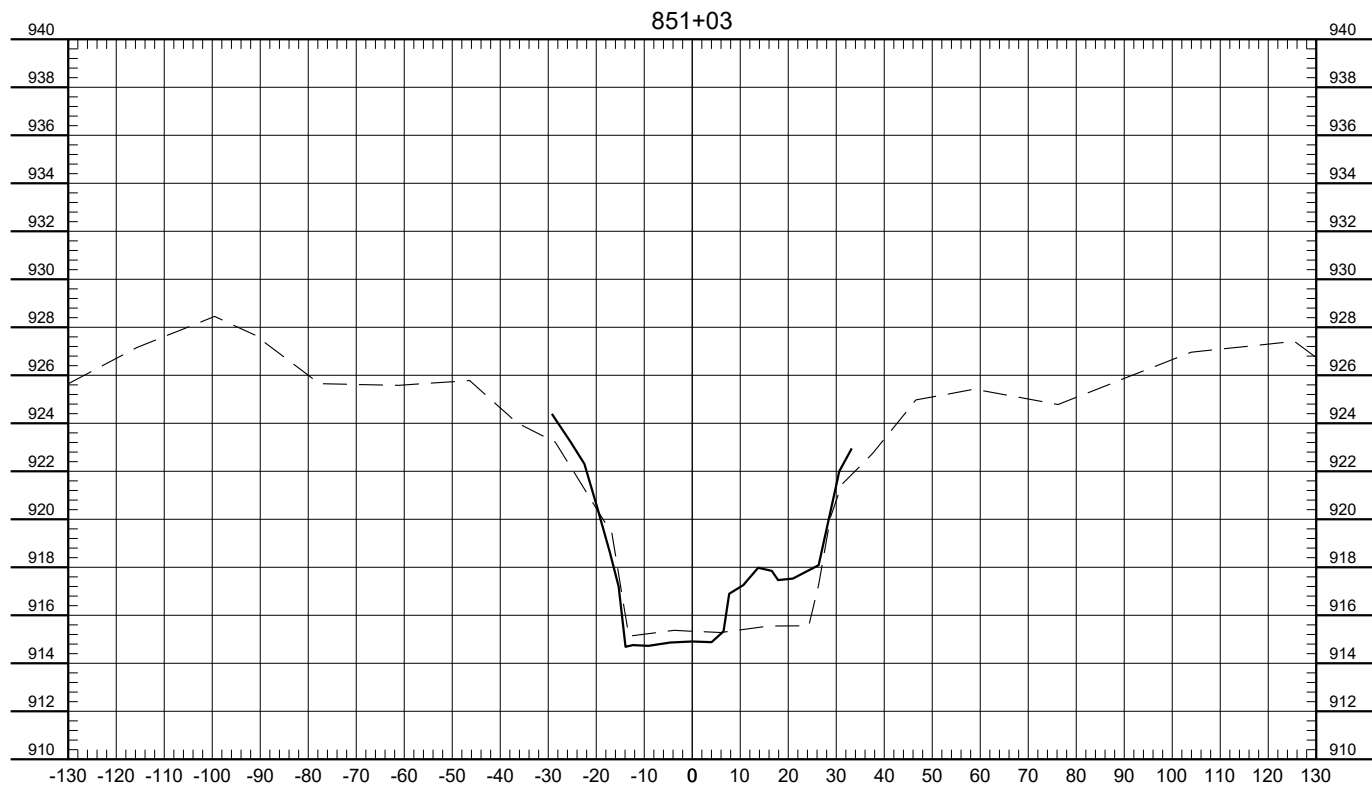
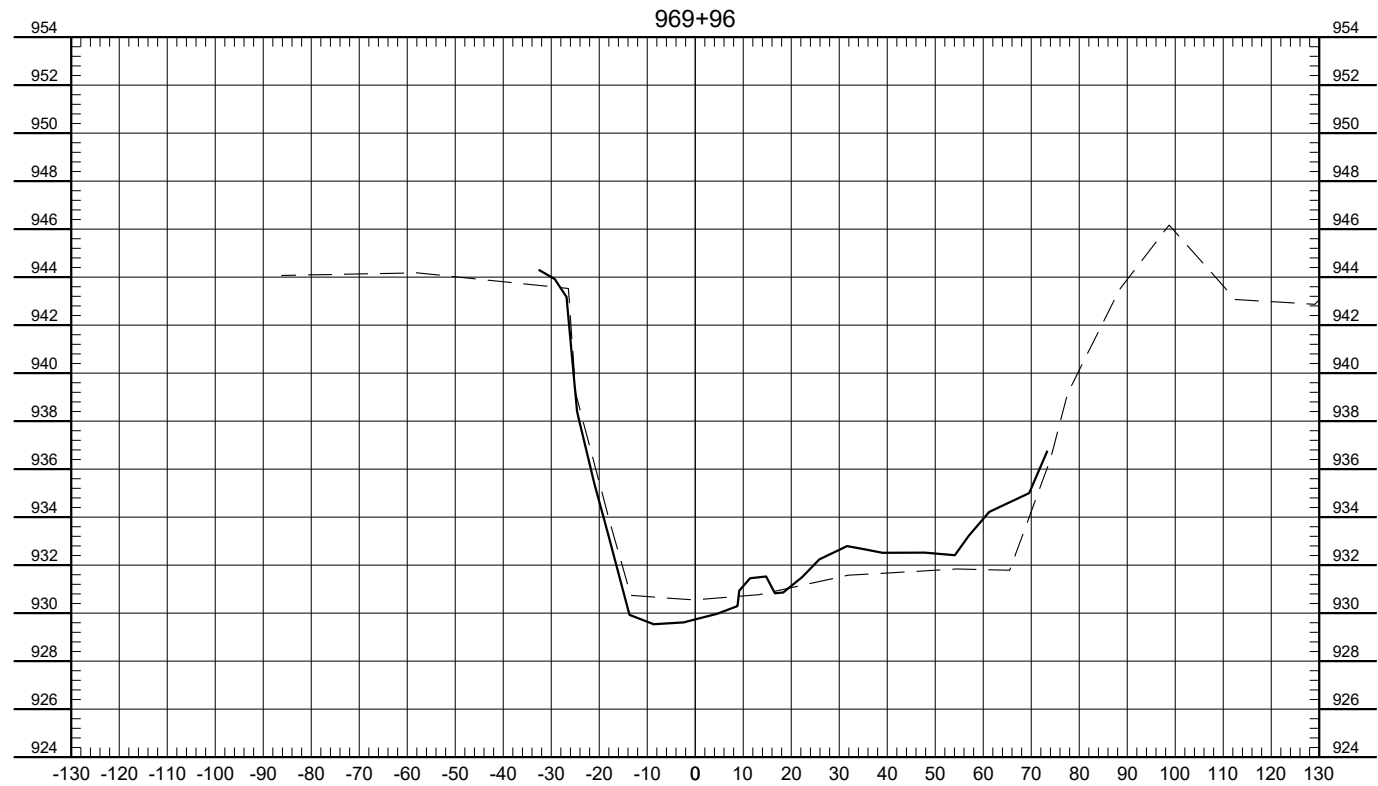
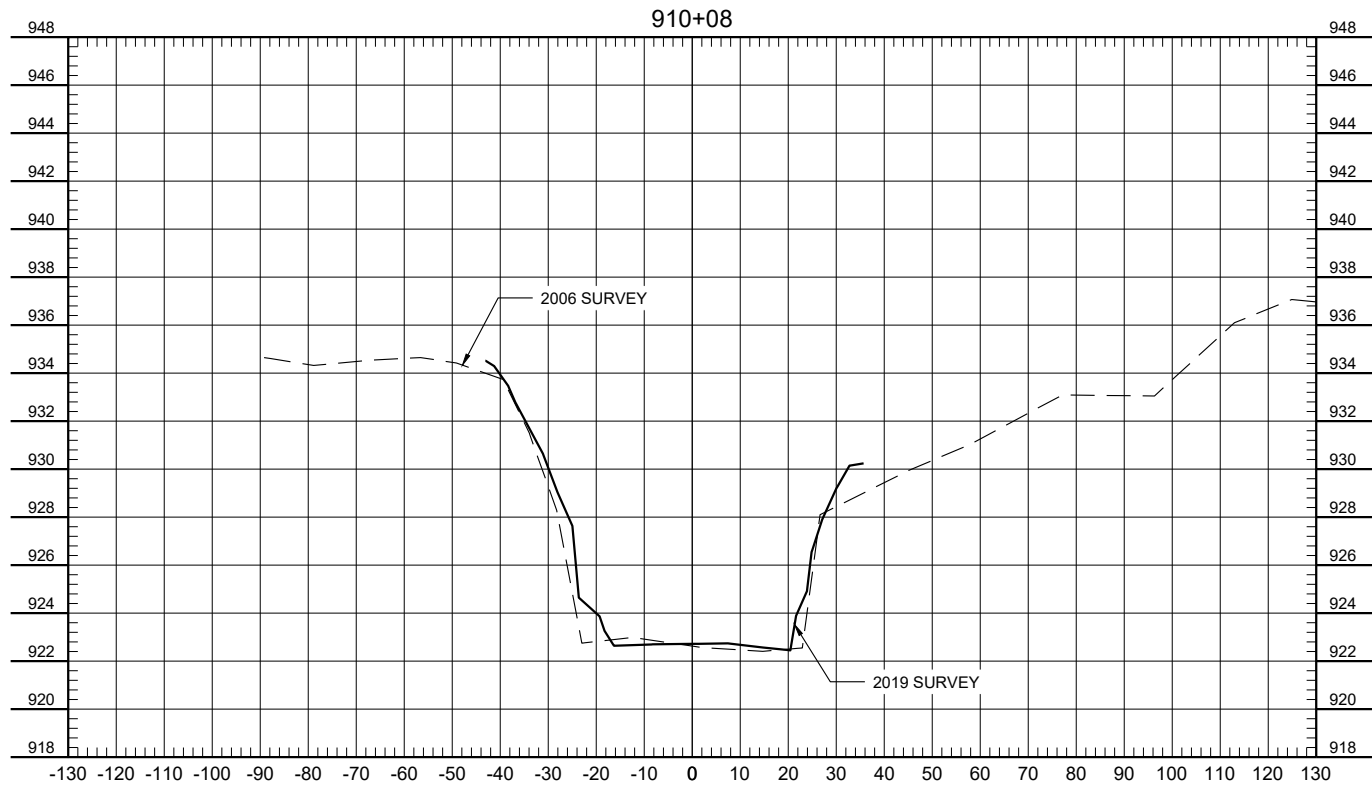
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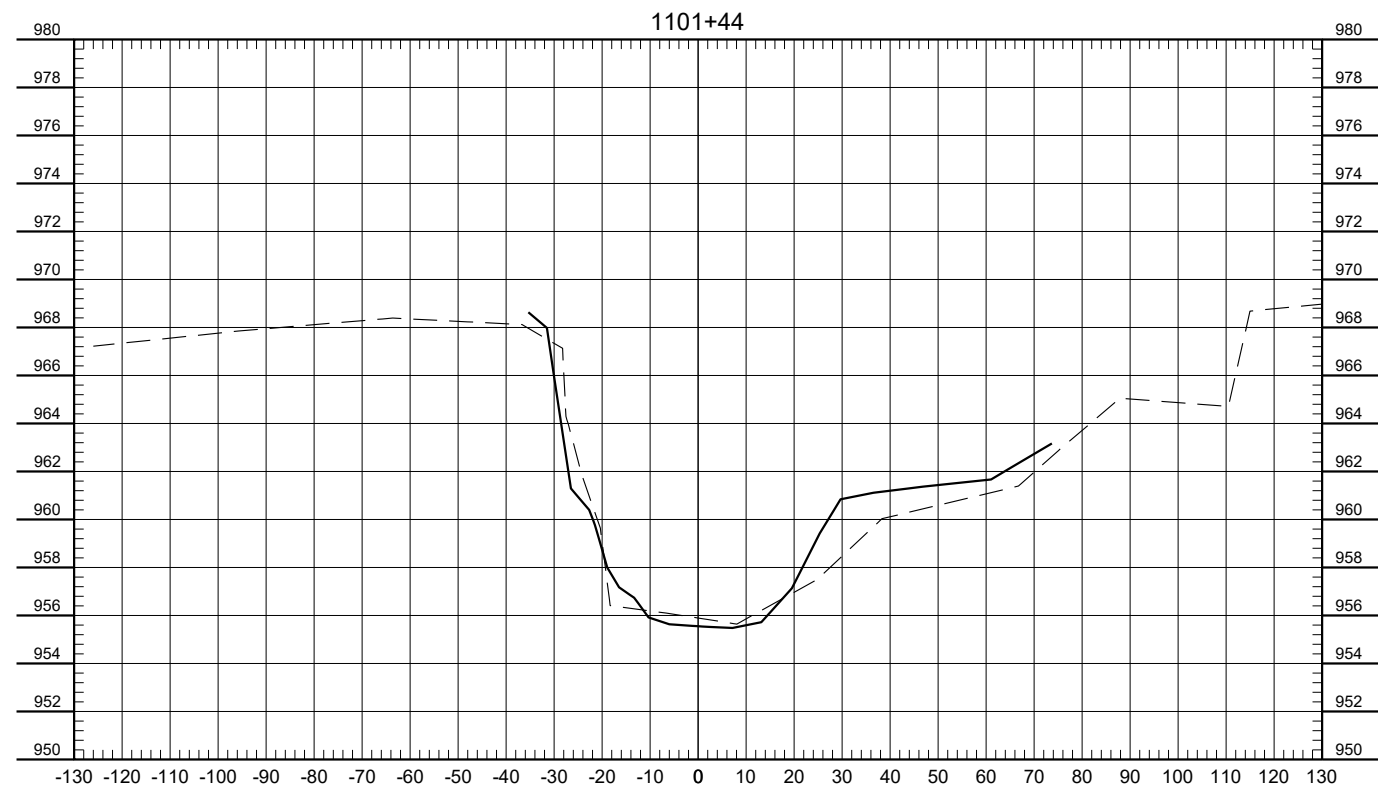
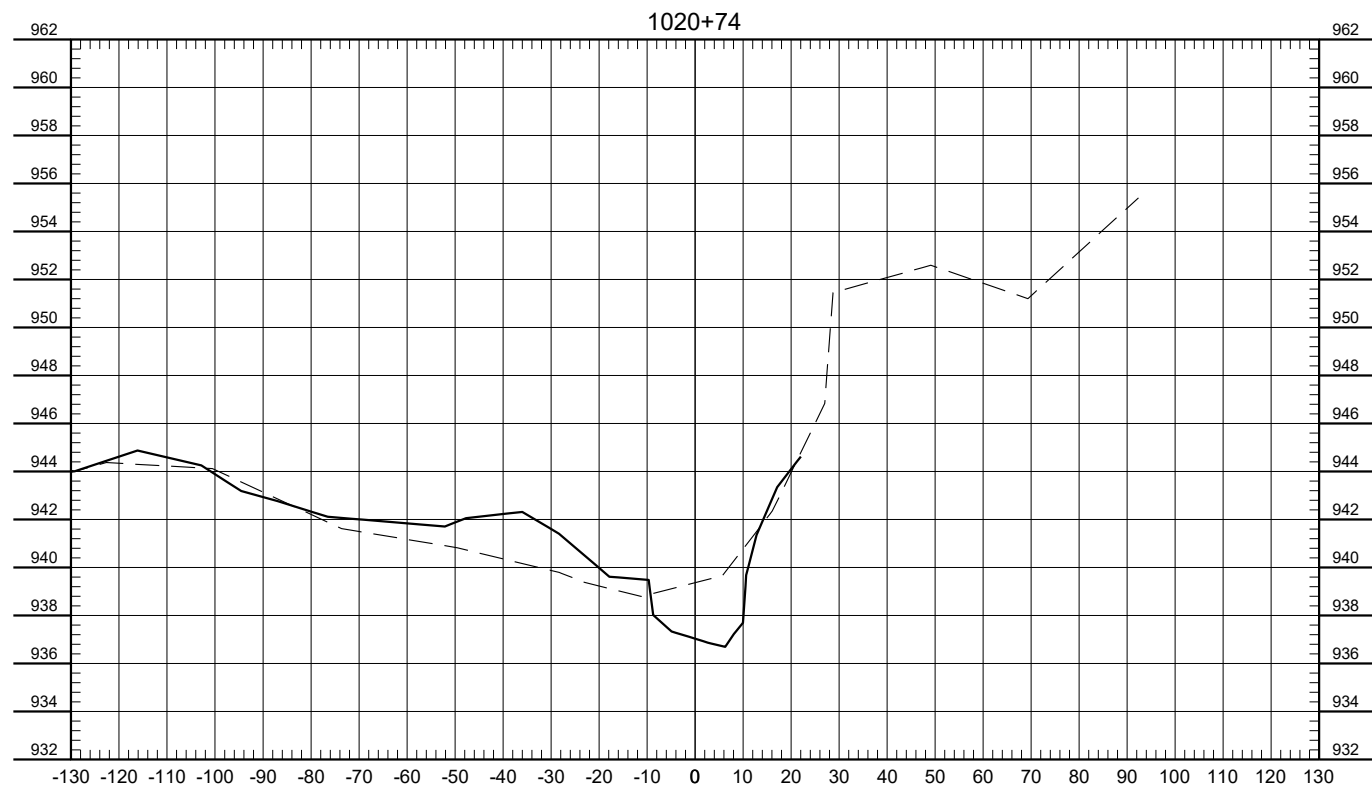
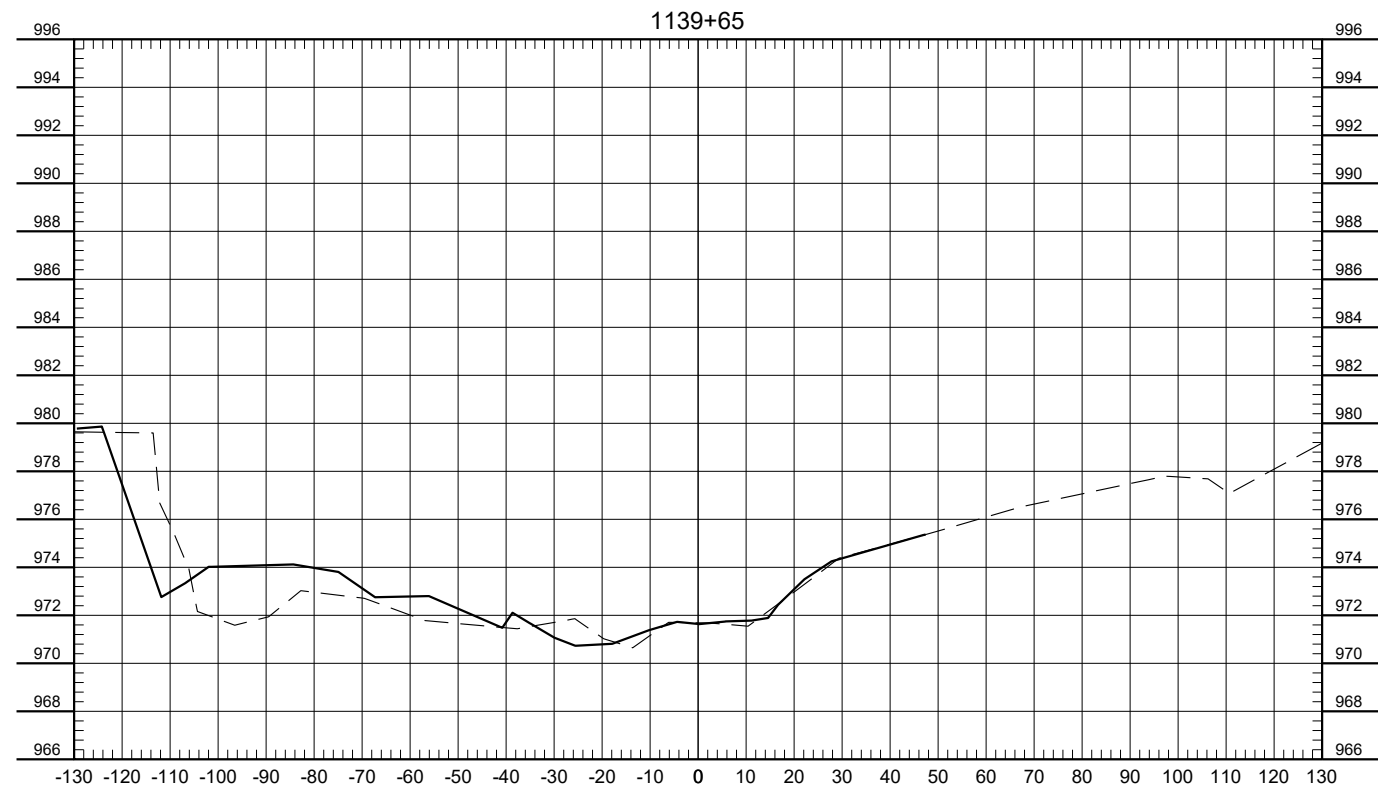
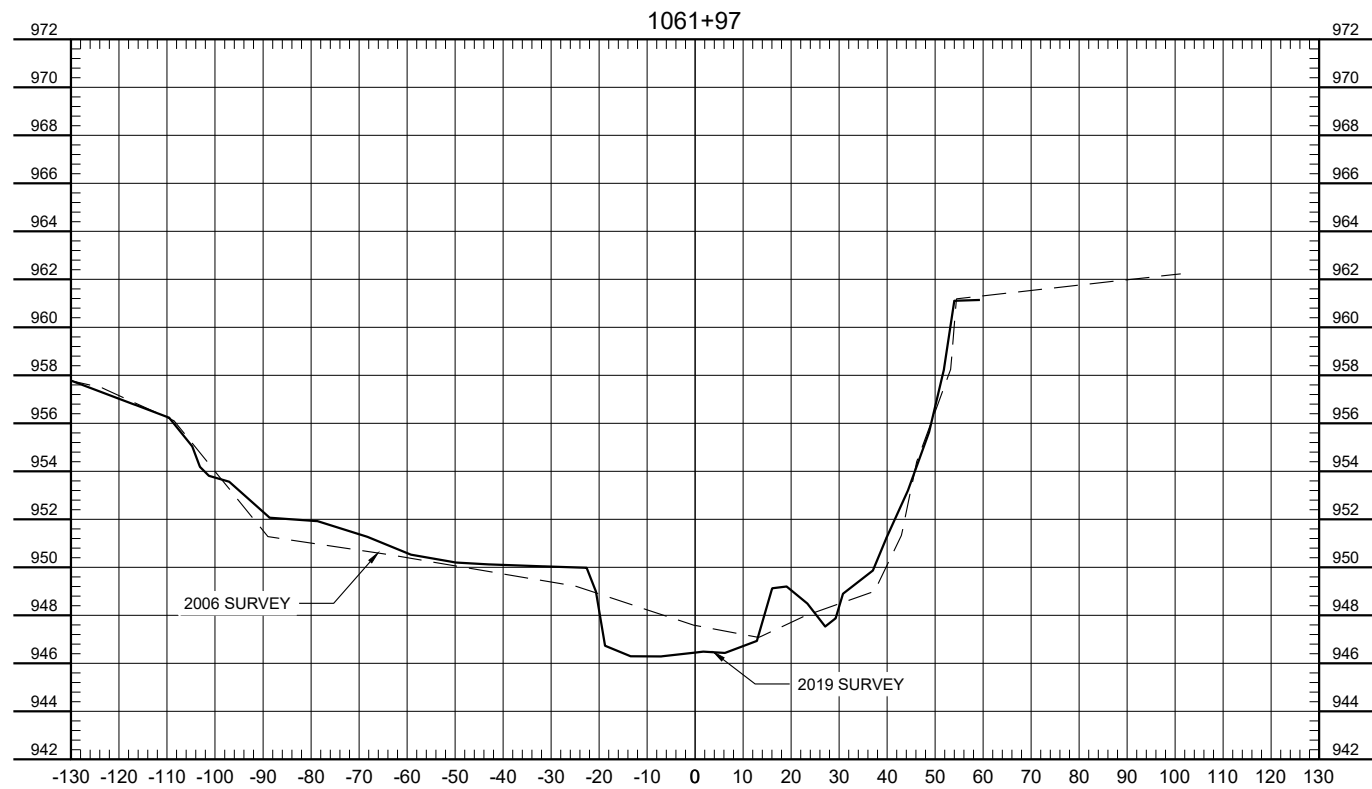
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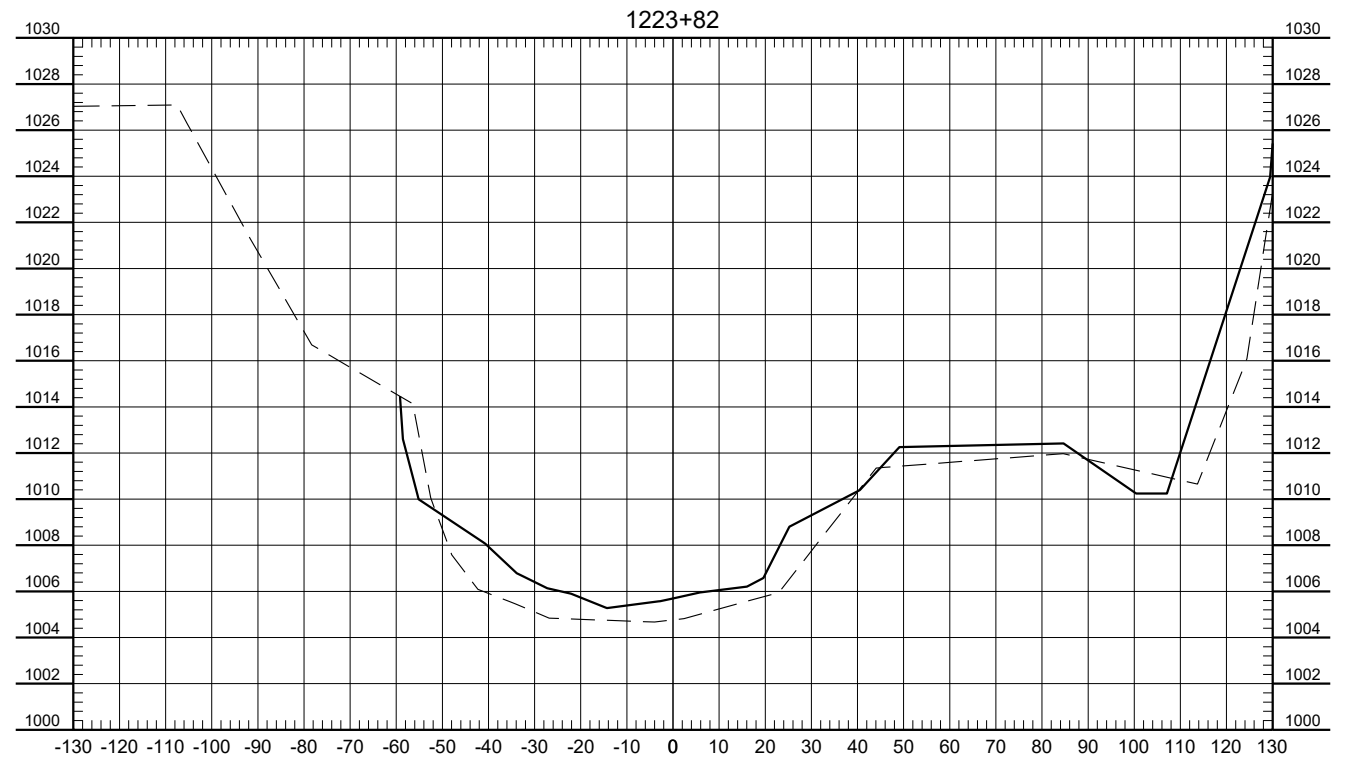
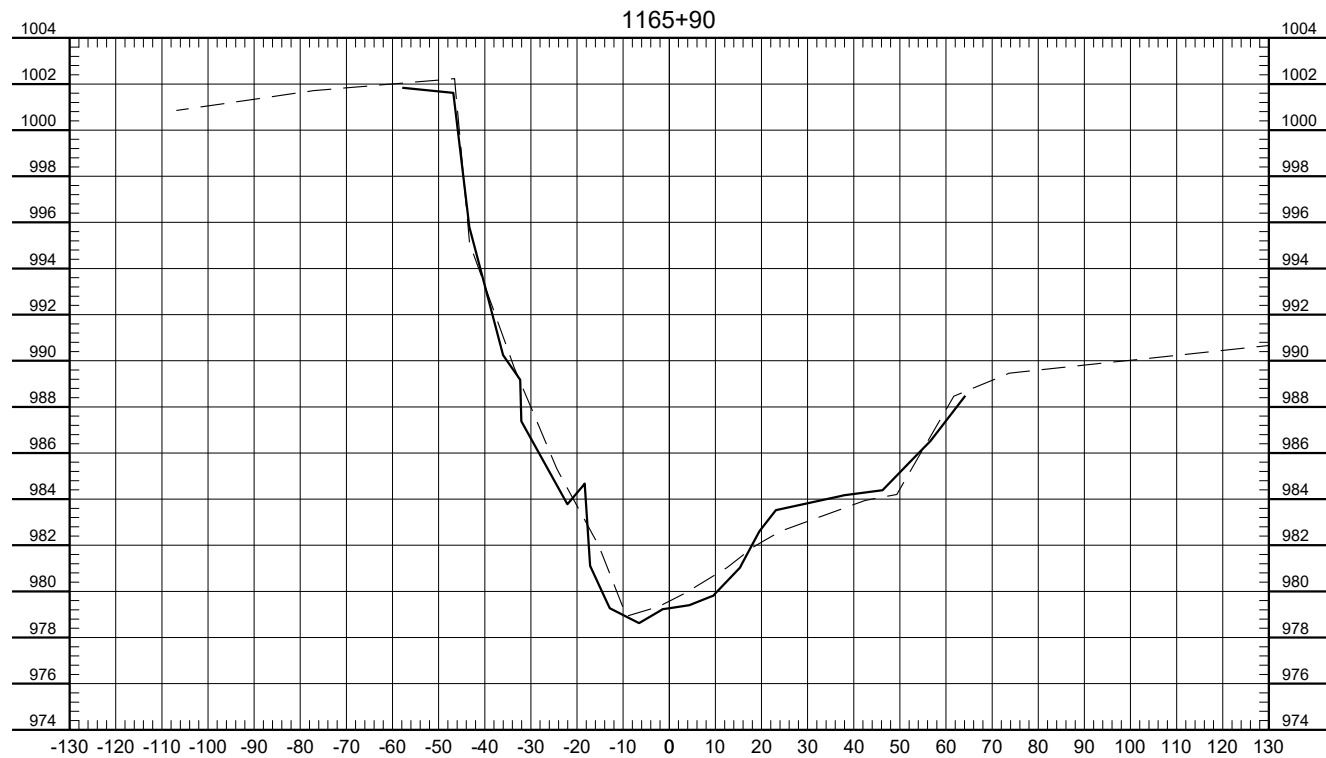
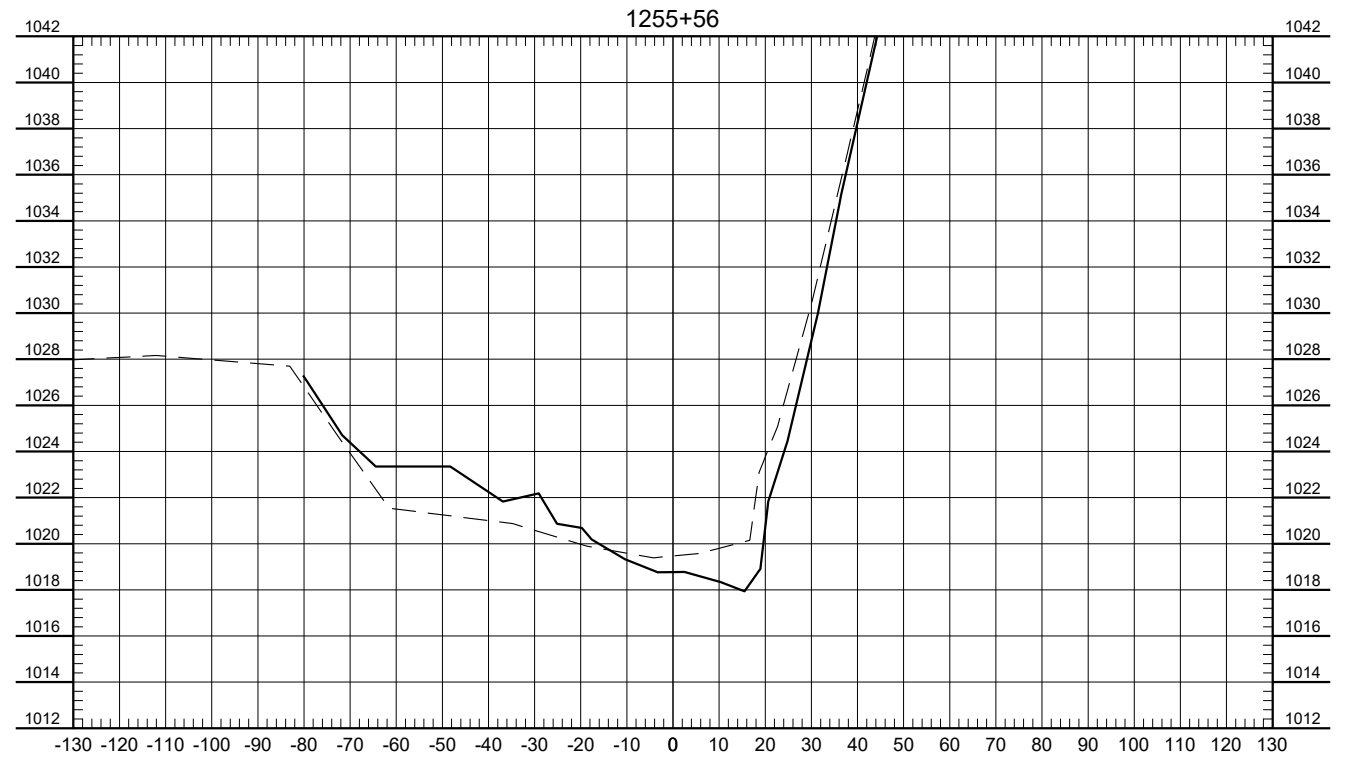
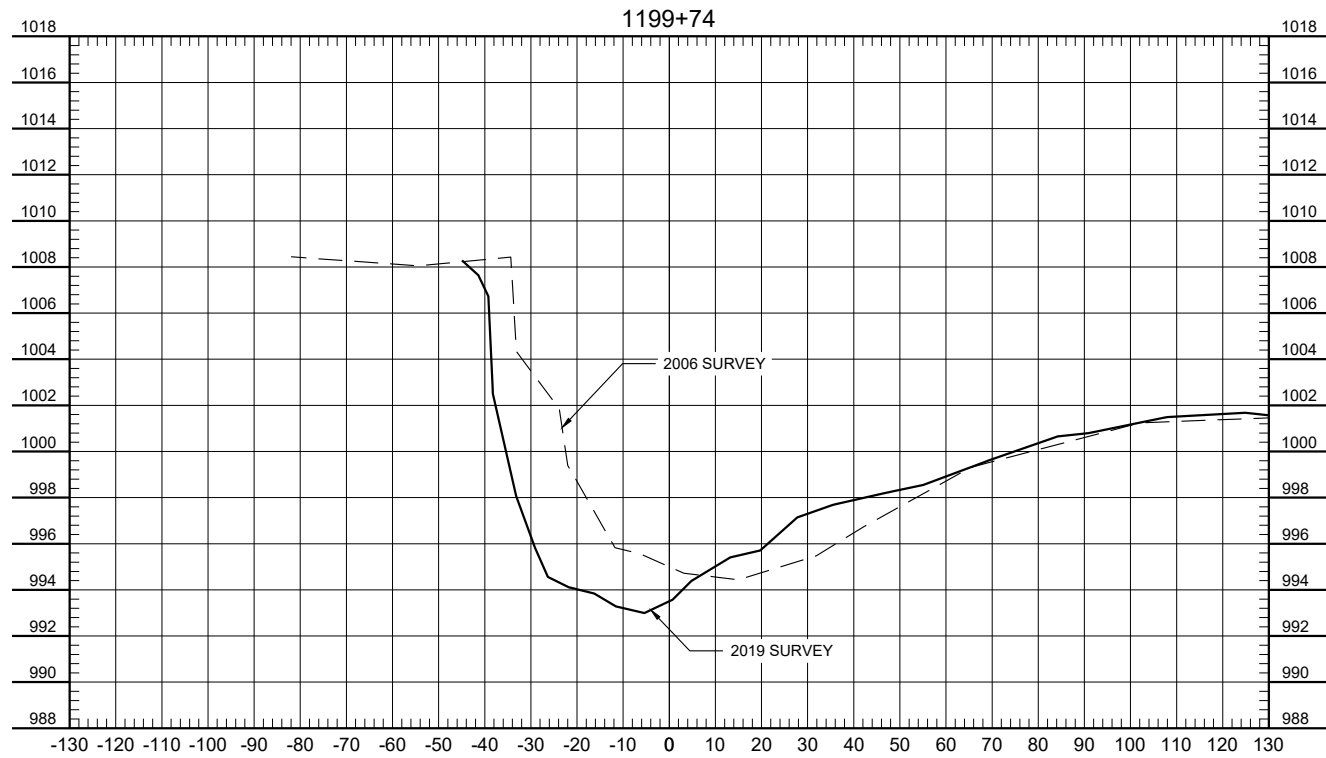
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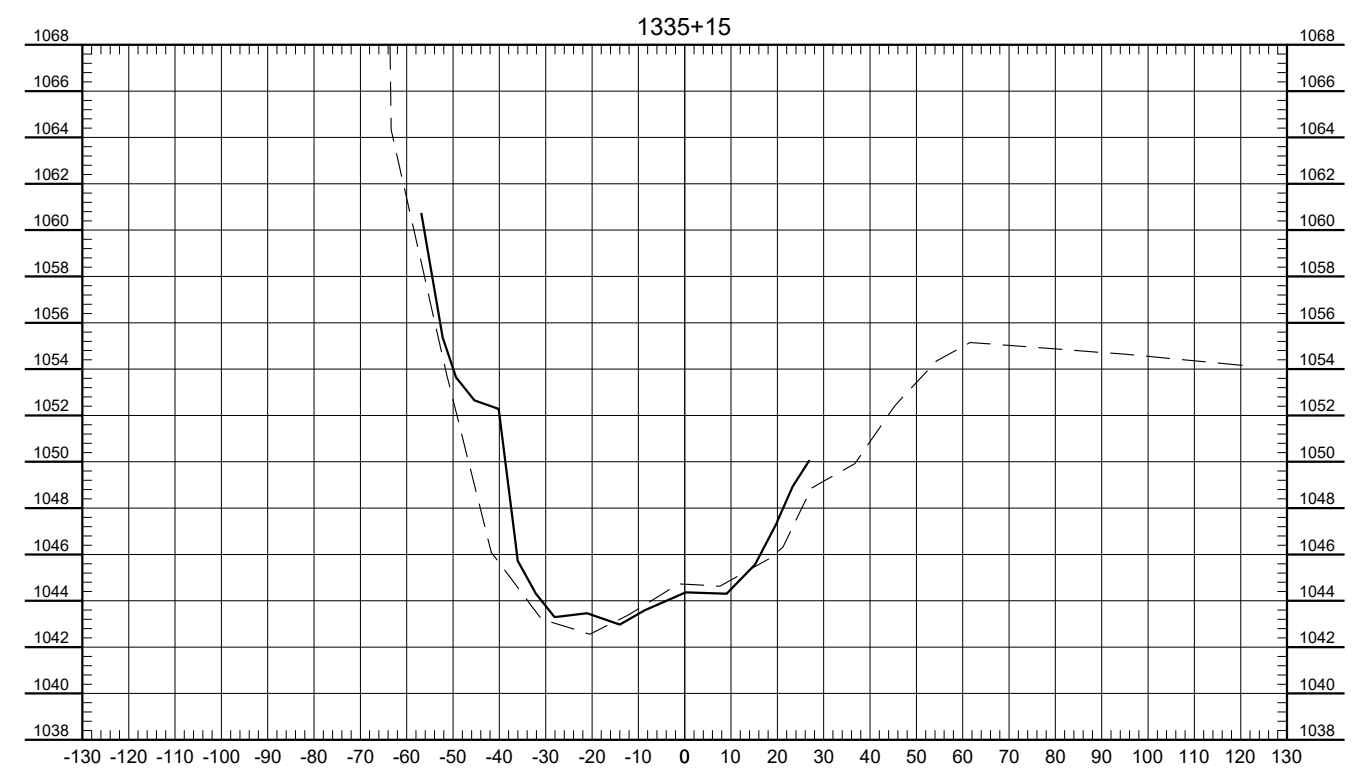
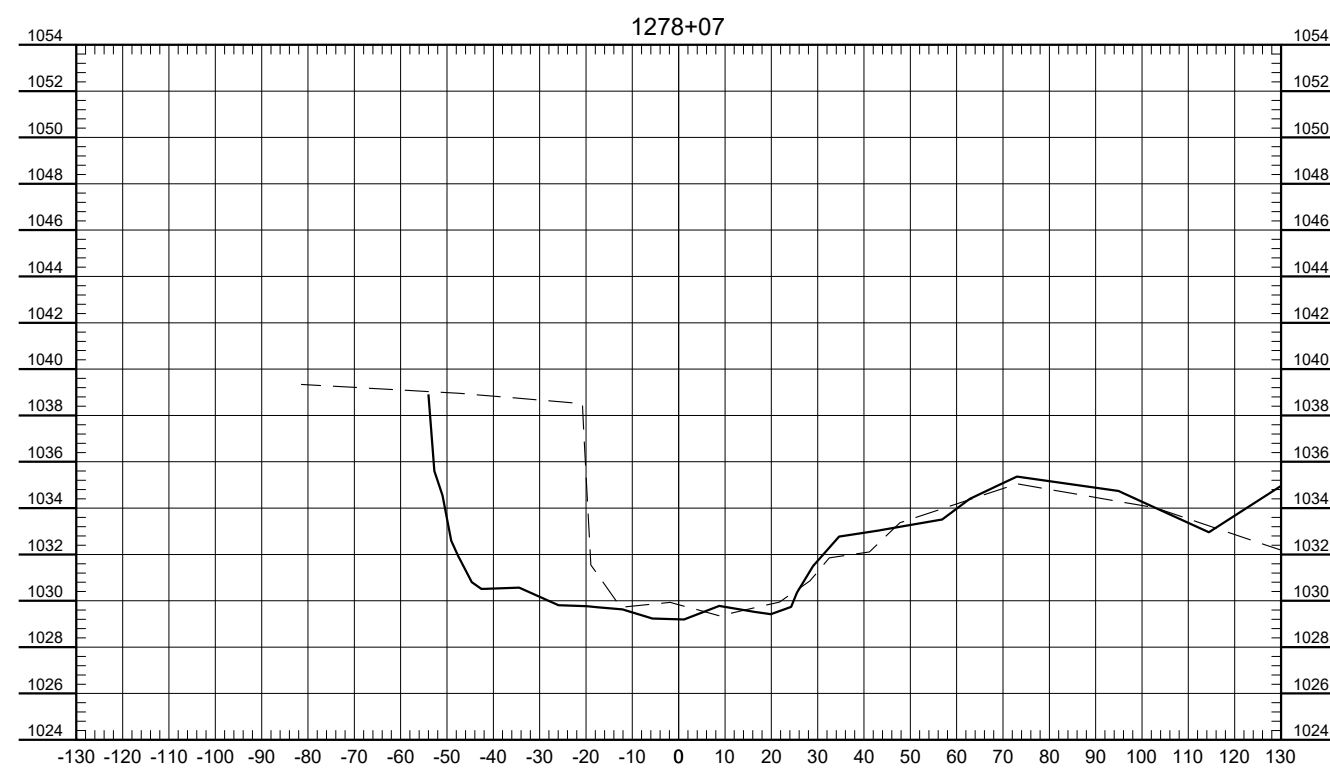
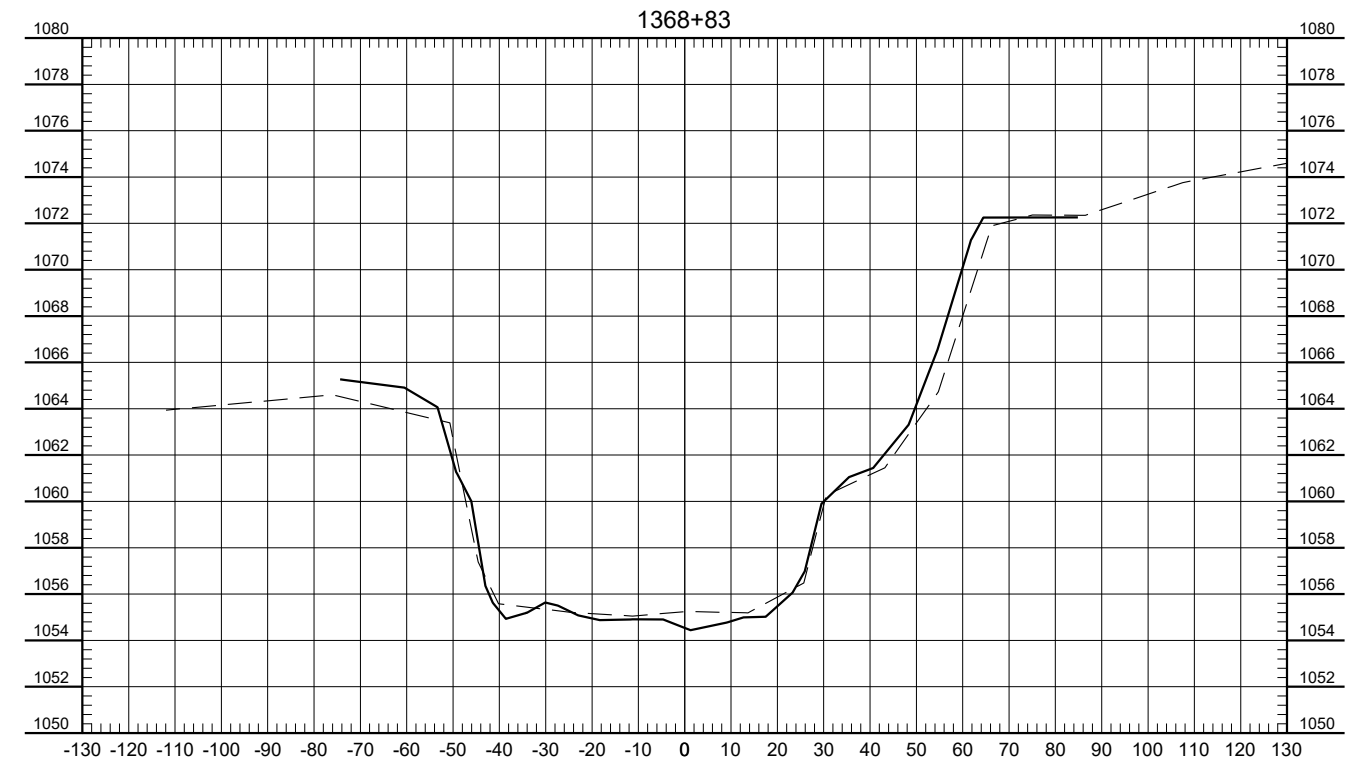
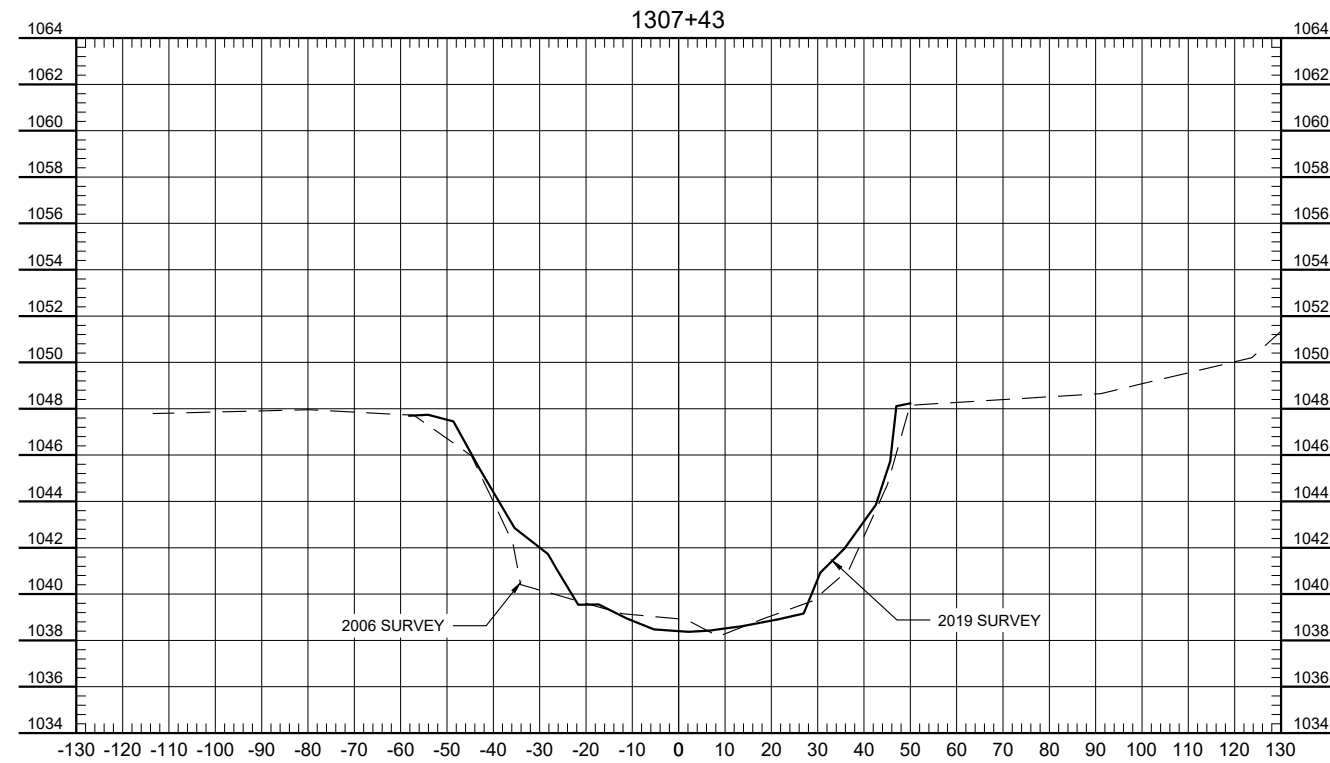
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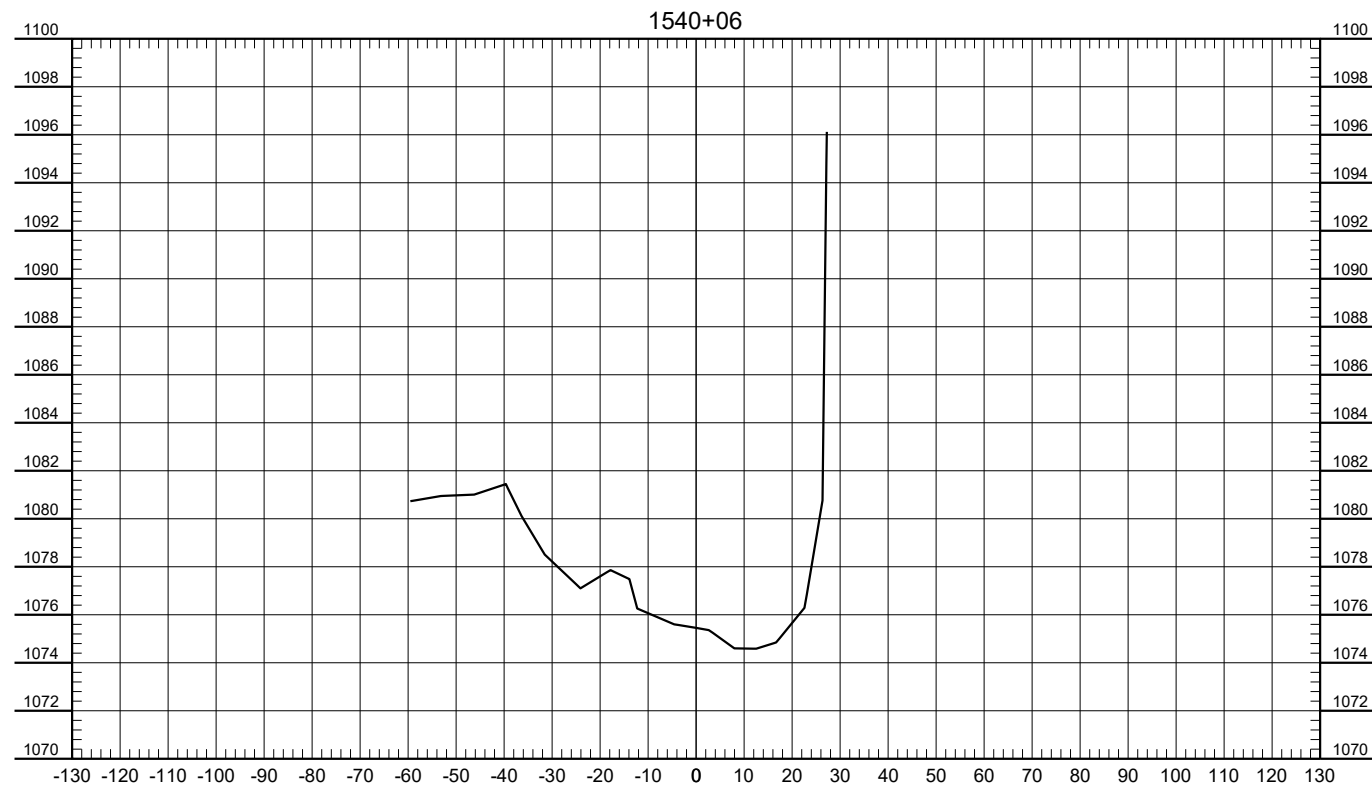
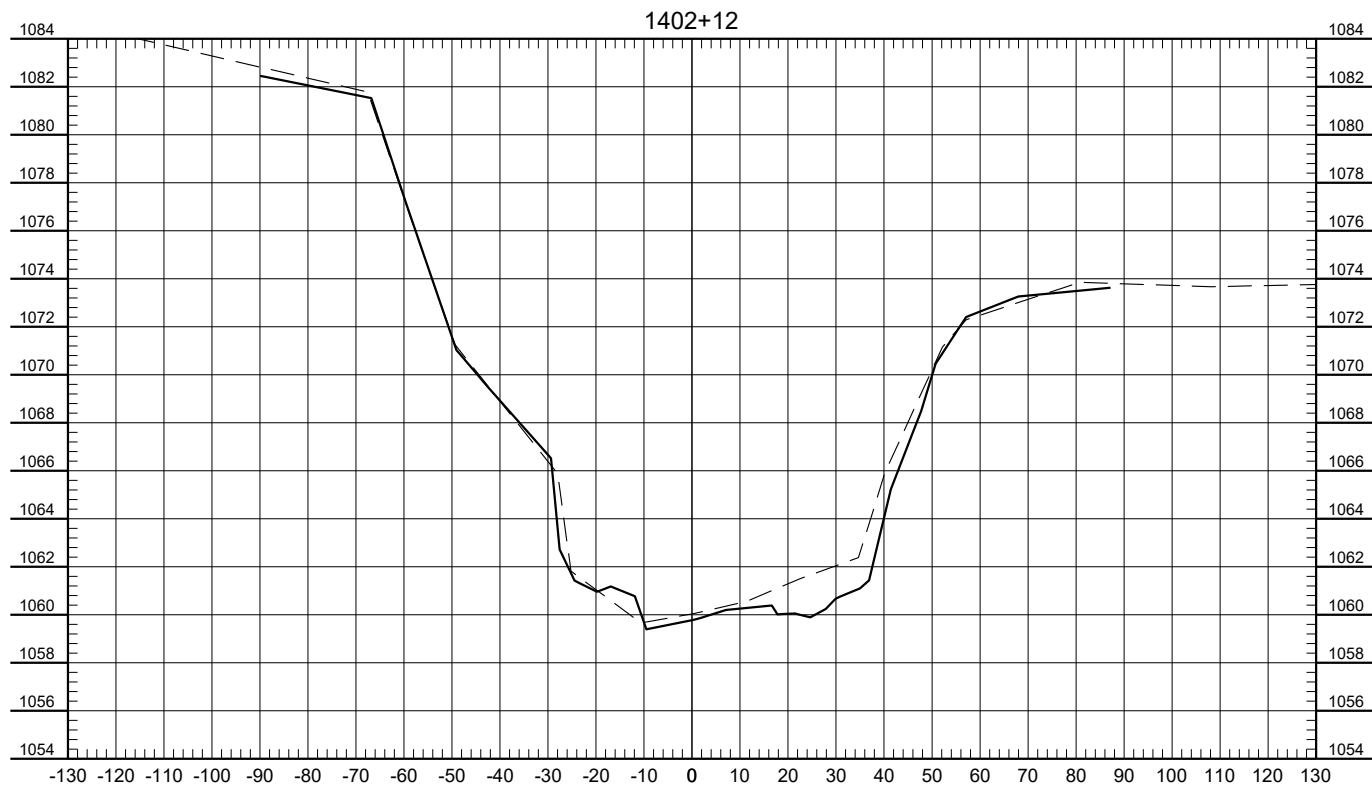
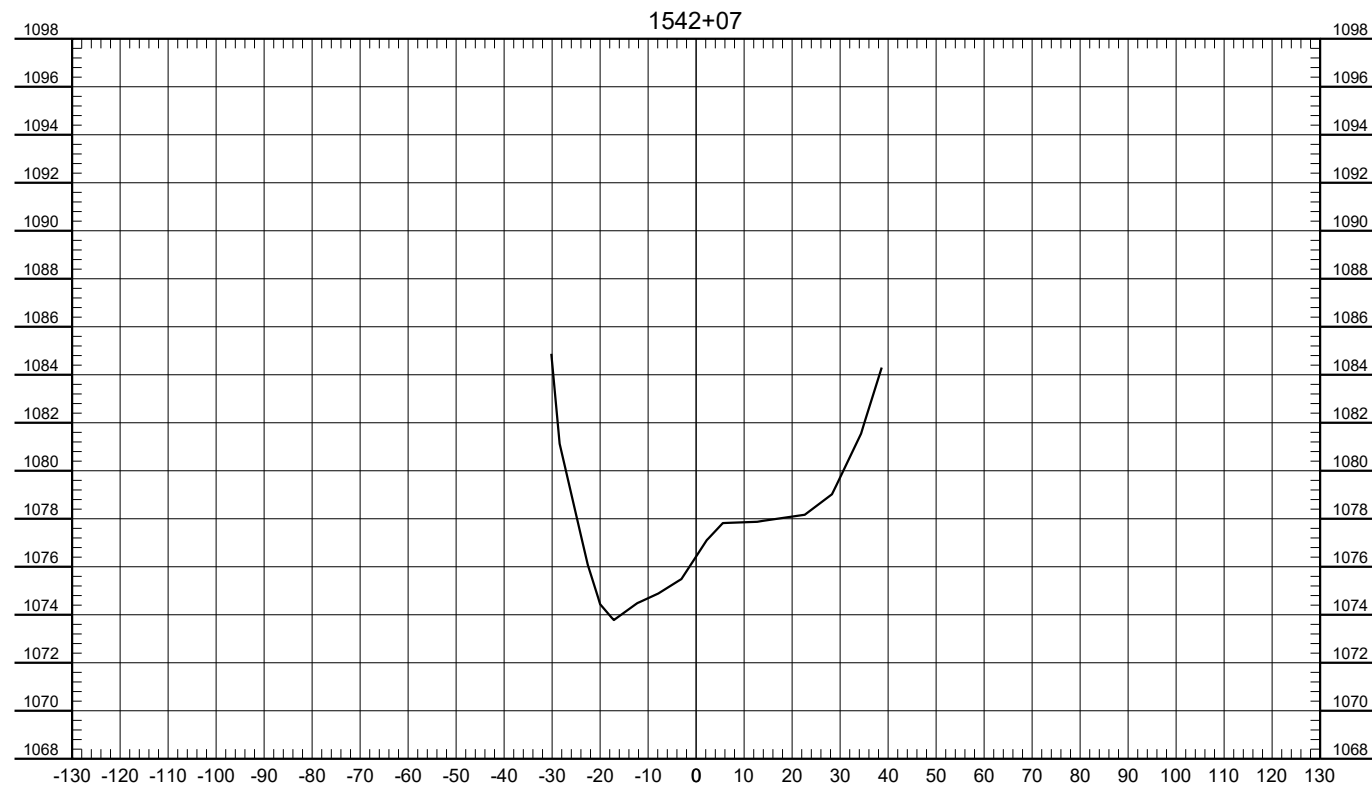
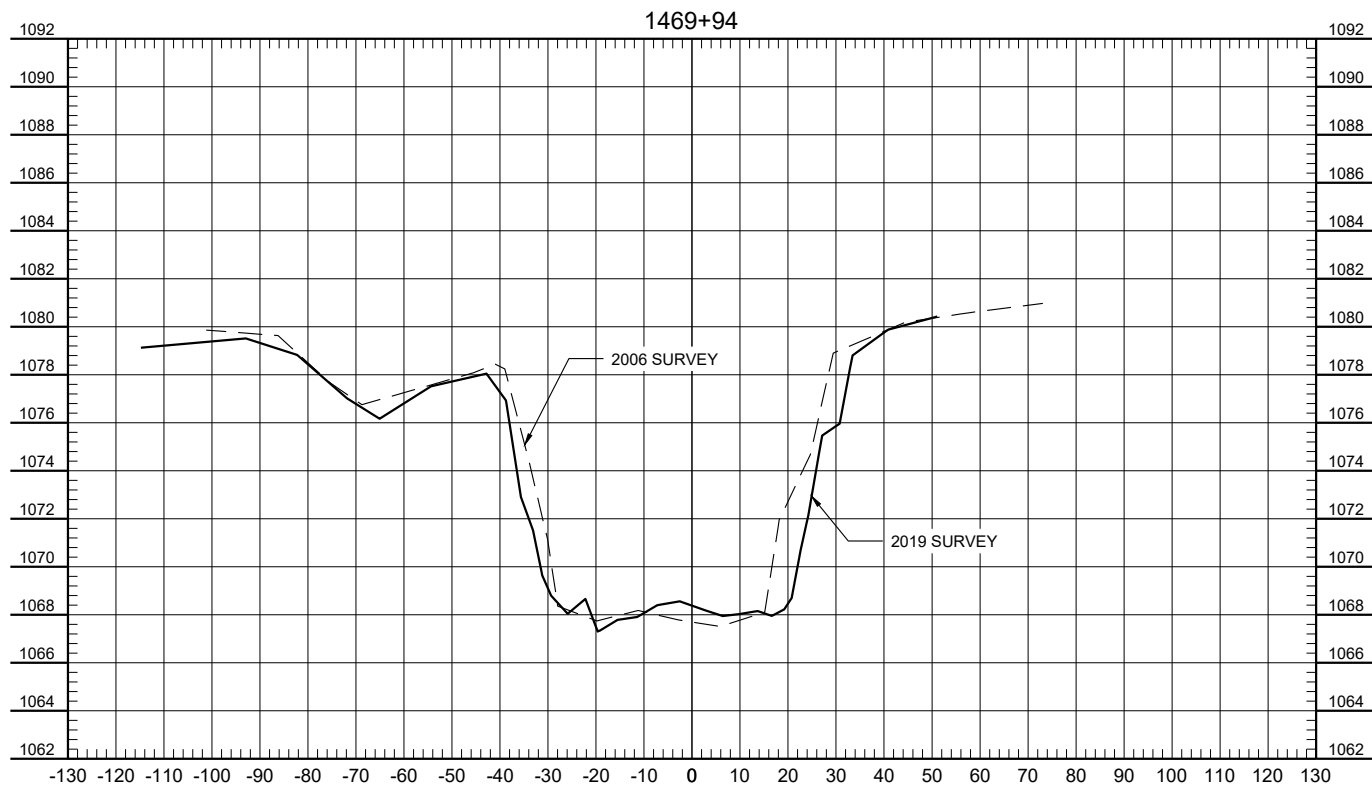


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P: 701.237.5065 F: 701.237.5101	Checked by GLB	Scale AS SHOWN			

PROJECT NO. 1432-0365



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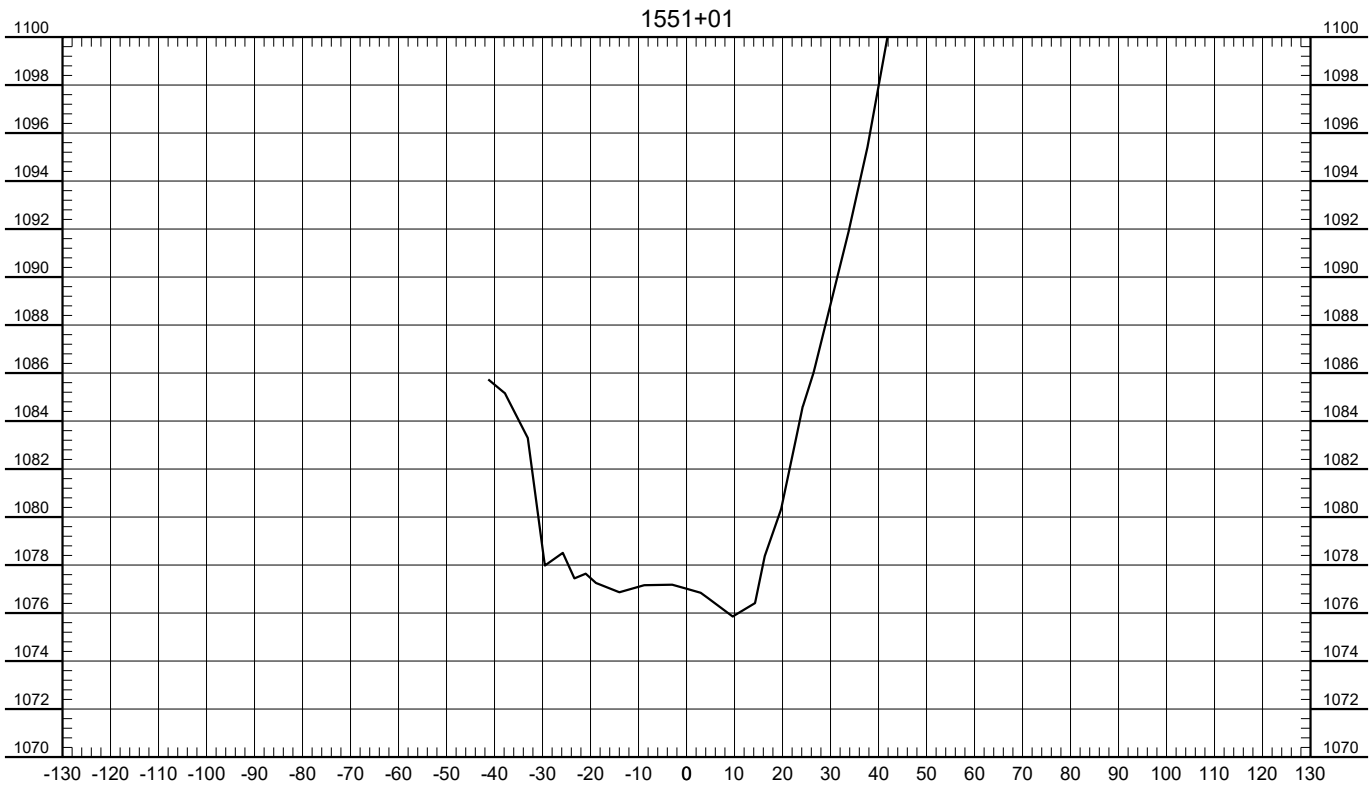
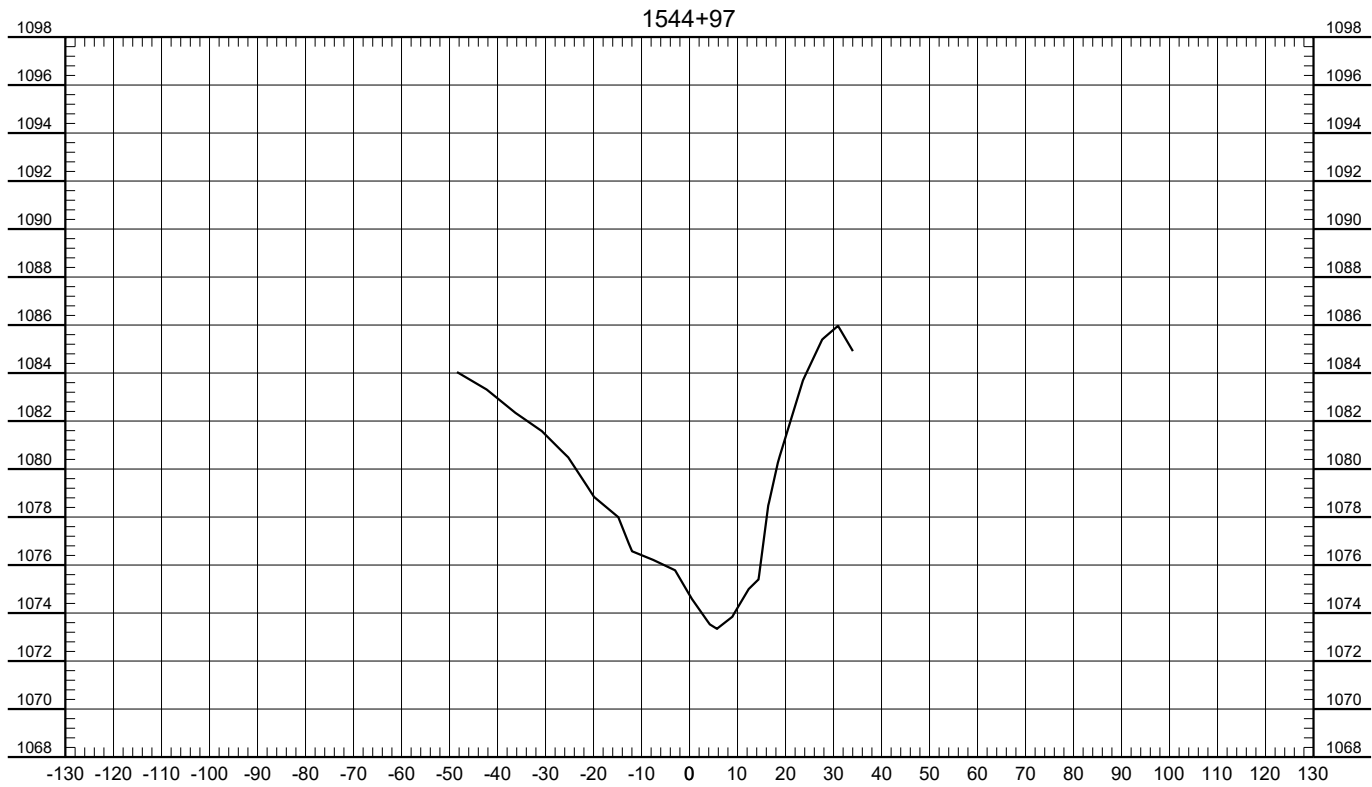
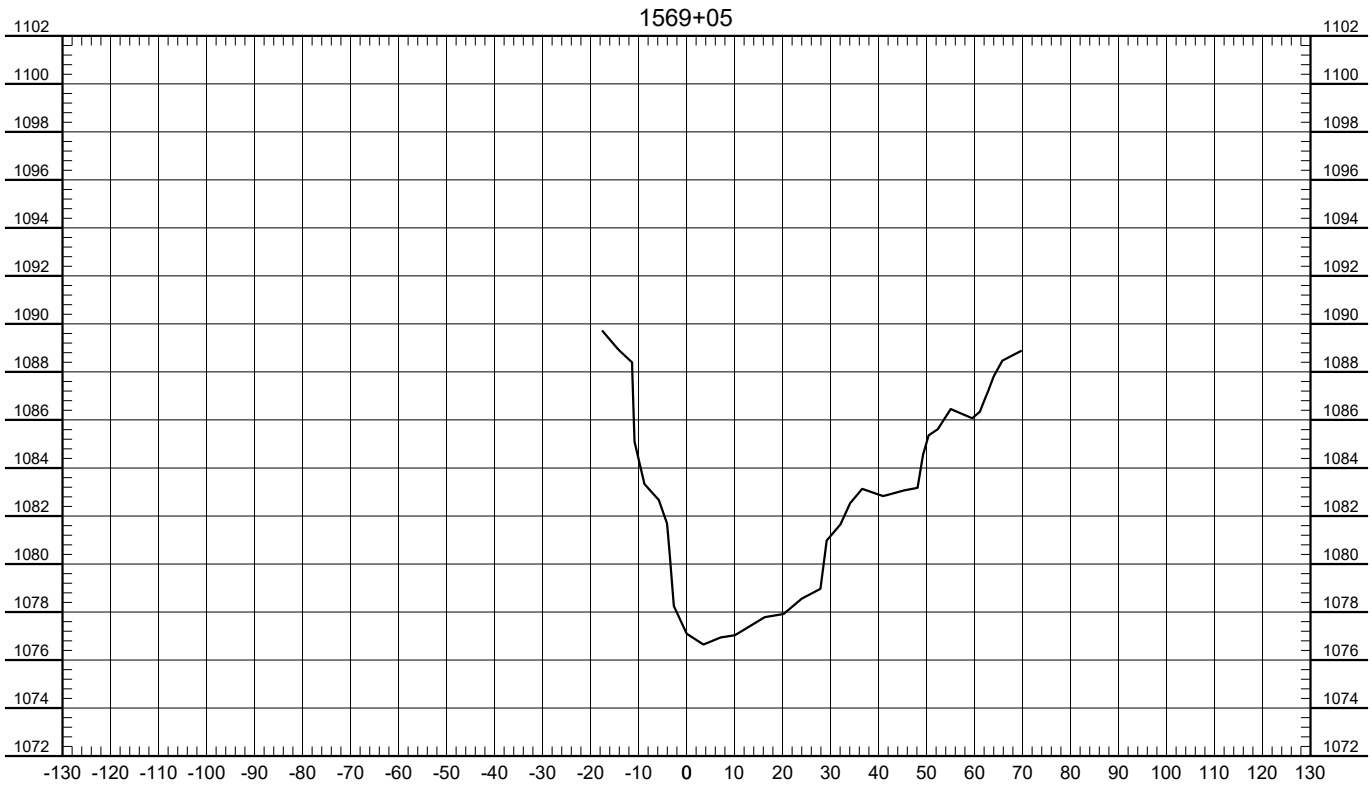
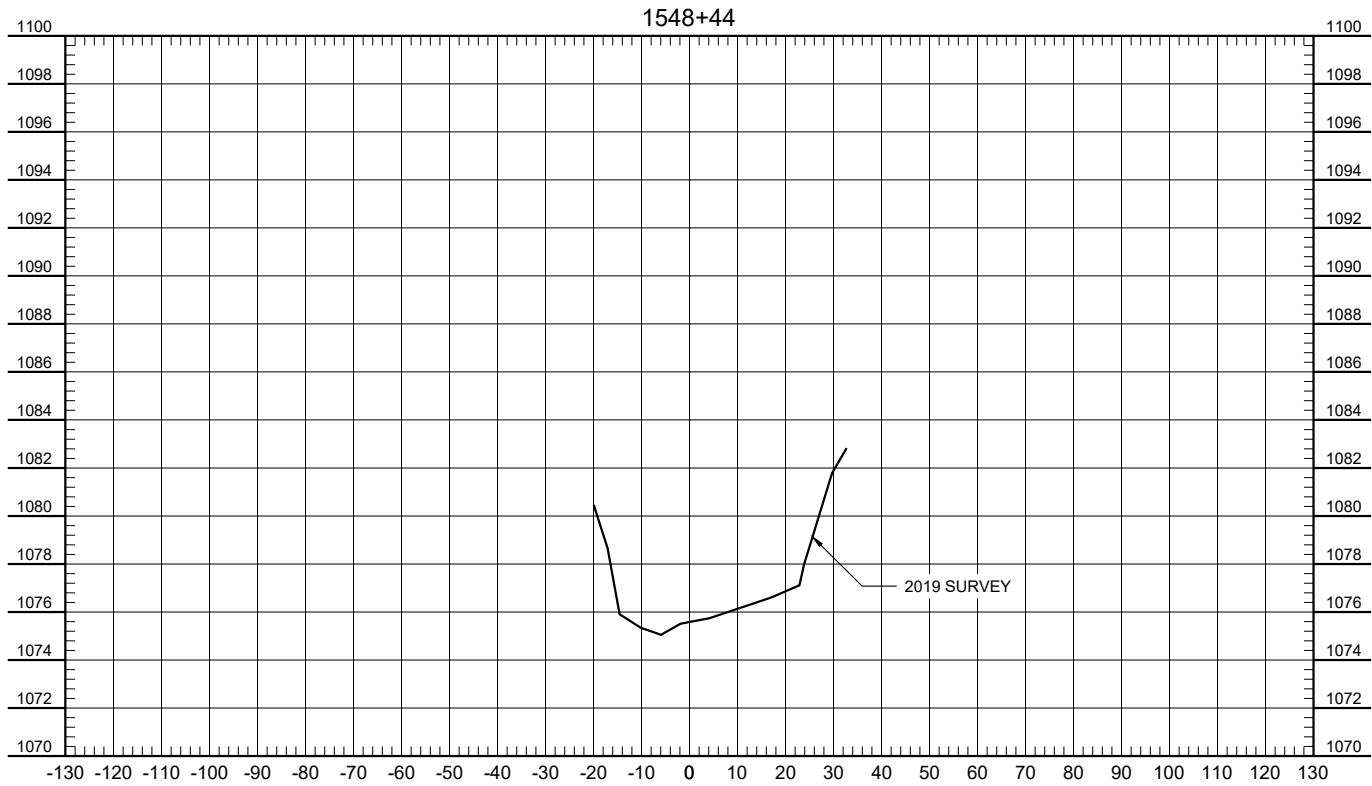
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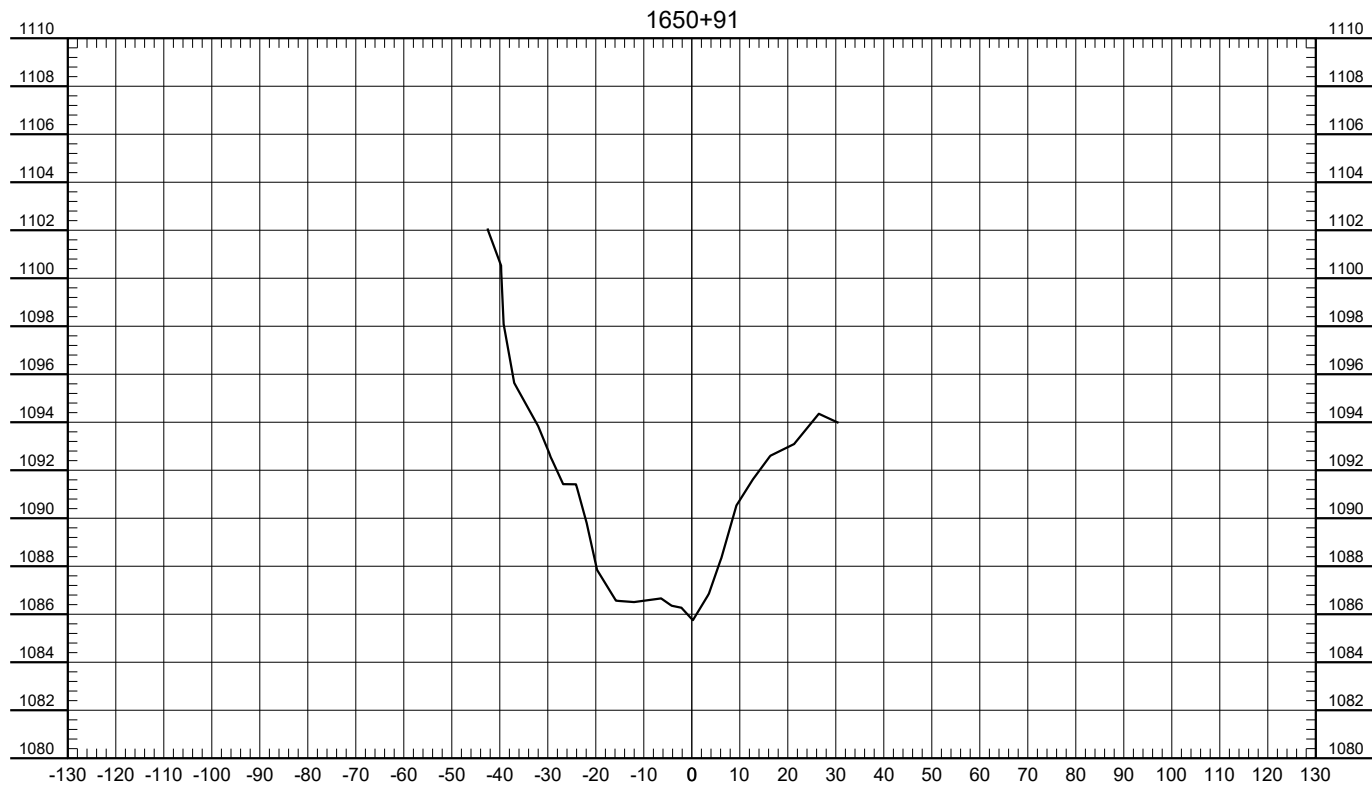
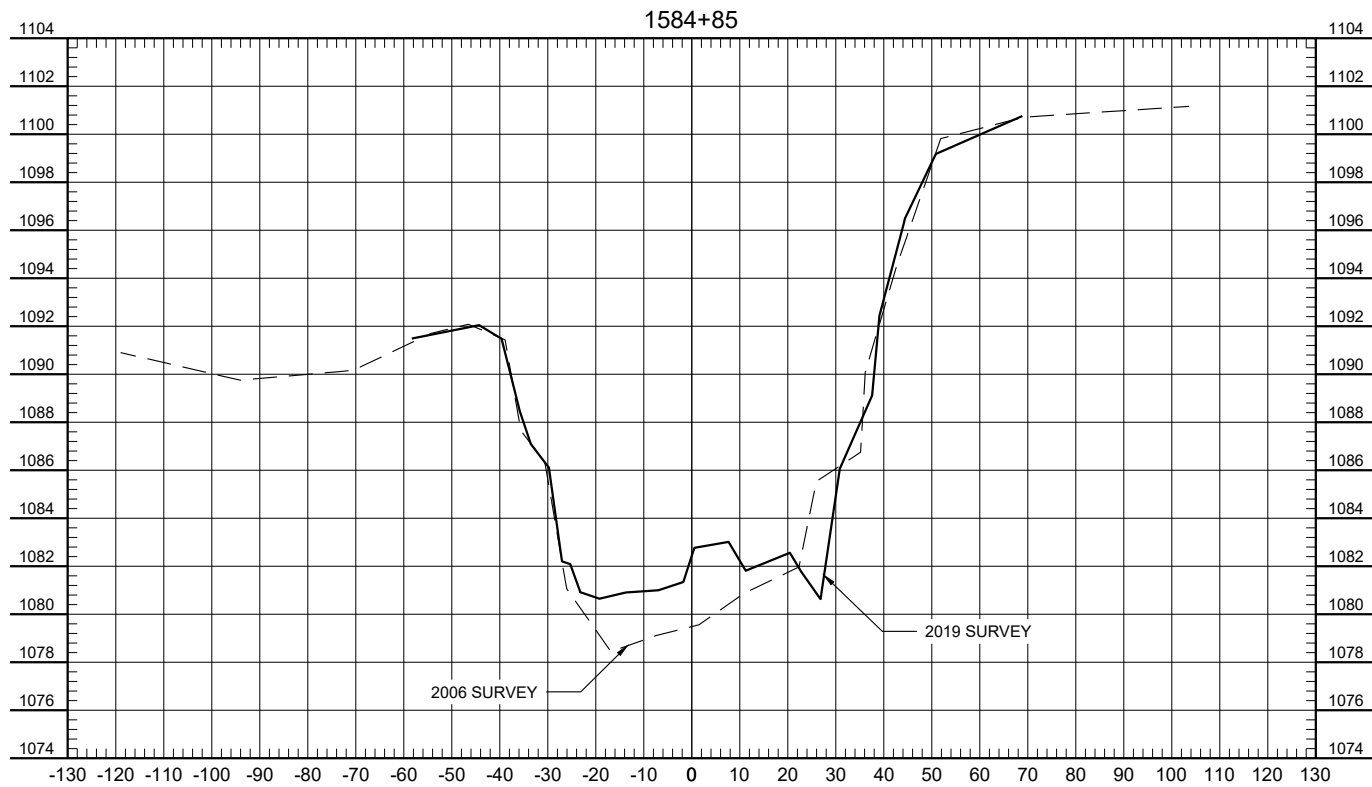
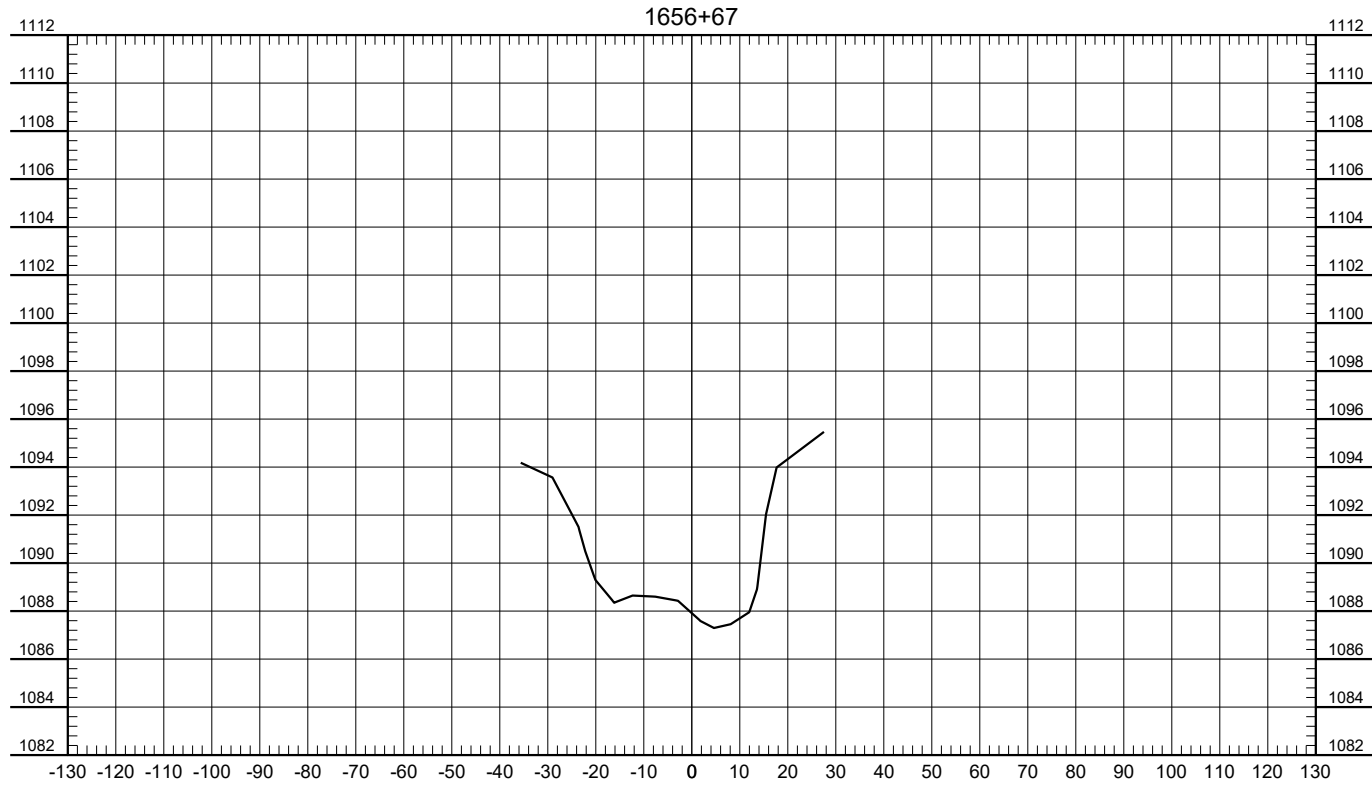
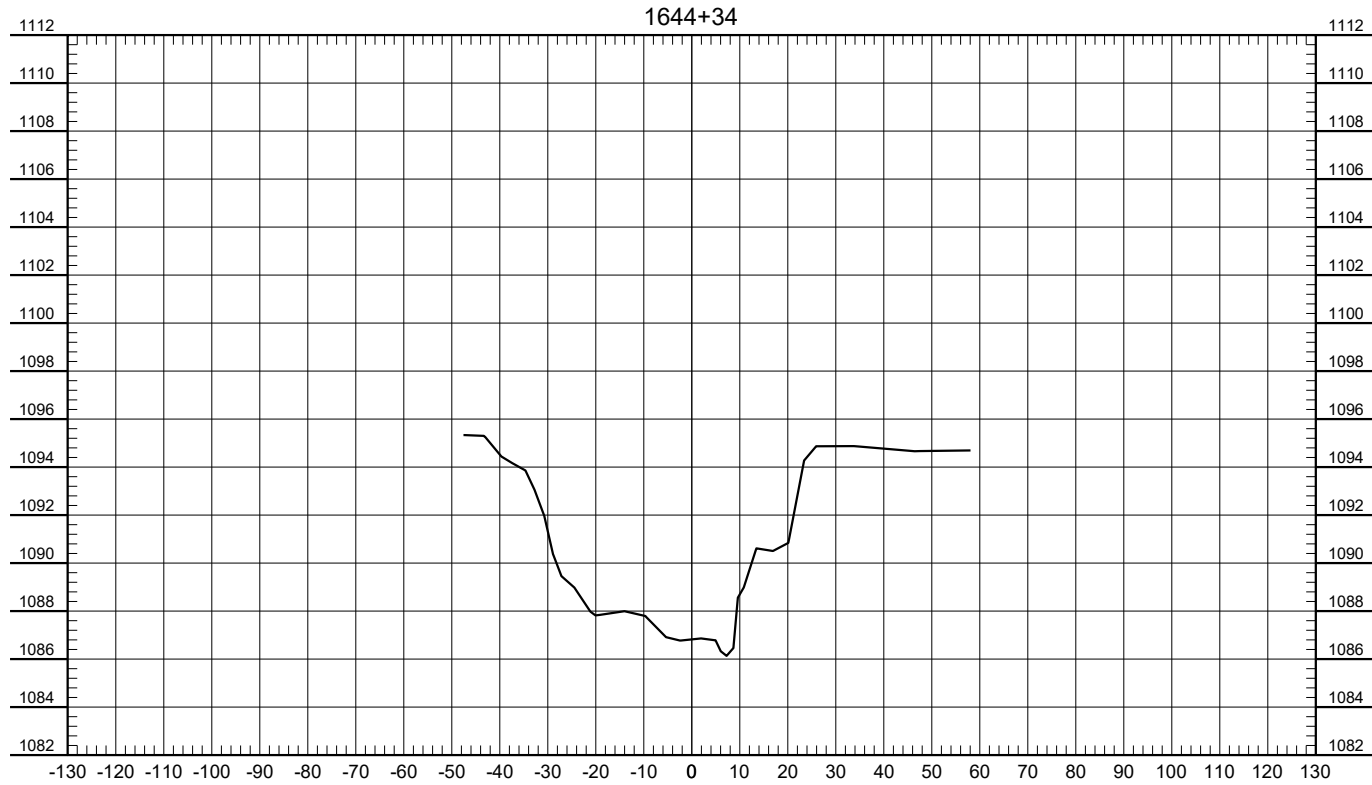
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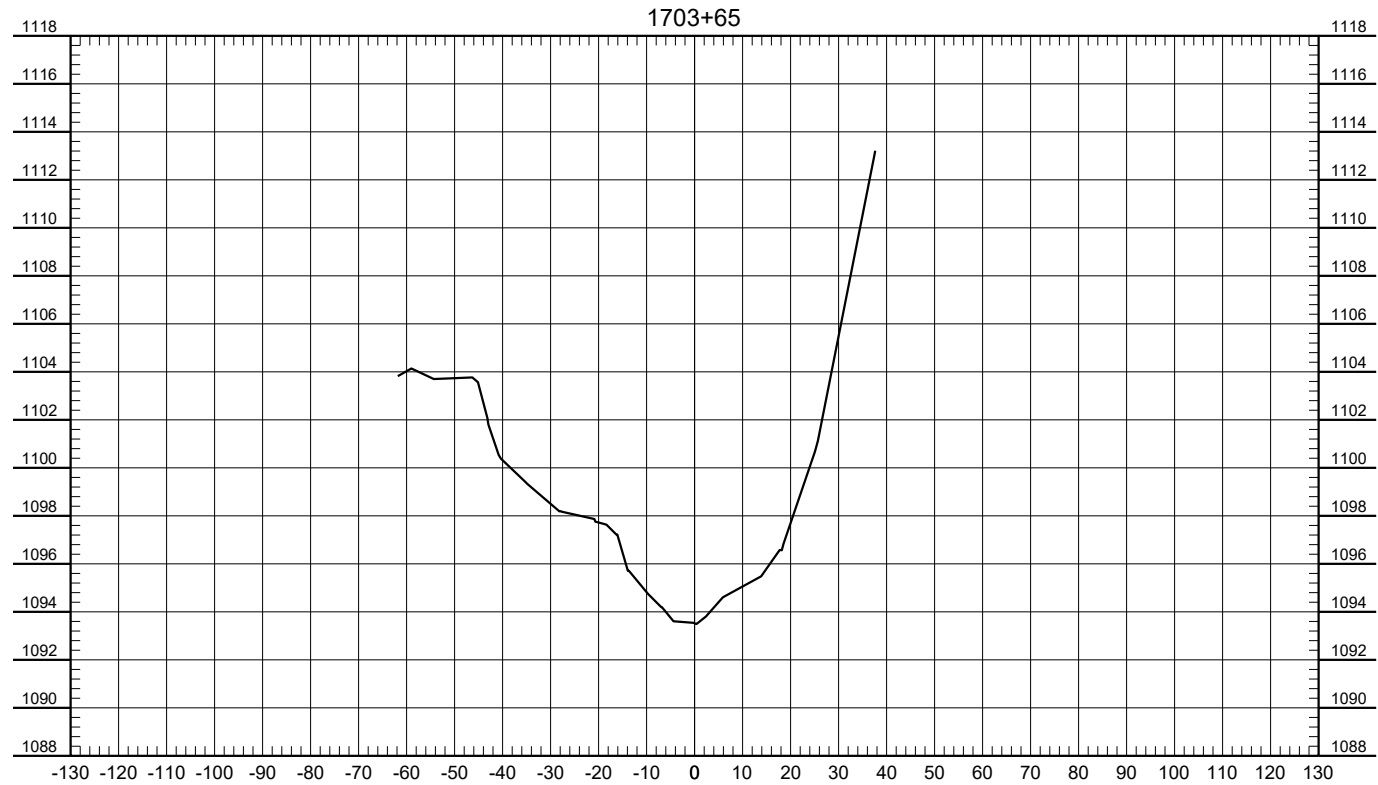
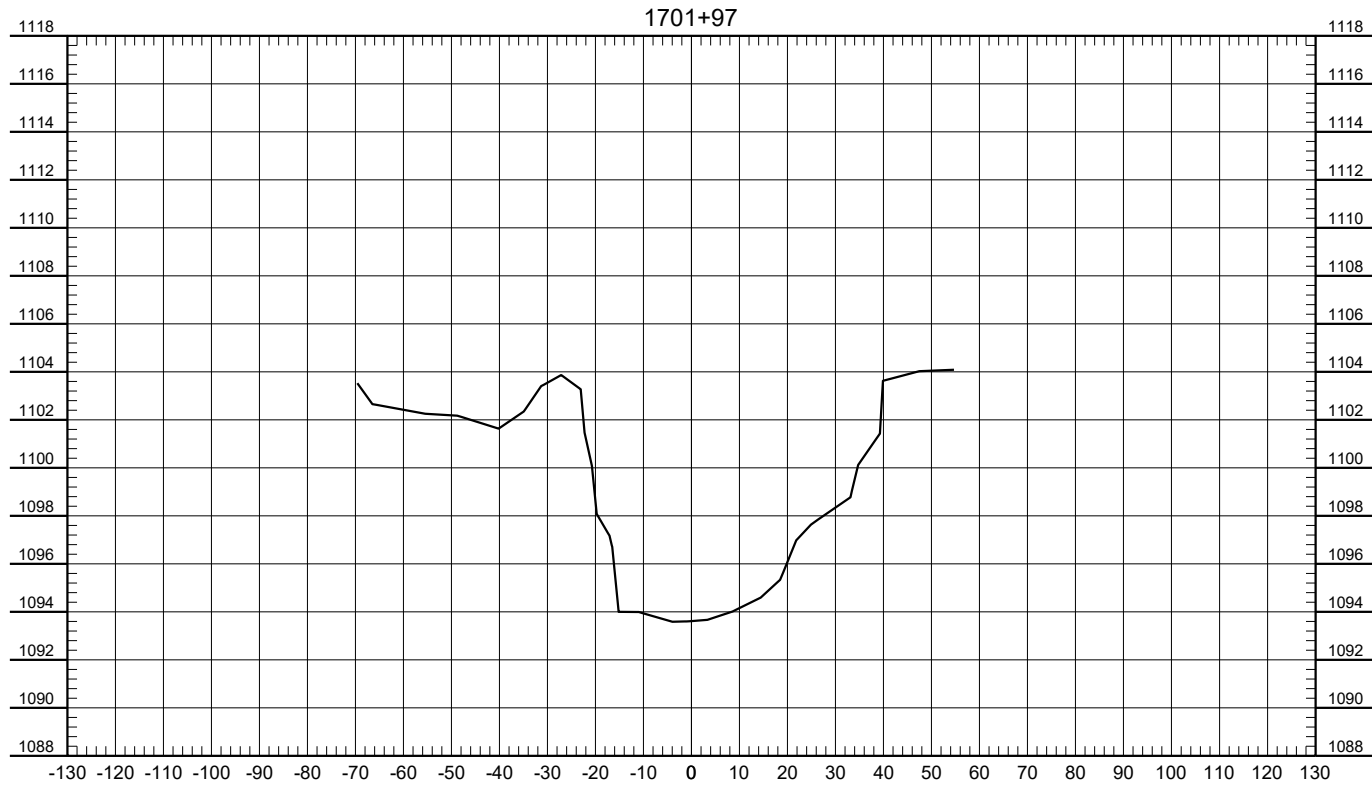
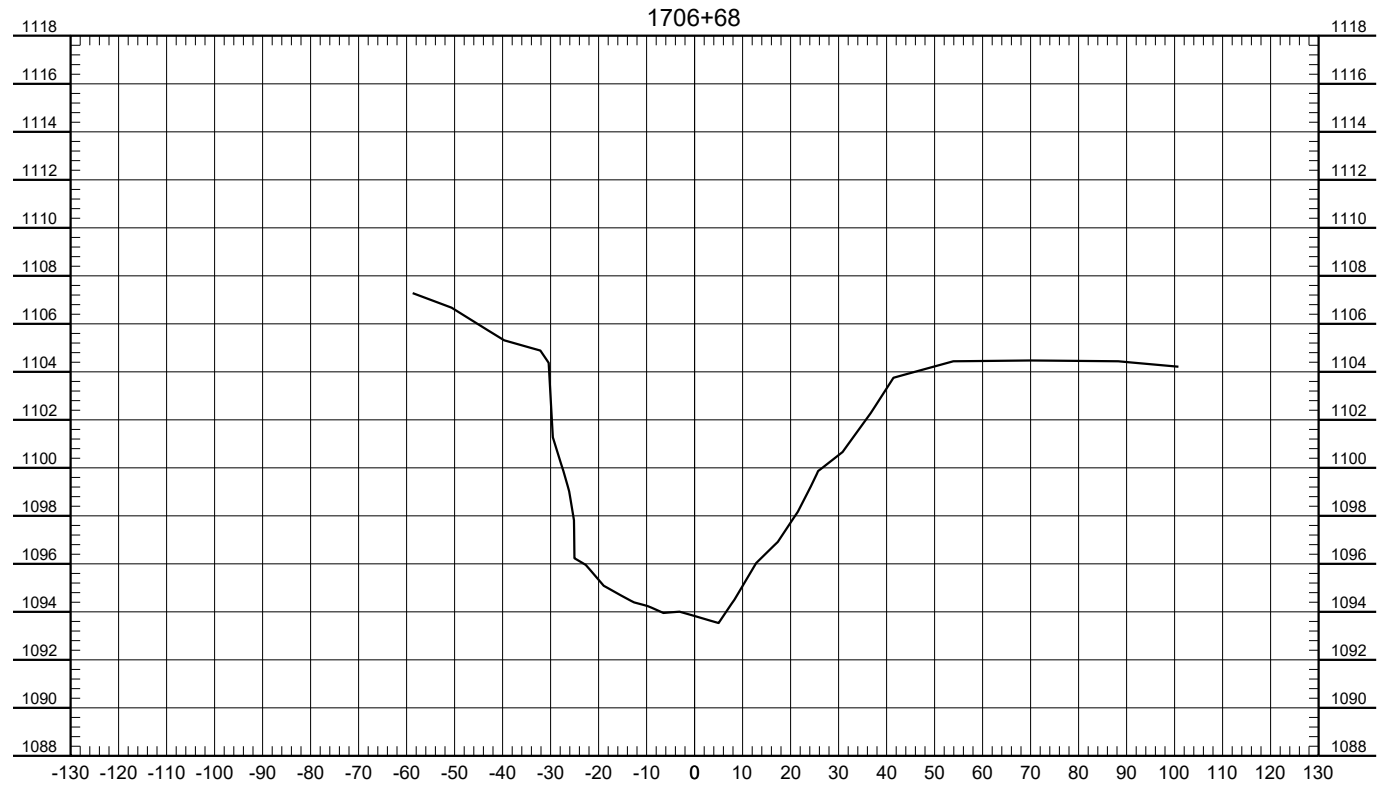
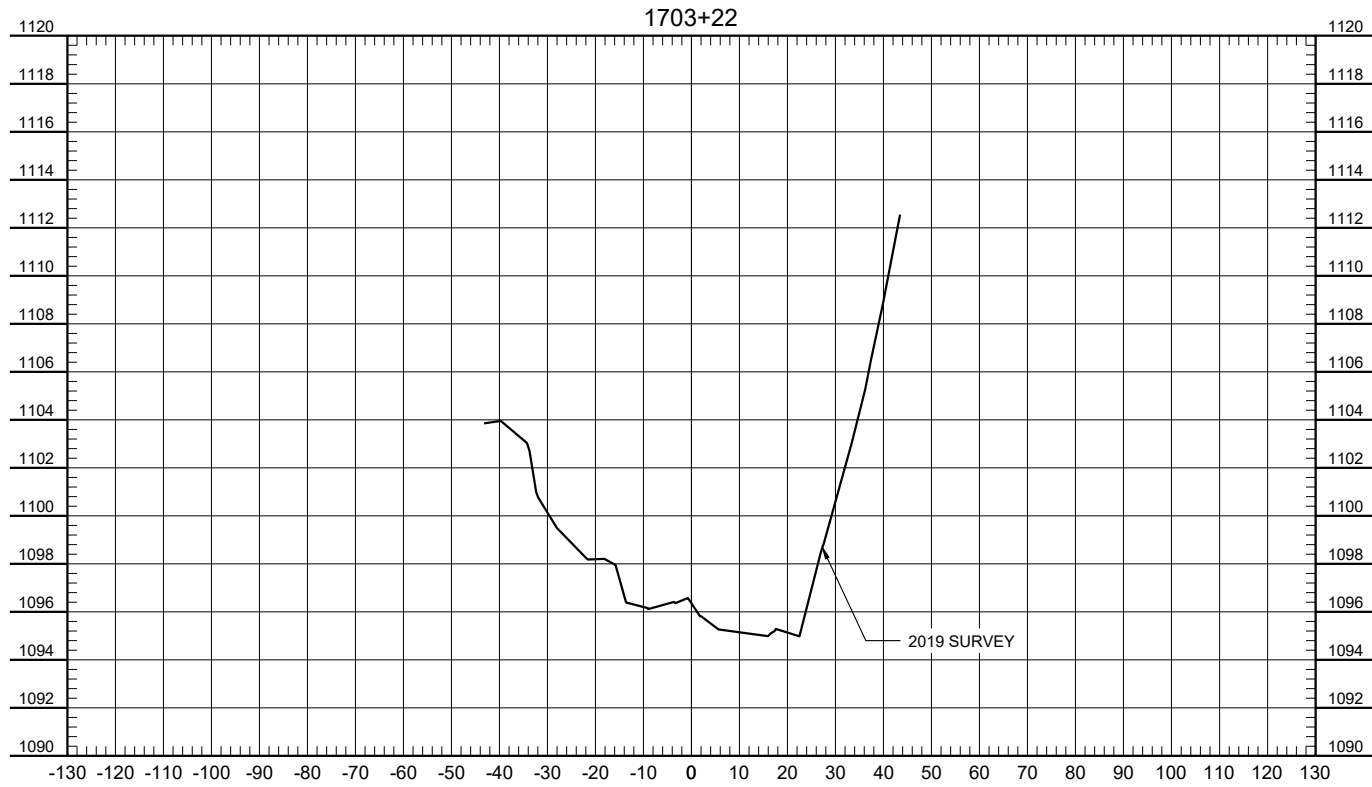
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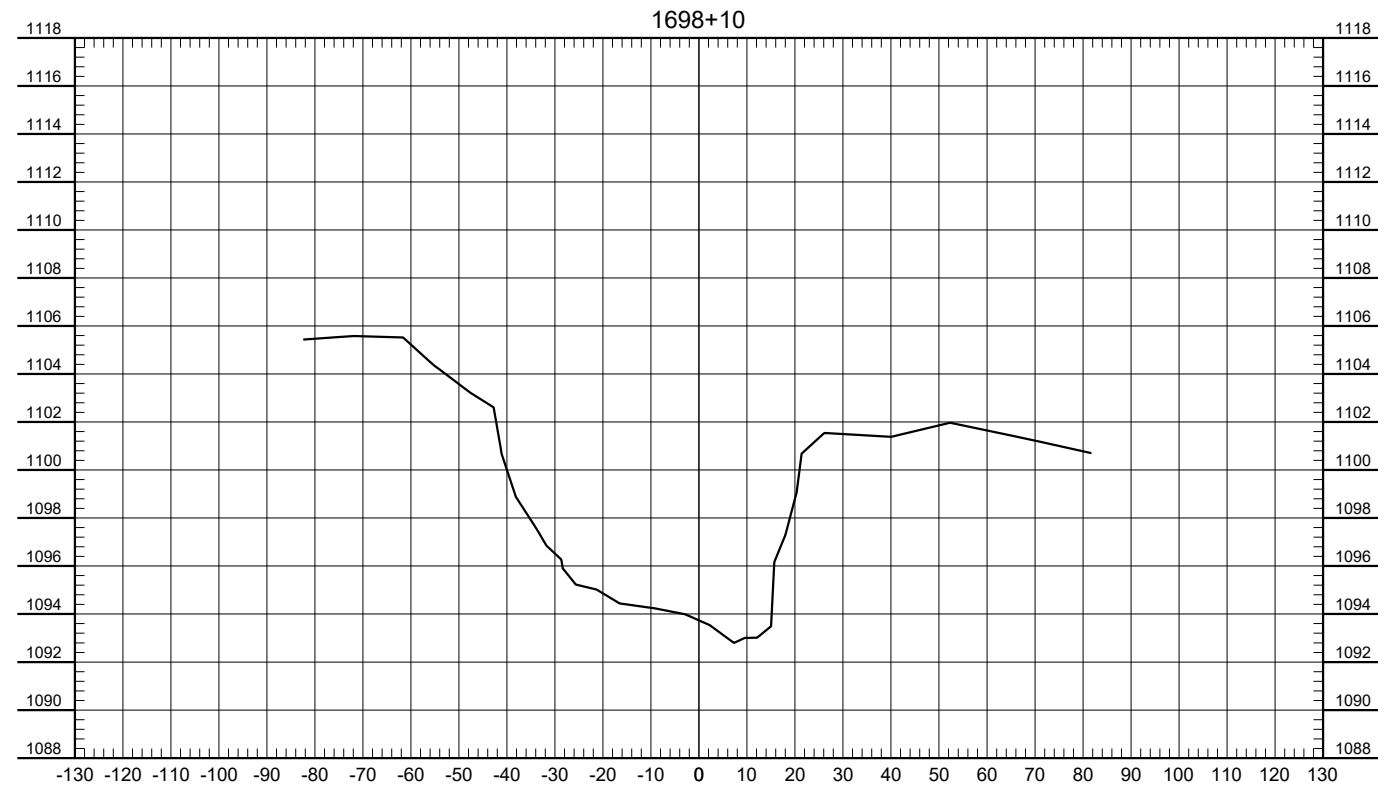
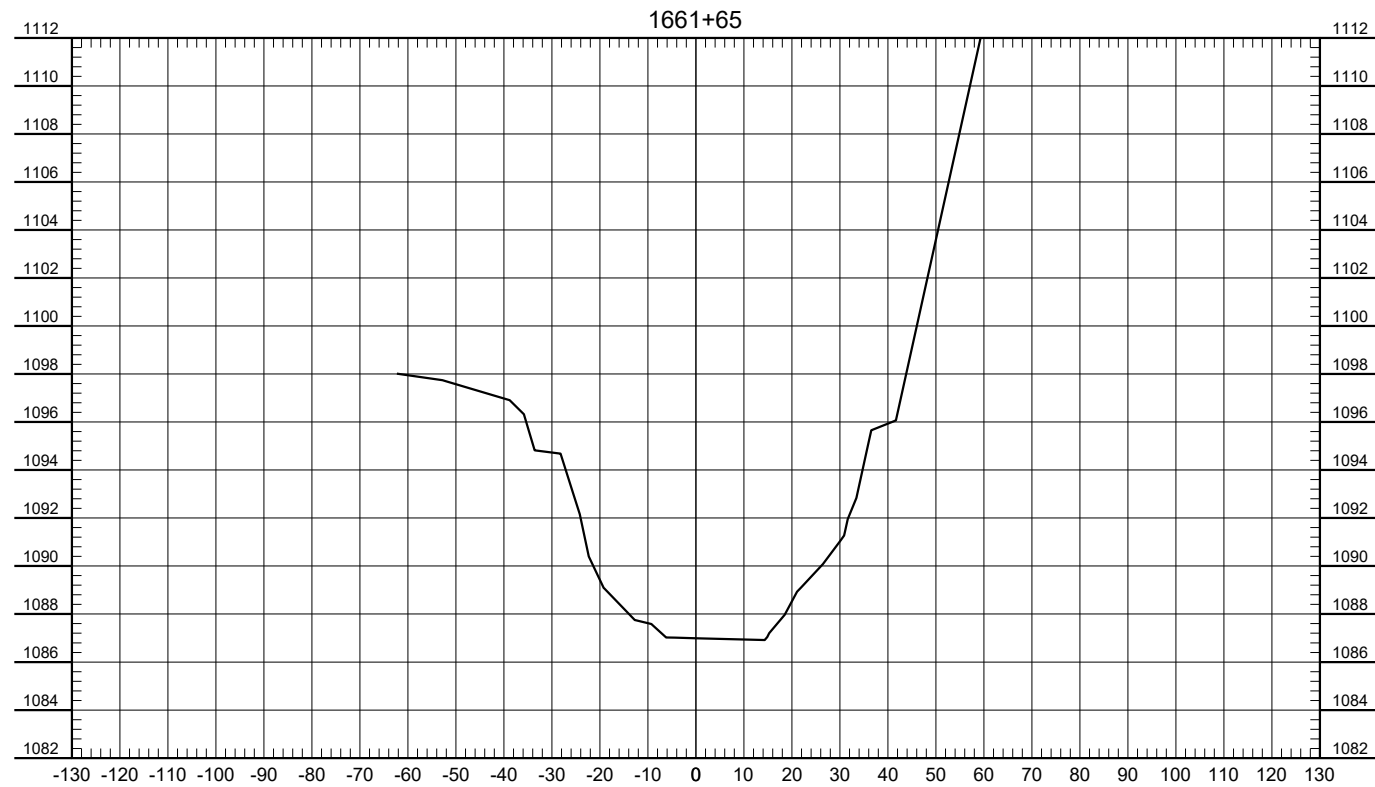
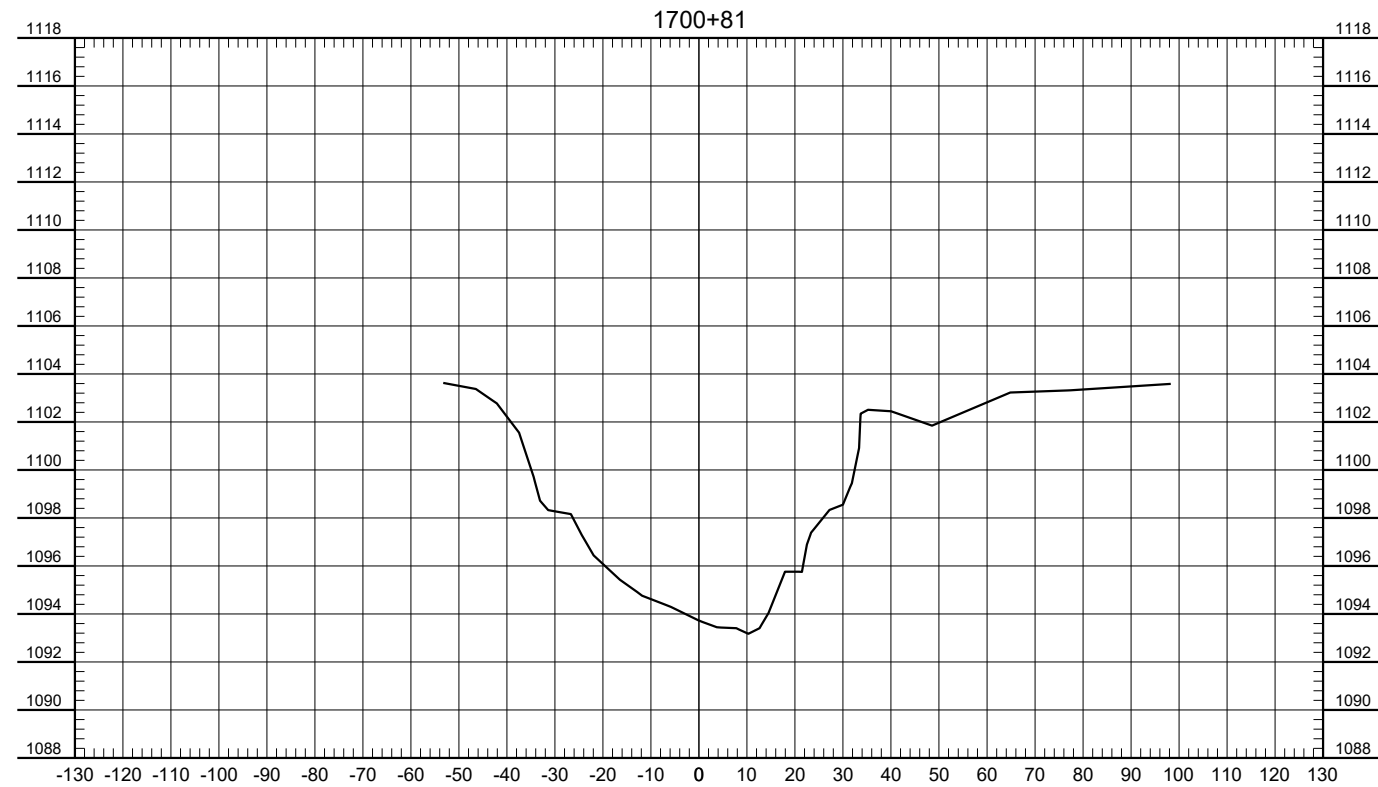
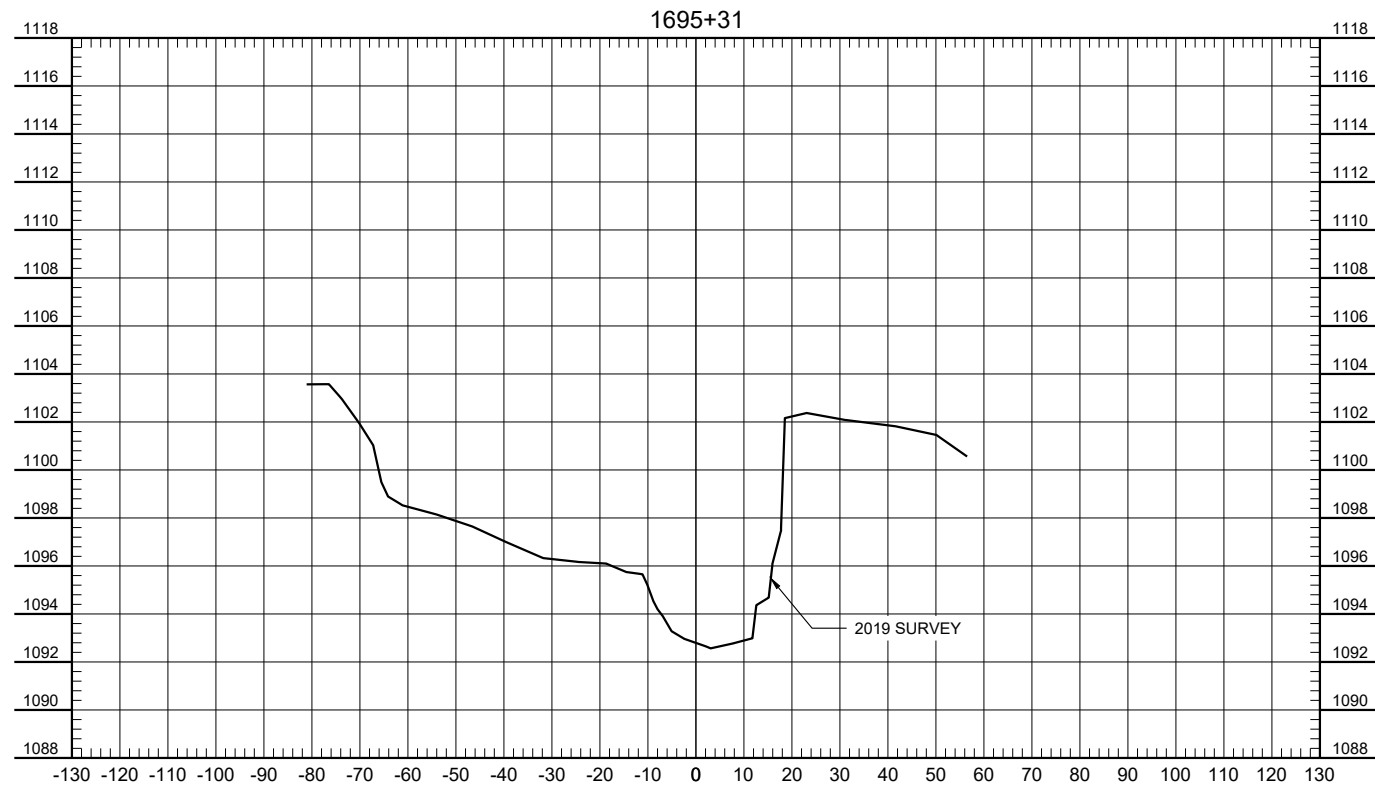
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GLB

Date
4-28-2020

Scale
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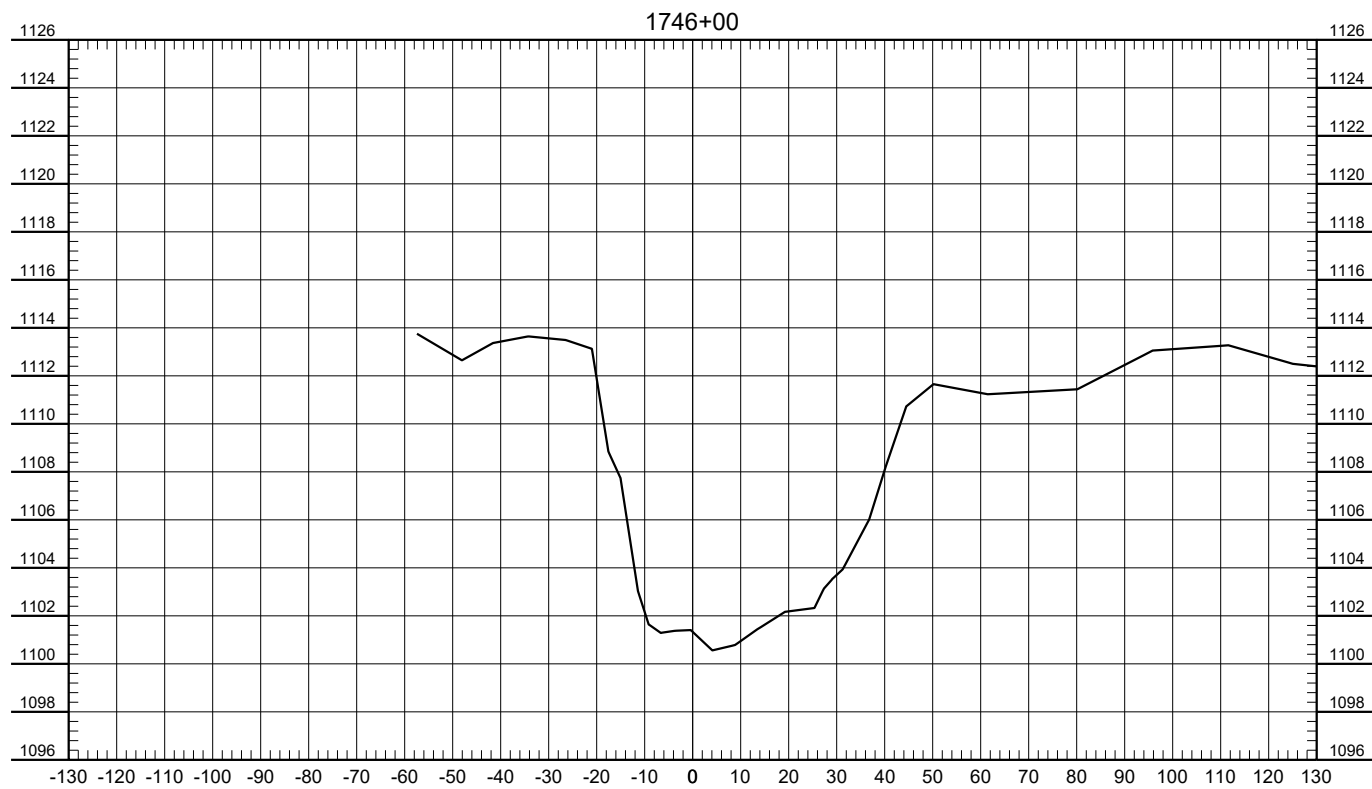
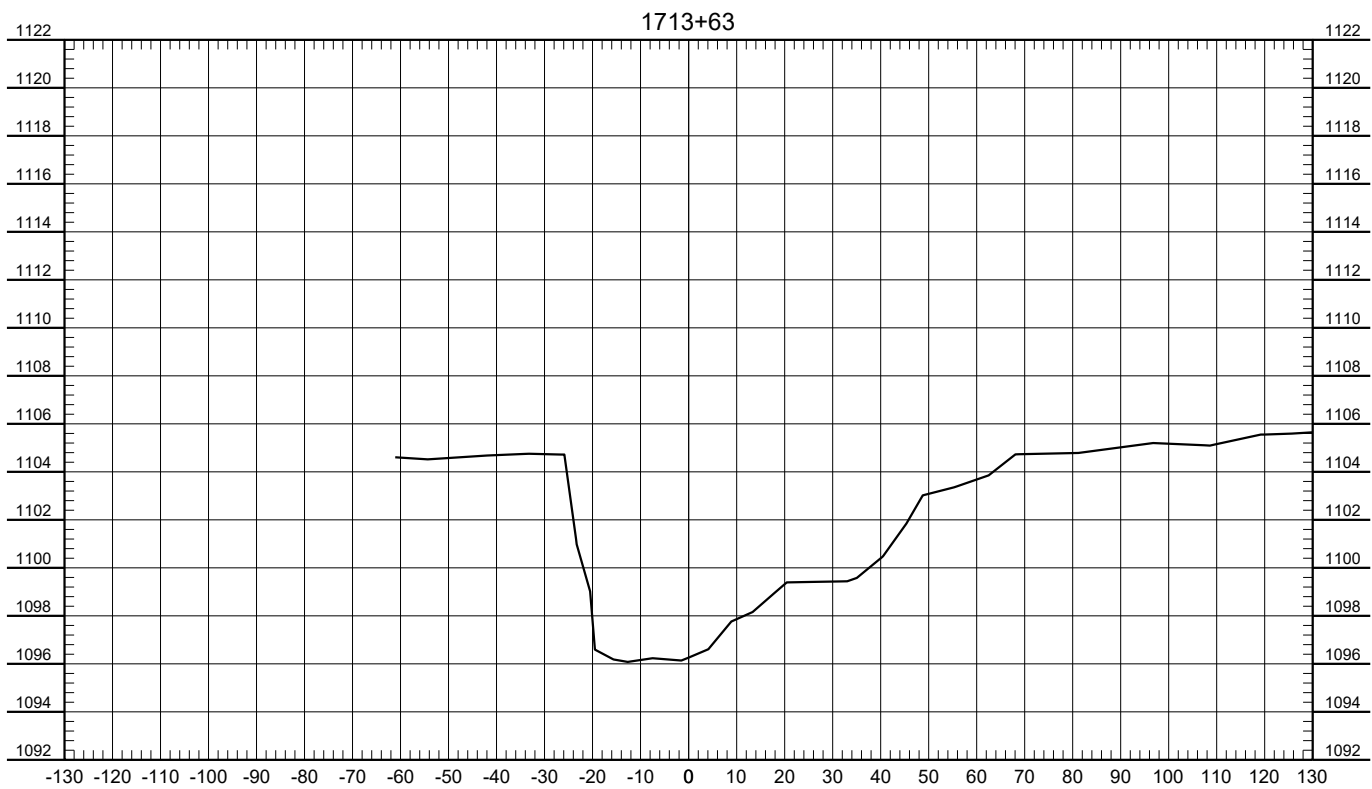
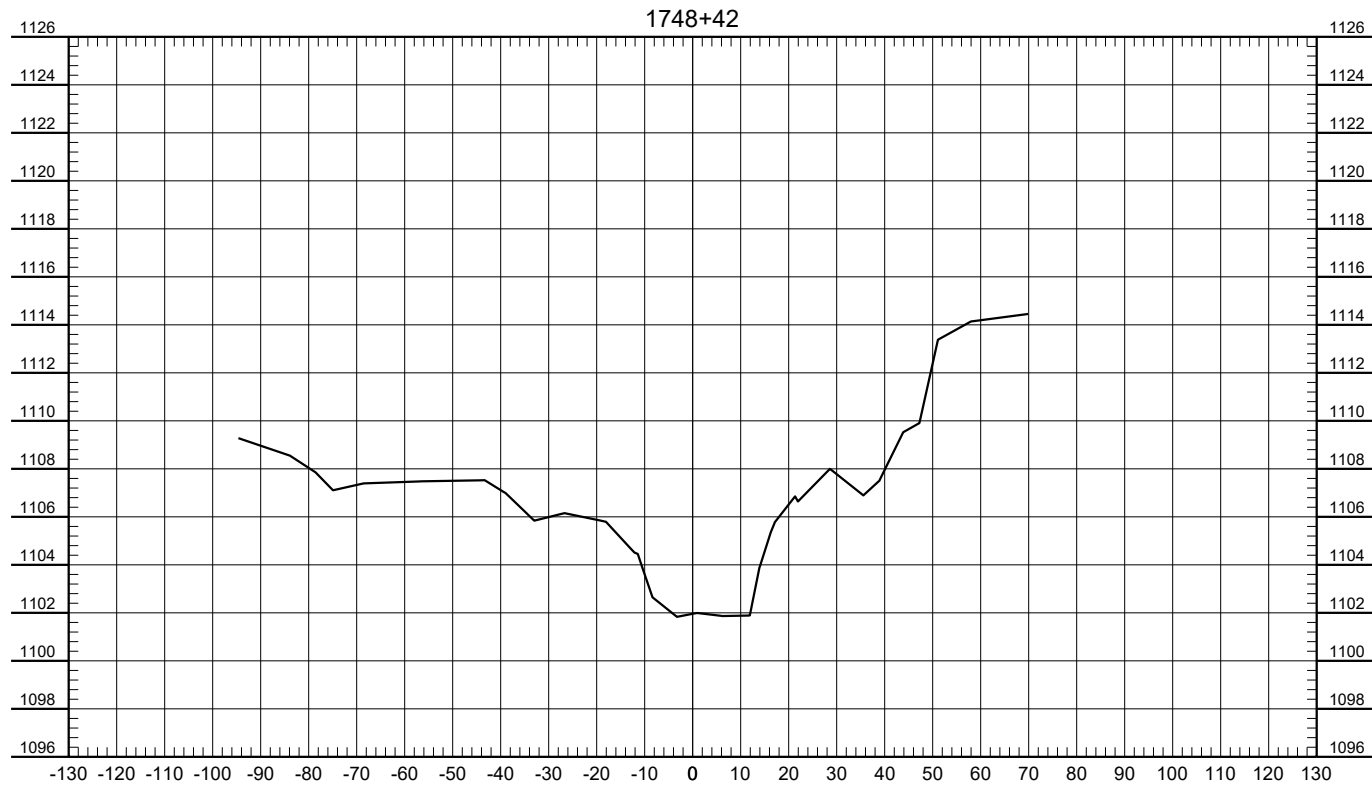
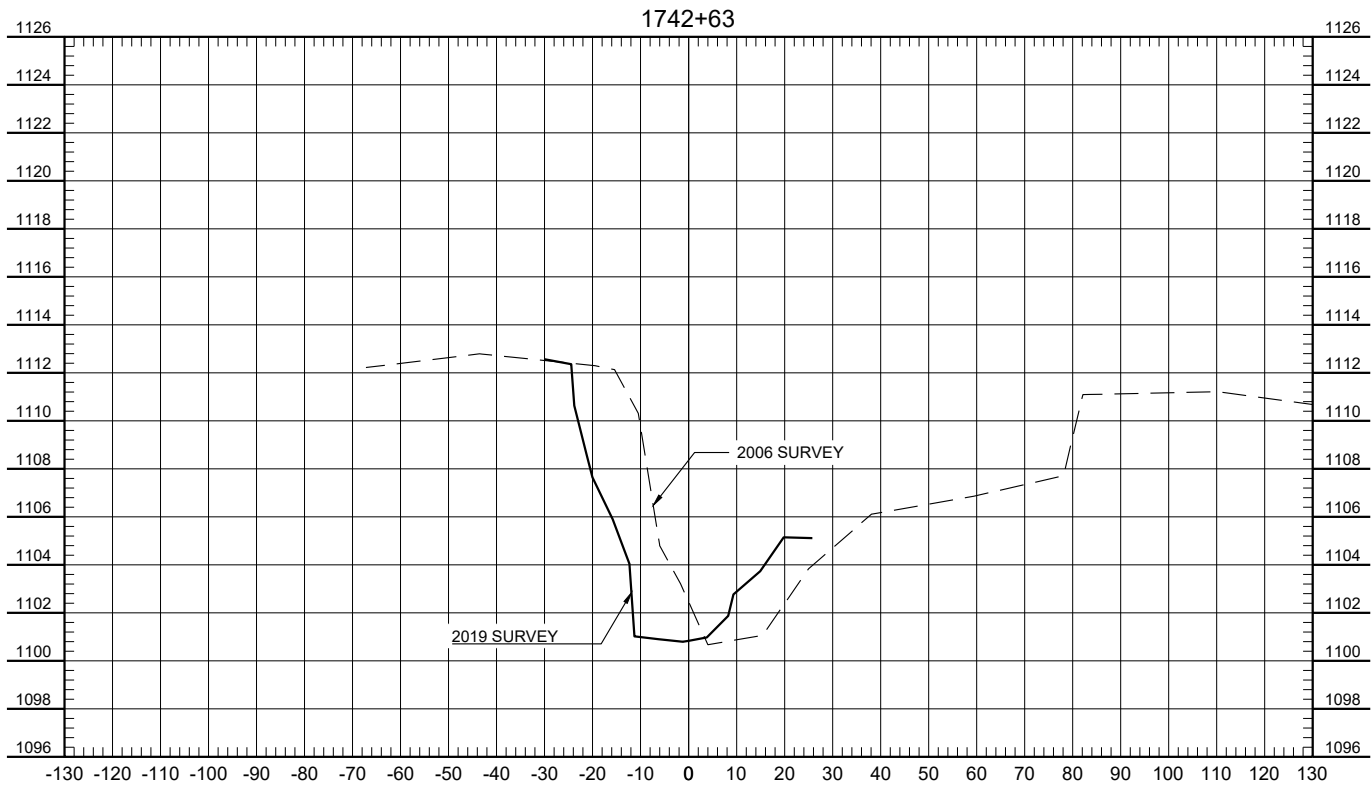
SOUTH BRANCH WILD RICE RIVER INVESTIGATION
WILD RICE WATERSHED DISTRICT
NORMAN COUNTY & CLAY COUNTY

EXISTING CROSS SECTIONS

PROJECT NO. 1432-0365

SHEET

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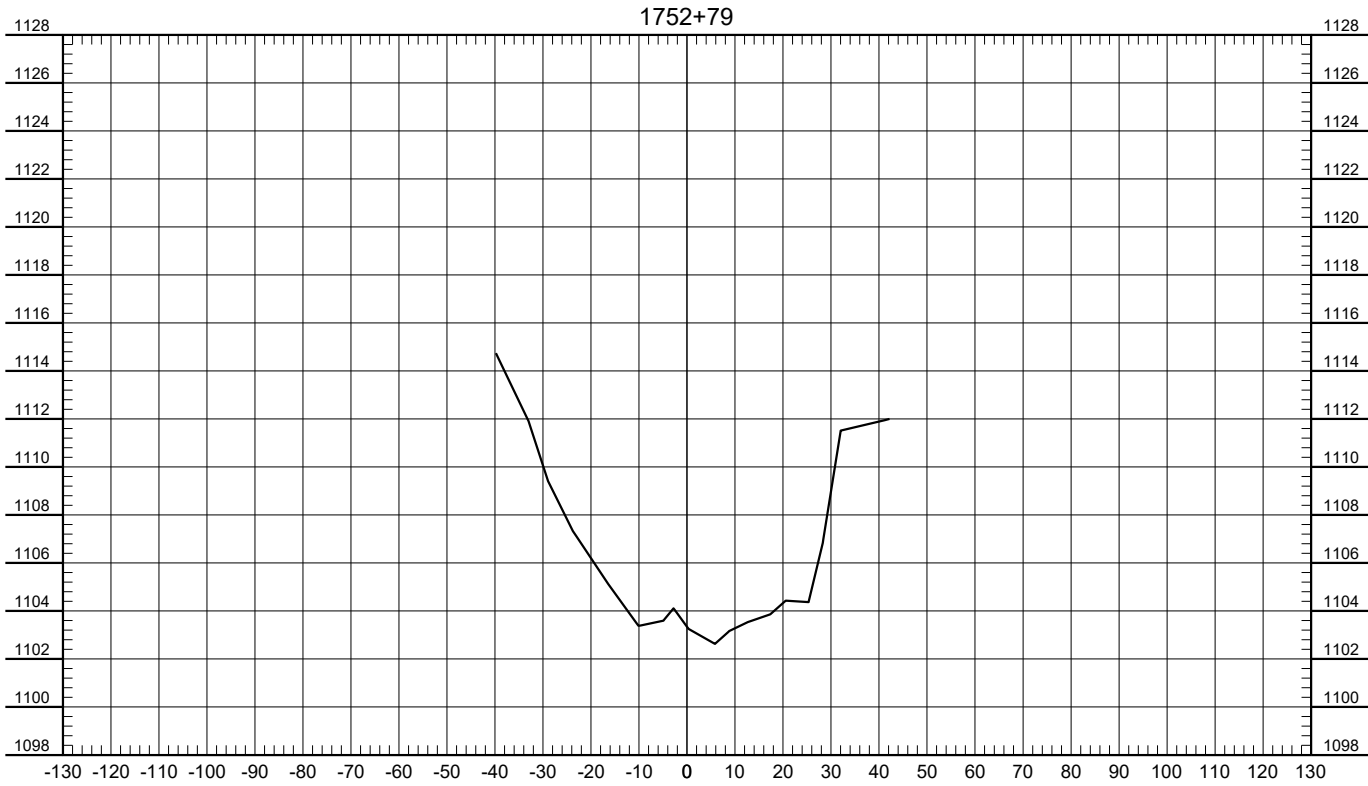
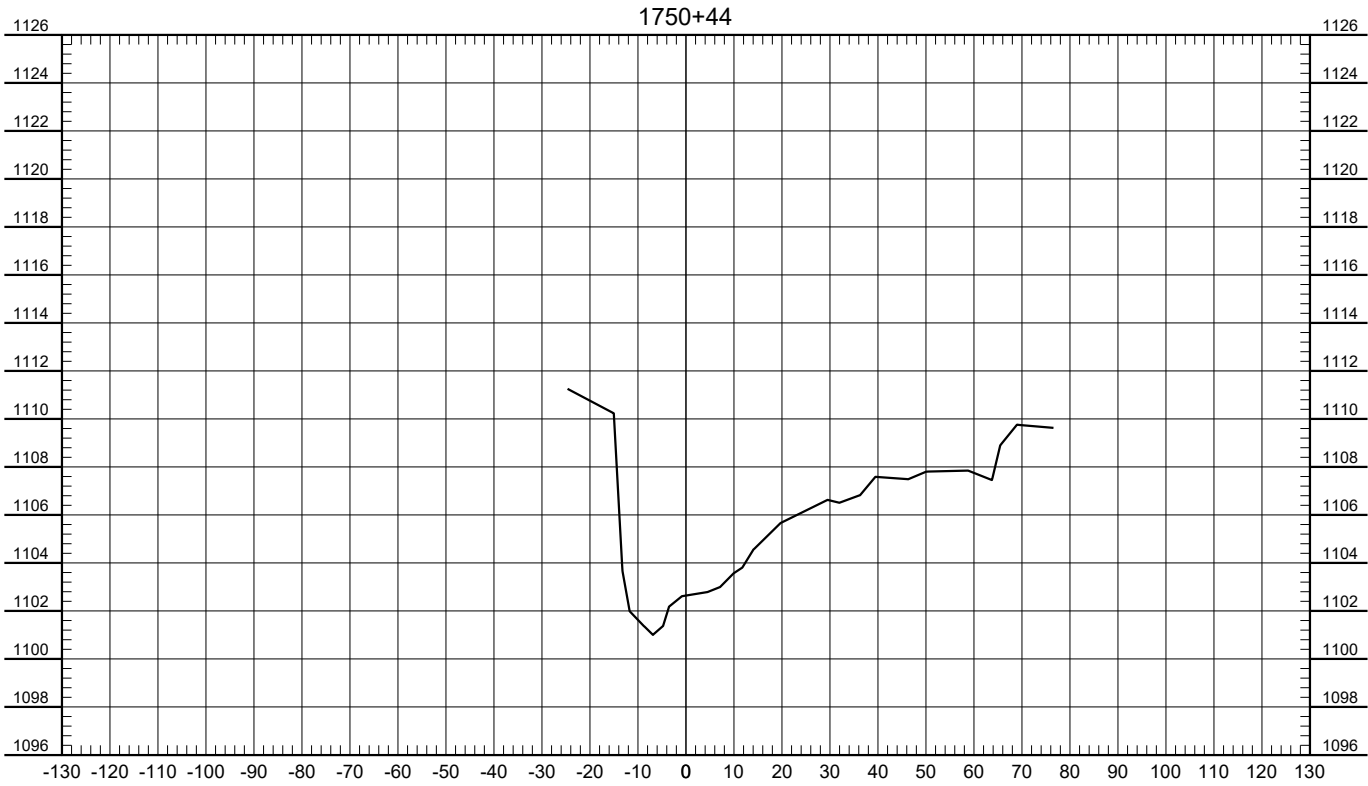
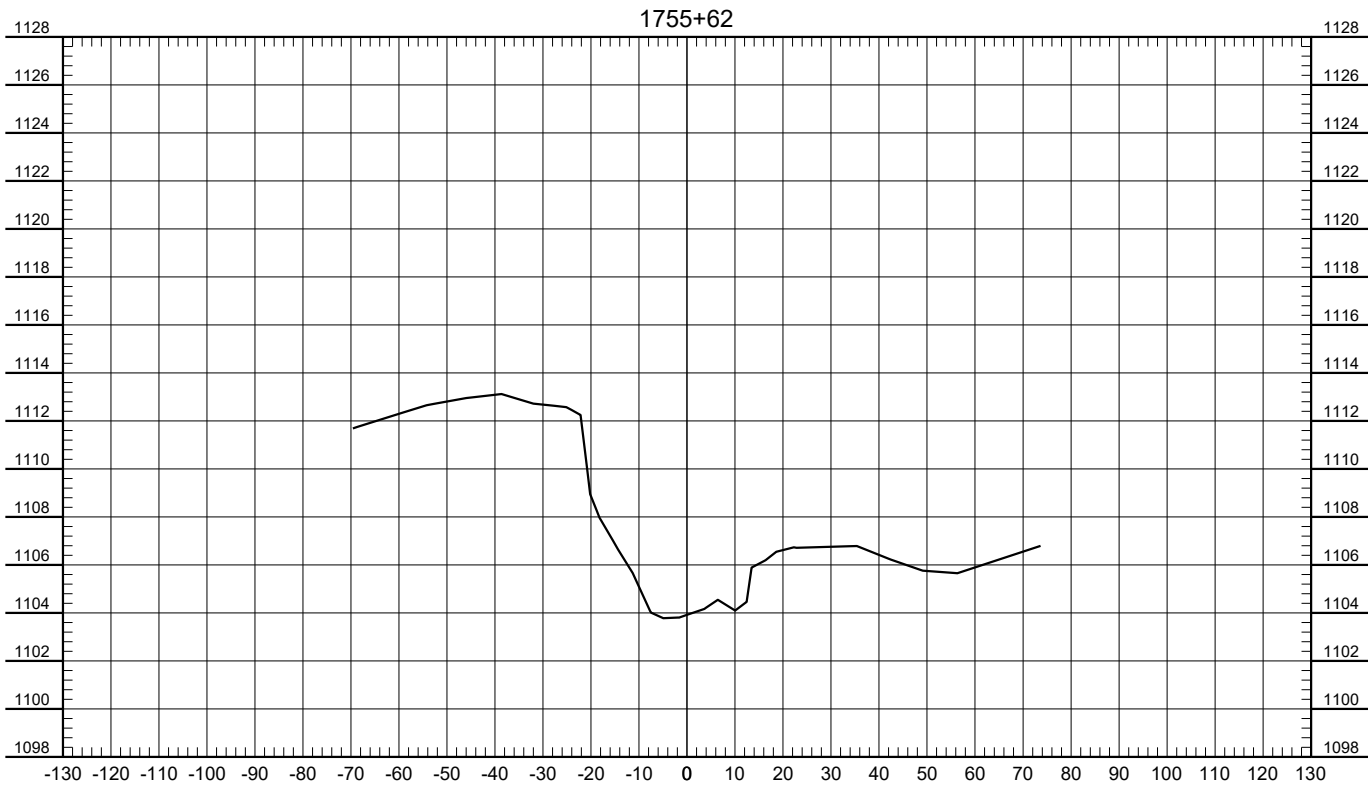
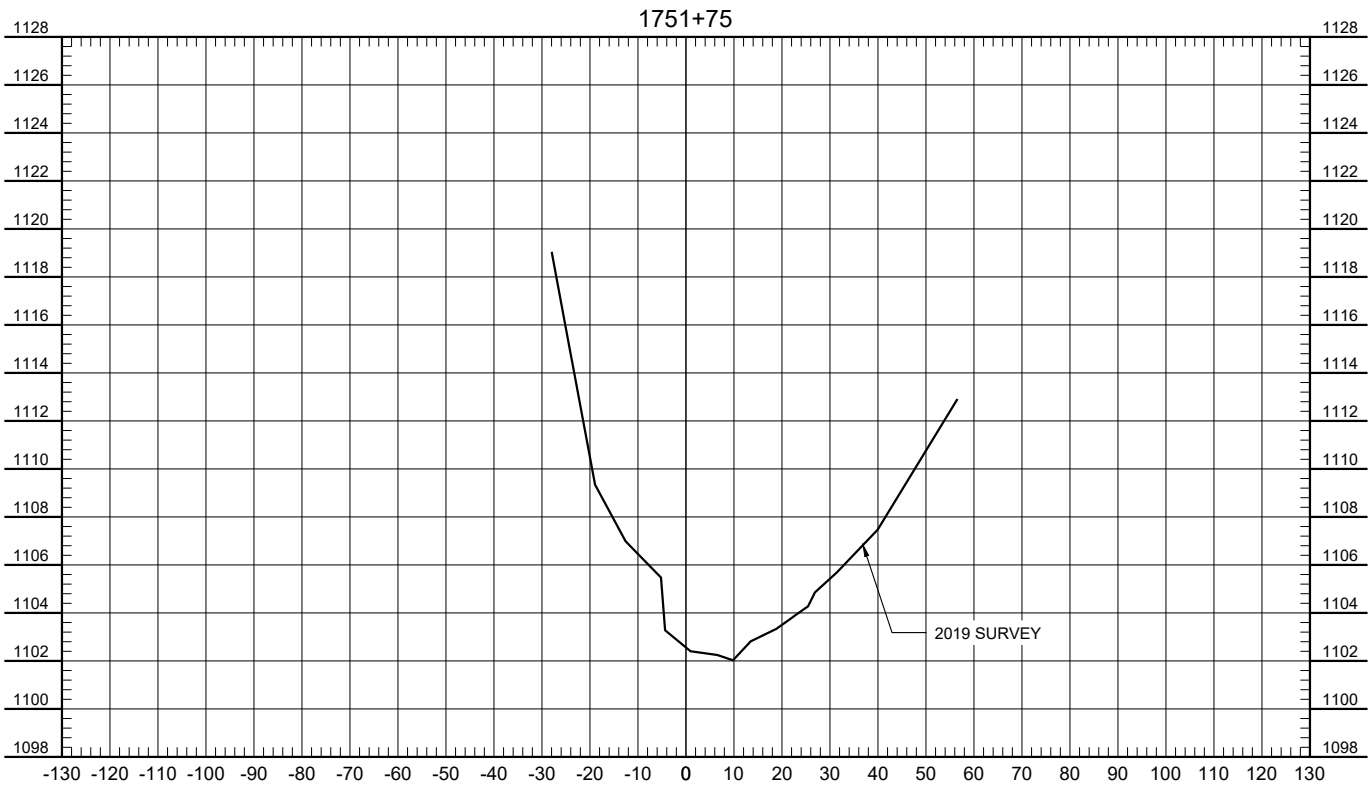
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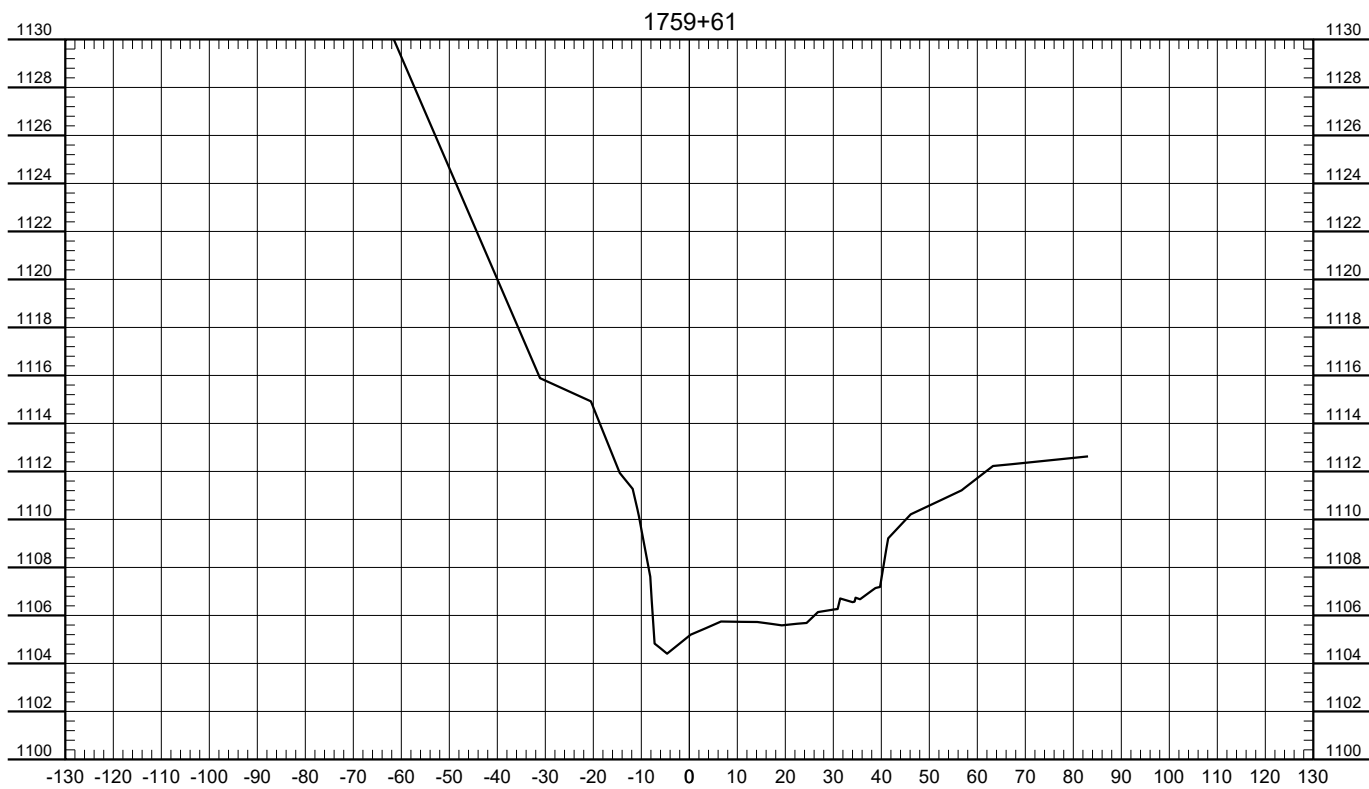
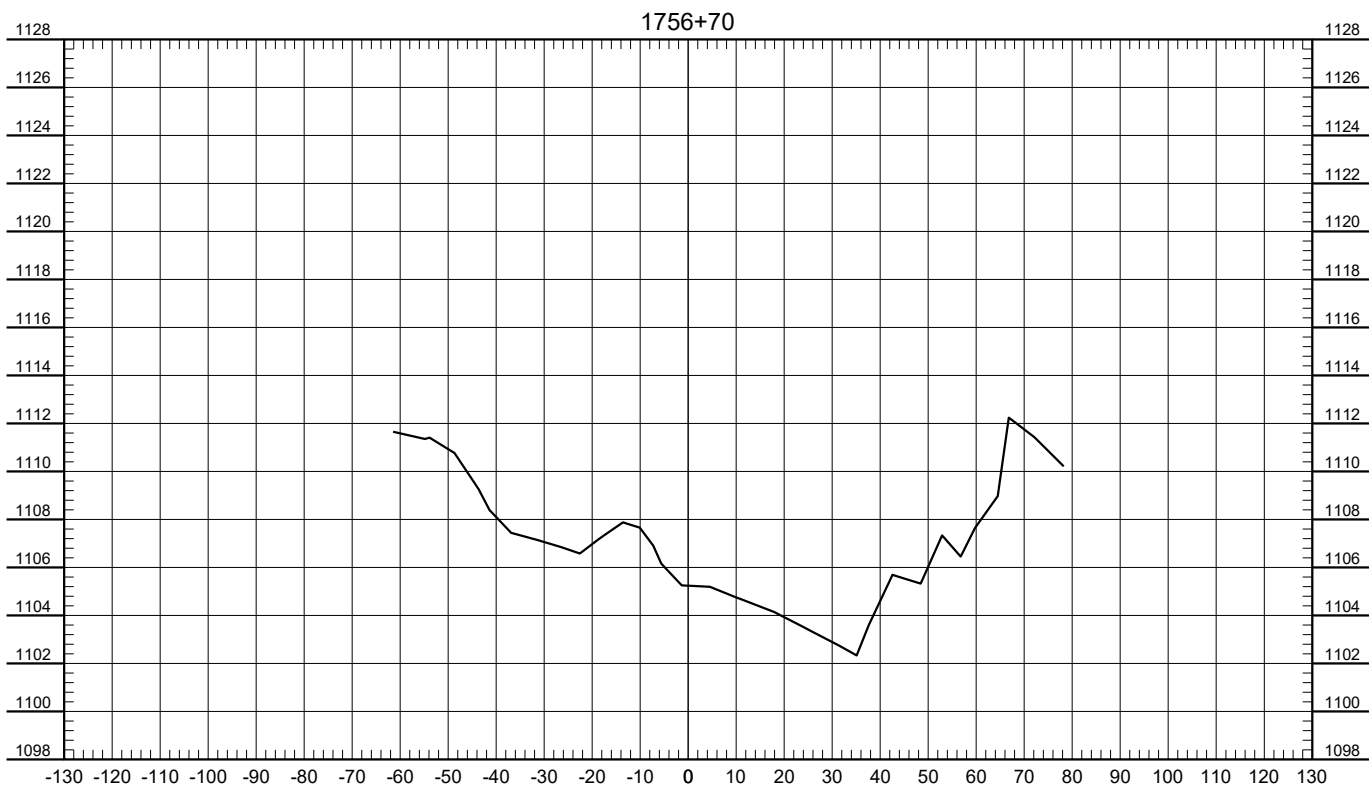
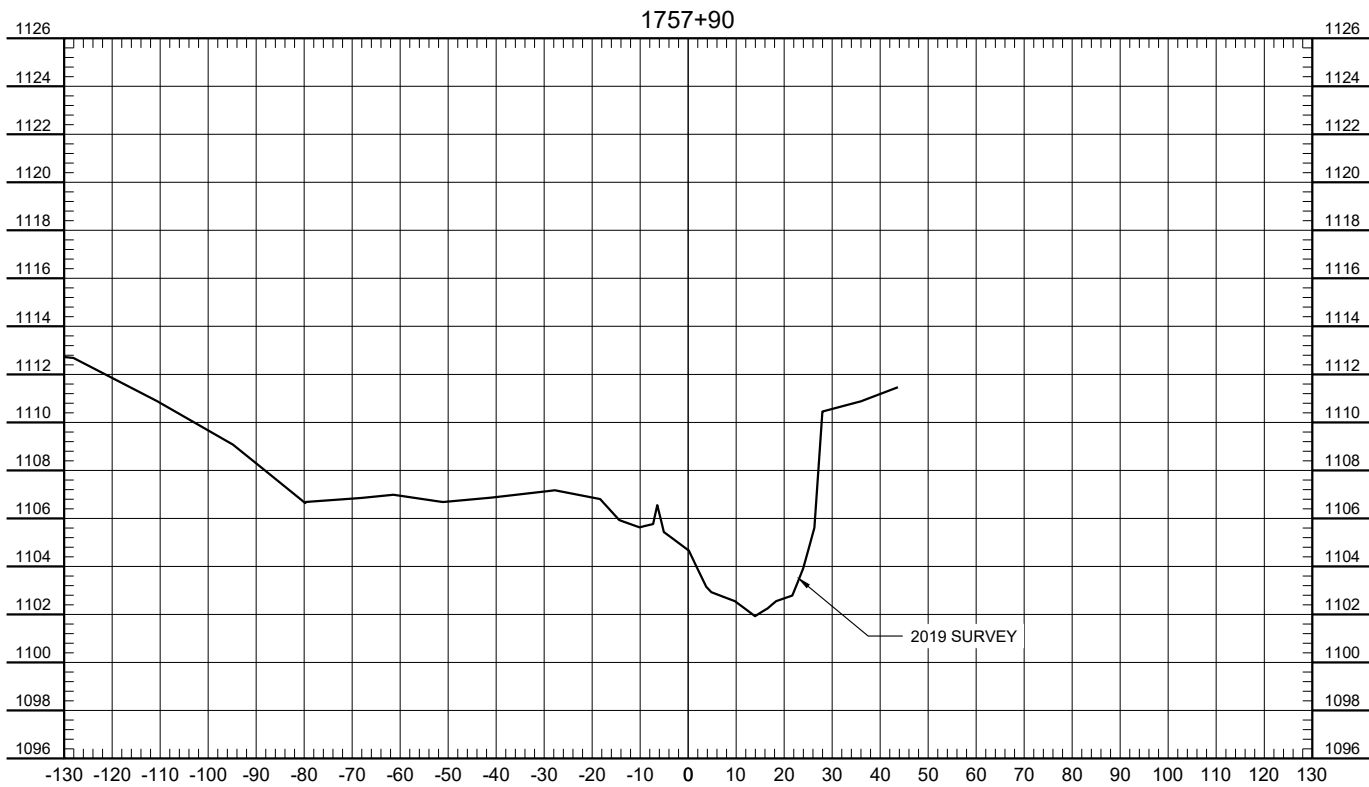
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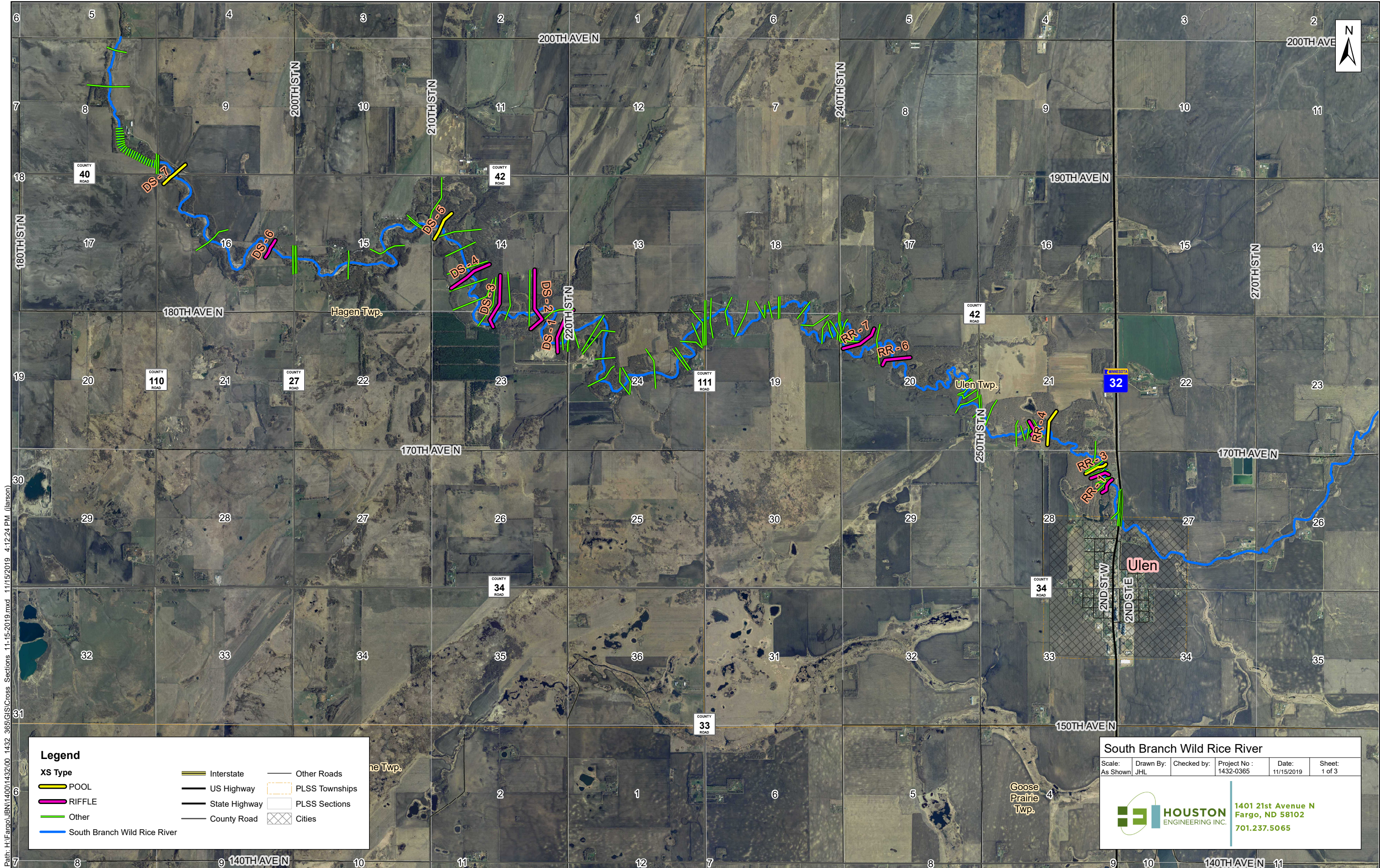


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P: 701.237.5065 F: 701.237.5101	Checked by GLB	Scale AS SHOWN			



APPENDIX C

Stream Classification Maps and Cross Sections



Legend

XS Type
POOL
RIFFLE
Other
South Branch Wild Rice River

Interstate
 US Highway
 State Highway
 County Road

PLSS Townships
 PLSS Sections
 Cities

South Branch Wild Rice River

Scale: As Shown

Drawn By: JHL

Checked by:

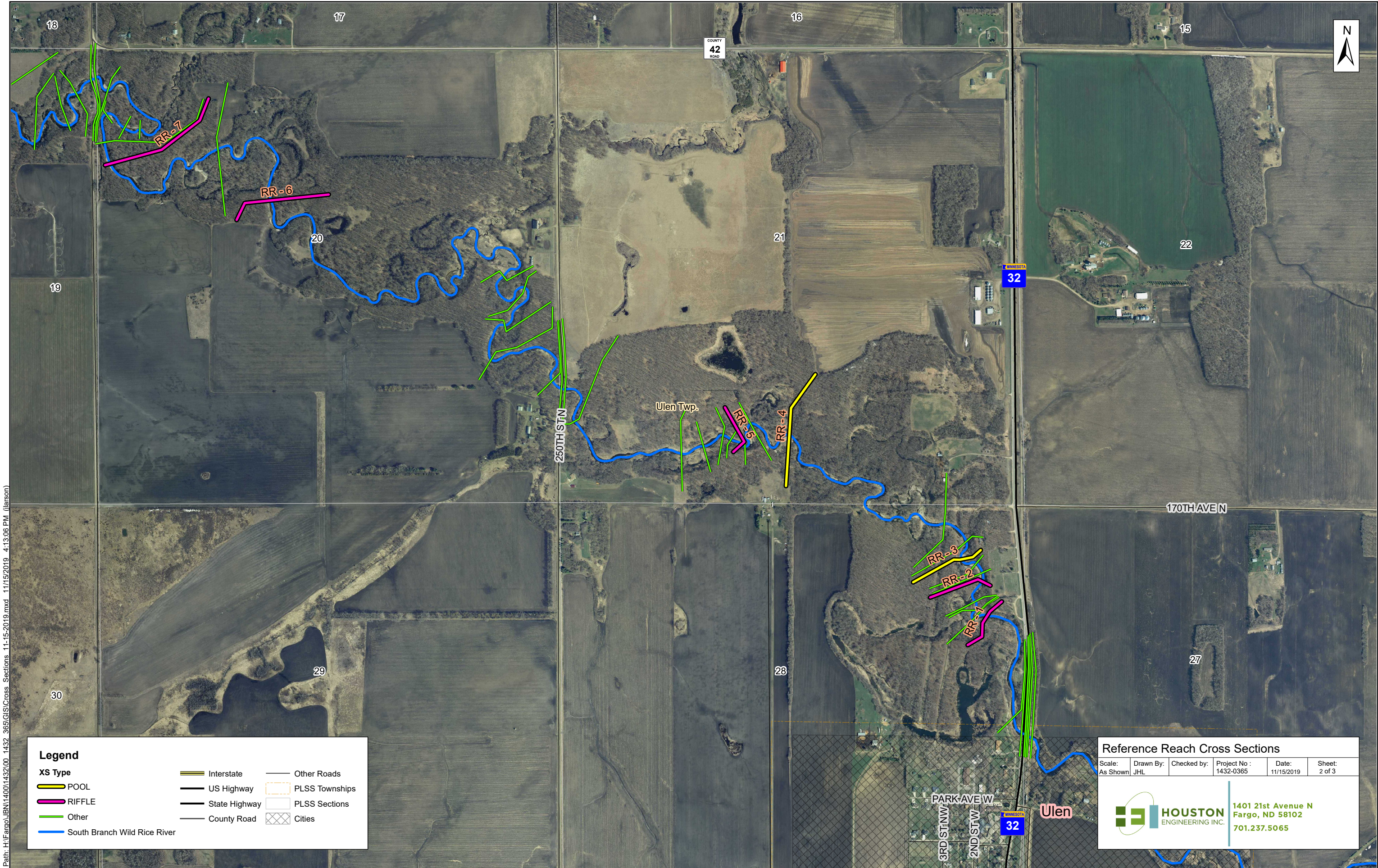
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Date: 11/15/2019

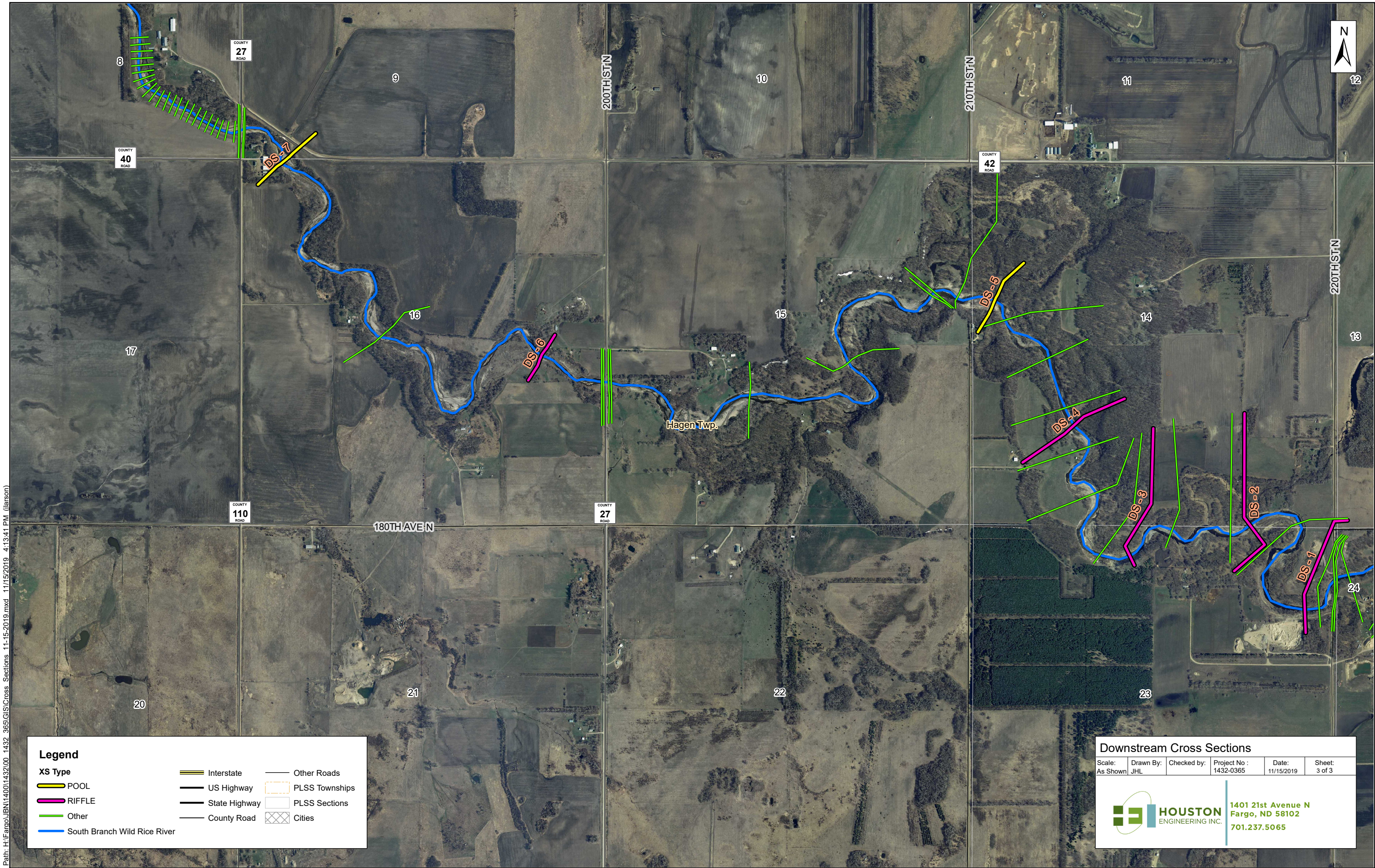
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HOUSTON
ENGINEERING INC.

1401 21st Avenue N
Fargo, ND 58102
701.237.5065



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Legend

XS Type
POOL
RIFFLE
Other
South Branch Wild Rice River

Interstate
 US Highway
 State Highway
 County Road

Other Roads
 PLSS Townships
 PLSS Sections
 Cities

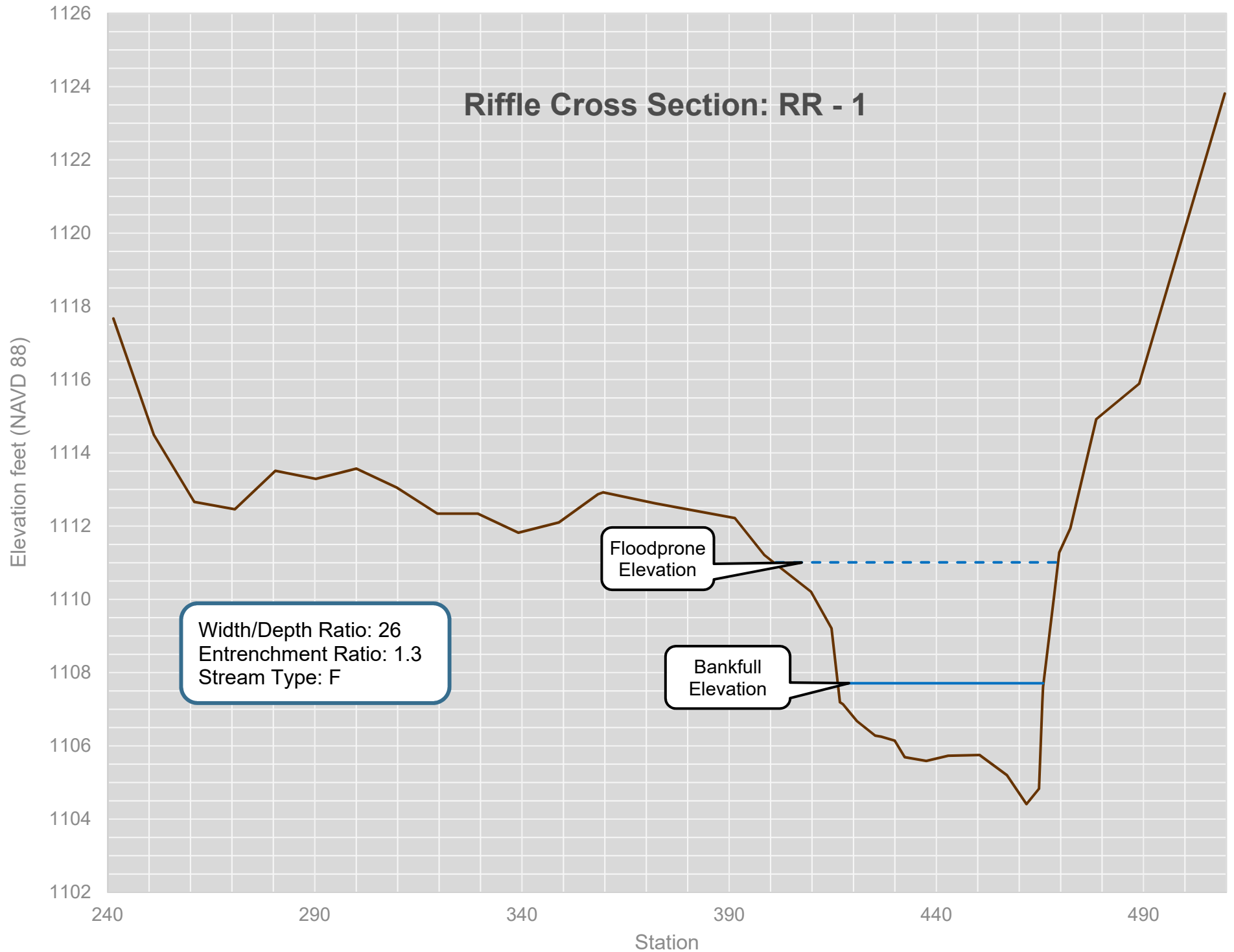
Downstream Cross Sections

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HOUSTON
ENGINEERING INC.

1401 21st Avenue N
Fargo, ND 58102
701.237.5065

Riffle Cross Section: RR - 1



Riffle Cross Section: RR - 2

Elevation feet (NAVD 88)

Floodprone
Elevation

Bankfull
Elevation

Width/Depth Ratio: 18
Entrenchment Ratio: 1.1
Stream Type: F

1116

1114

1112

1110

1108

1106

1104

1102

440

490

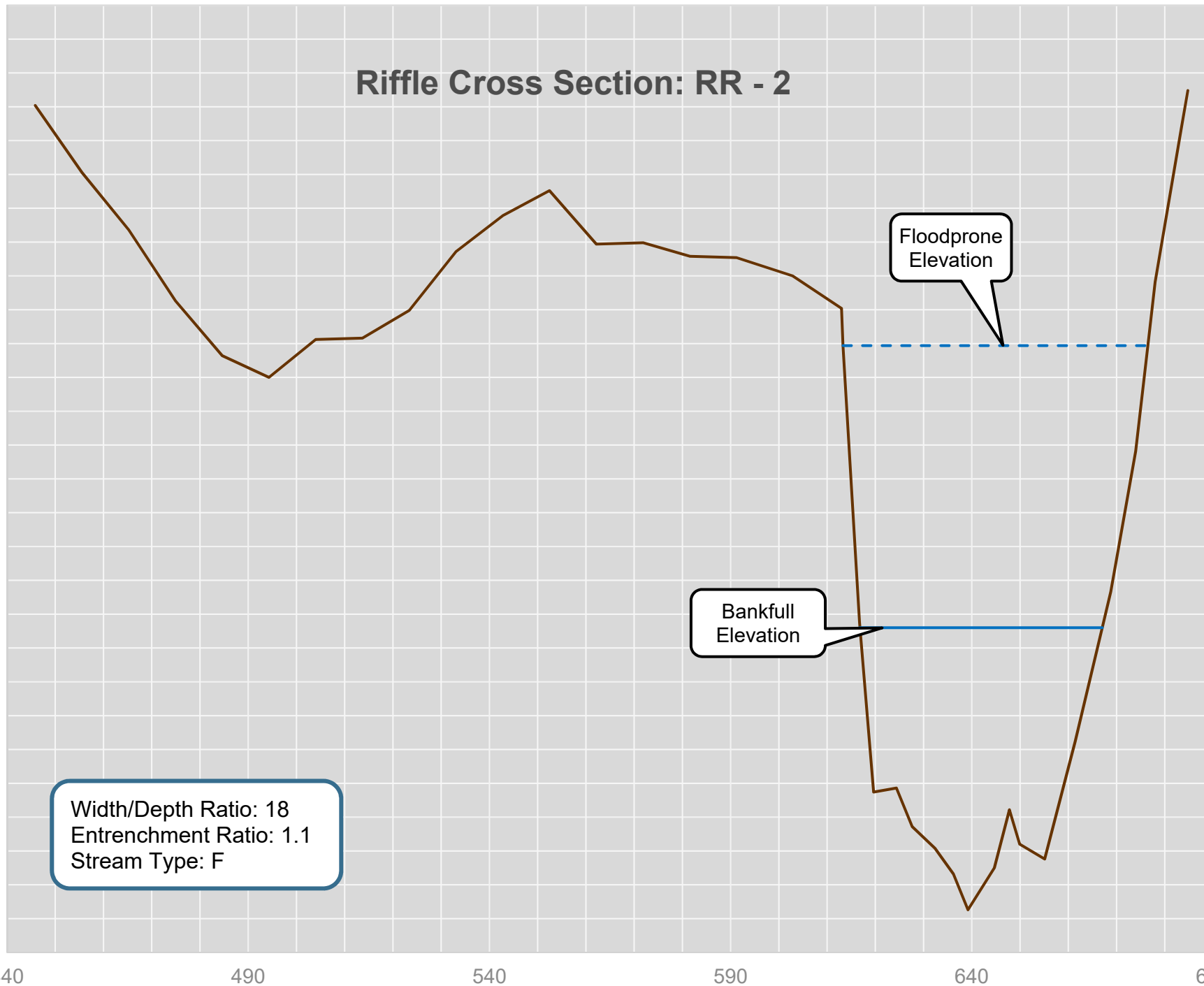
540

590

640

690

Station (feet)



Pool Cross Section: RR - 3

Elevation feet (NAVD 88)

Bankfull
Elevation

Mean Bankfull Depth: 2.5 ft
Bankfull Discharge: 328 cfs
Max Depth: 4.3
Radius of Curvature: 79 ft

1114
1112
1110
1108
1106
1104
1102
1100

570

590

610

630

650

670

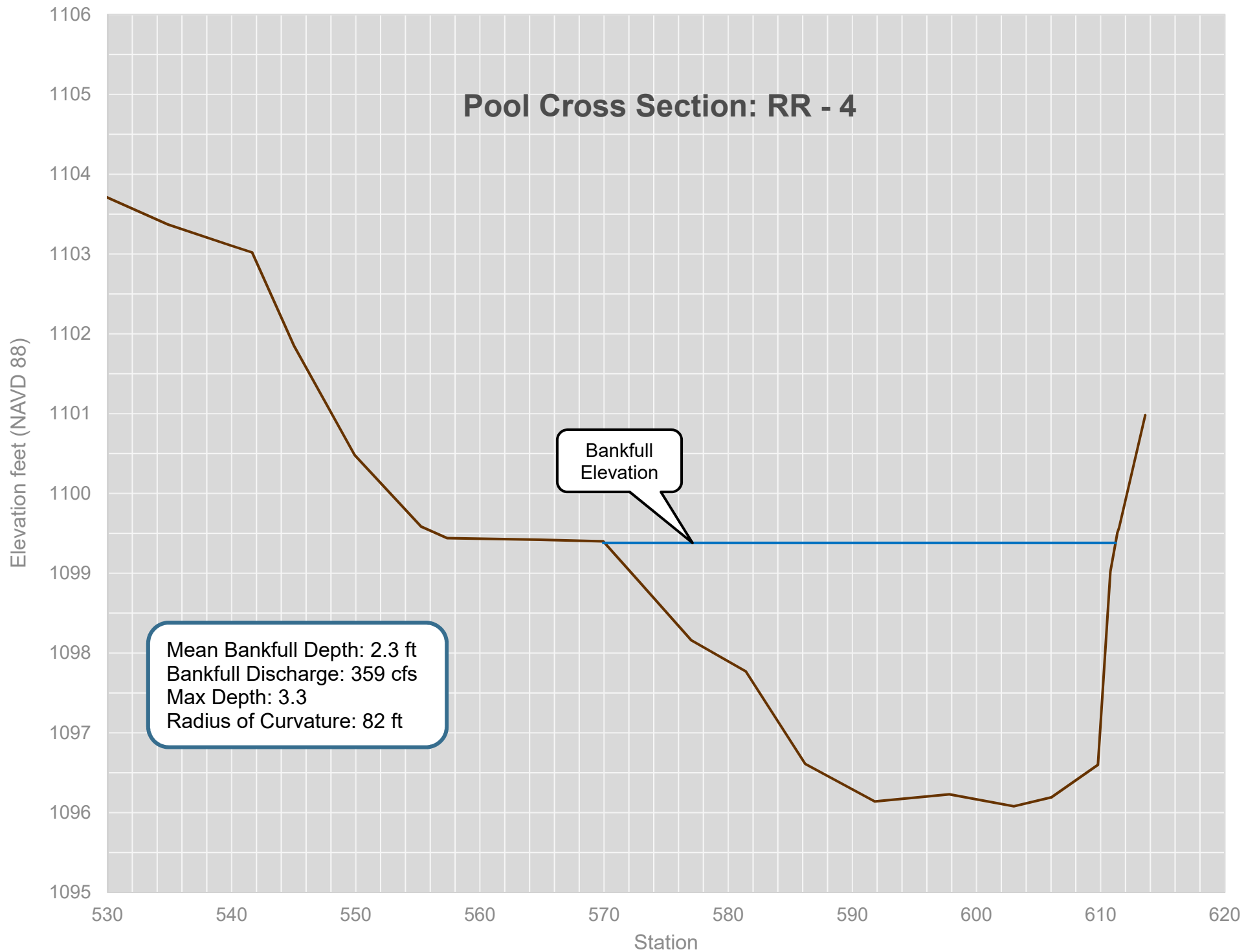
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710

730

Station

Pool Cross Section: RR - 4



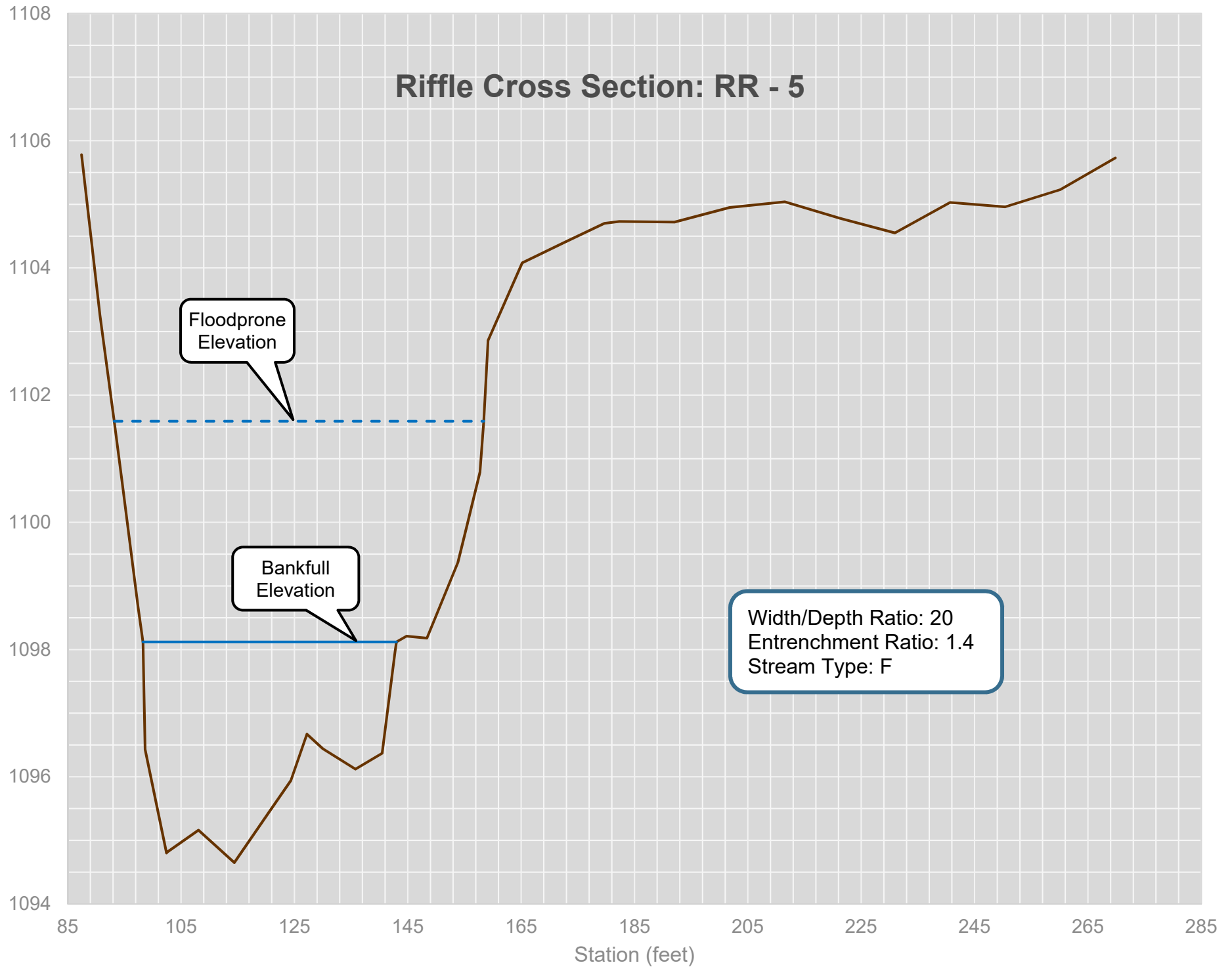
Riffle Cross Section: RR - 5

Elevation feet (NAVD 88)

Floodprone
Elevation

Bankfull
Elevation

Width/Depth Ratio: 20
Entrenchment Ratio: 1.4
Stream Type: F



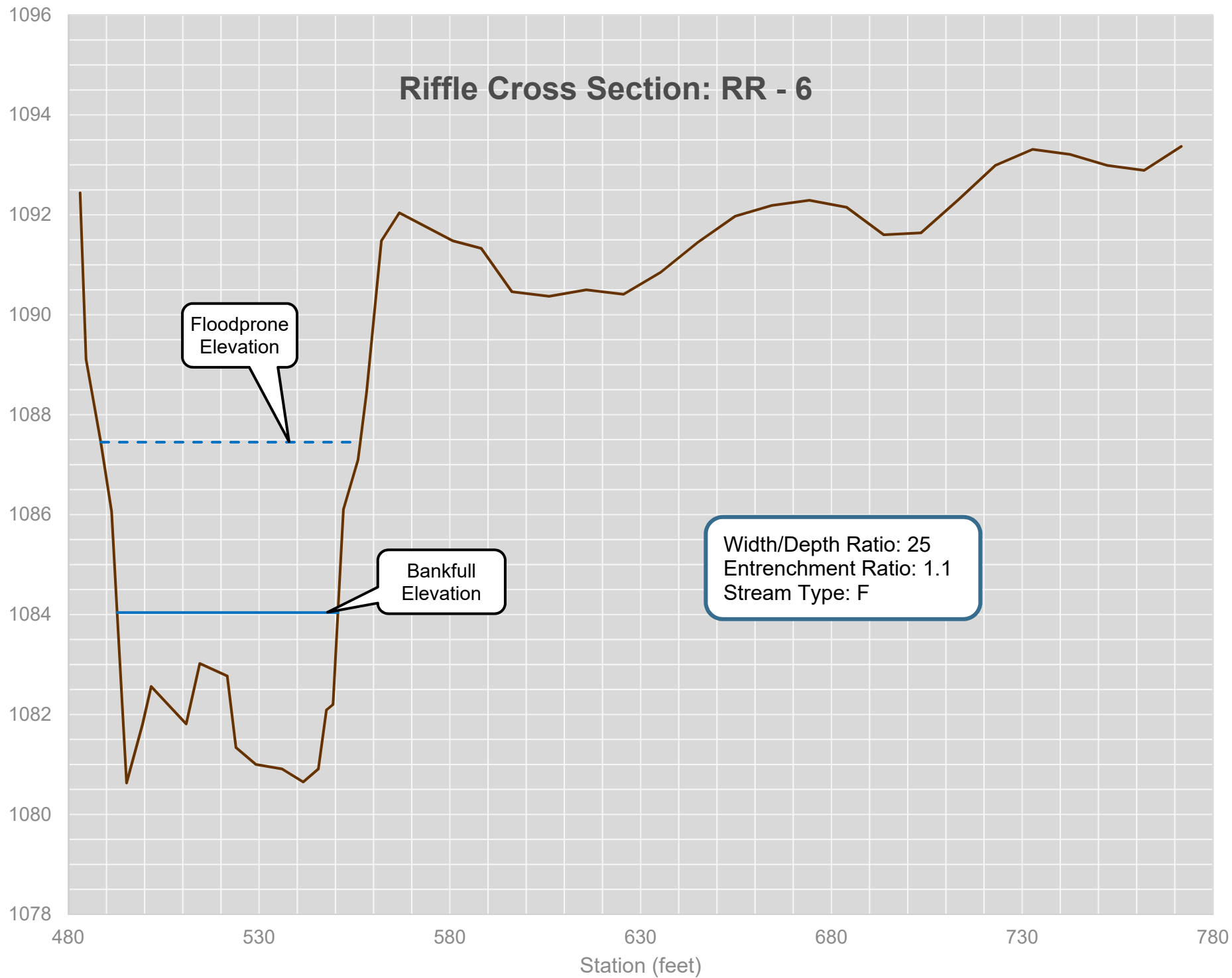
Riffle Cross Section: RR - 6

Elevation feet (NAVD 88)

Floodprone
Elevation

Bankfull
Elevation

Width/Depth Ratio: 25
Entrenchment Ratio: 1.1
Stream Type: F



Riffle Cross Section: RR - 7

Elevation feet (NAVD 88)

Width/Depth Ratio: 17
Entrenchment Ratio: 1.1
Stream Type: F

Floodprone
Elevation

Bankfull
Elevation

50

150

250

350

450

550

650

Station (feet)

1096
1094
1092
1090
1088
1086
1084
1082
1080
1078
1076
1074

Riffle Cross Section: DS - 1

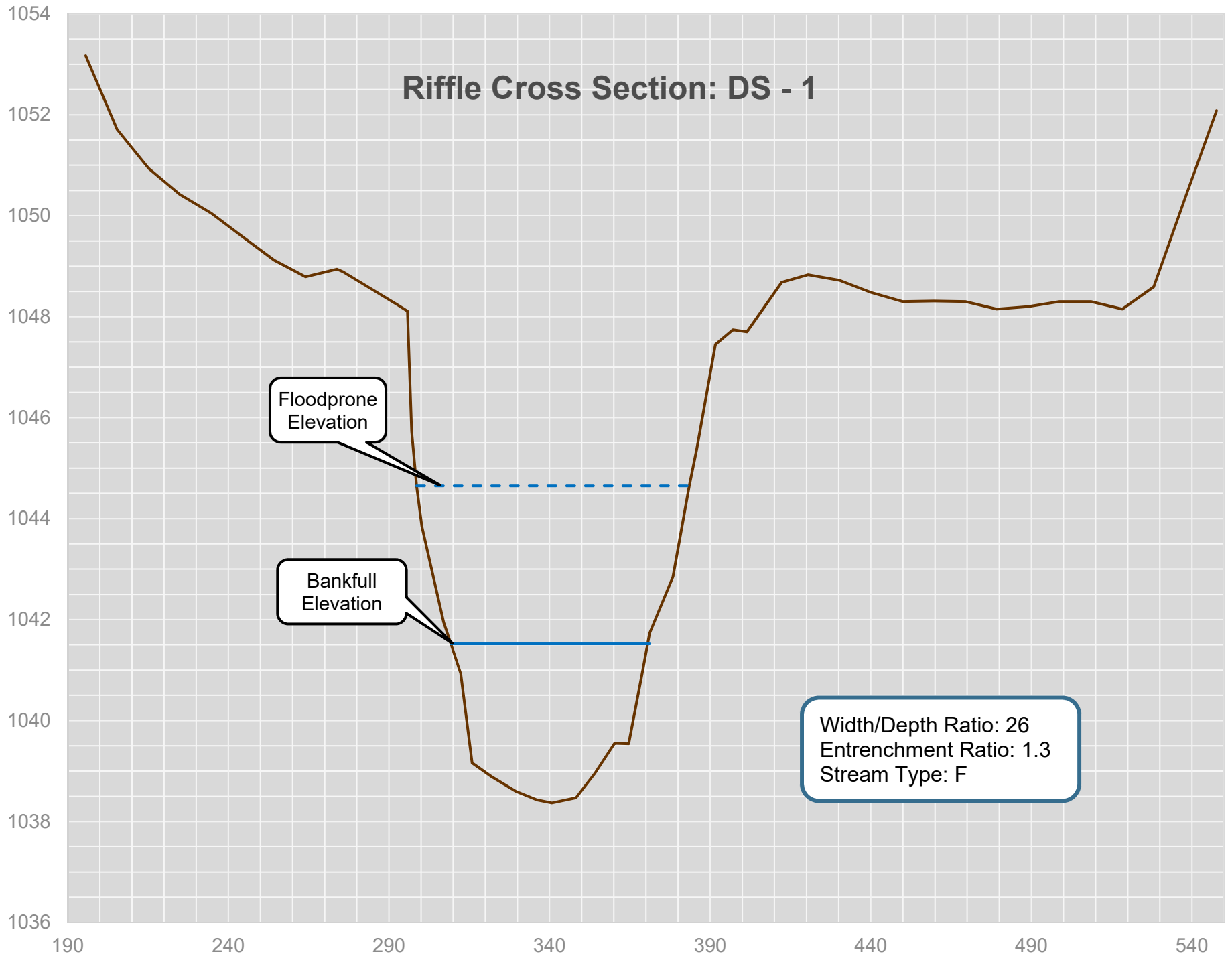
Elevation feet (NAVD 88)

Floodprone
Elevation

Bankfull
Elevation

Width/Depth Ratio: 26
Entrenchment Ratio: 1.3
Stream Type: F

Station (feet)



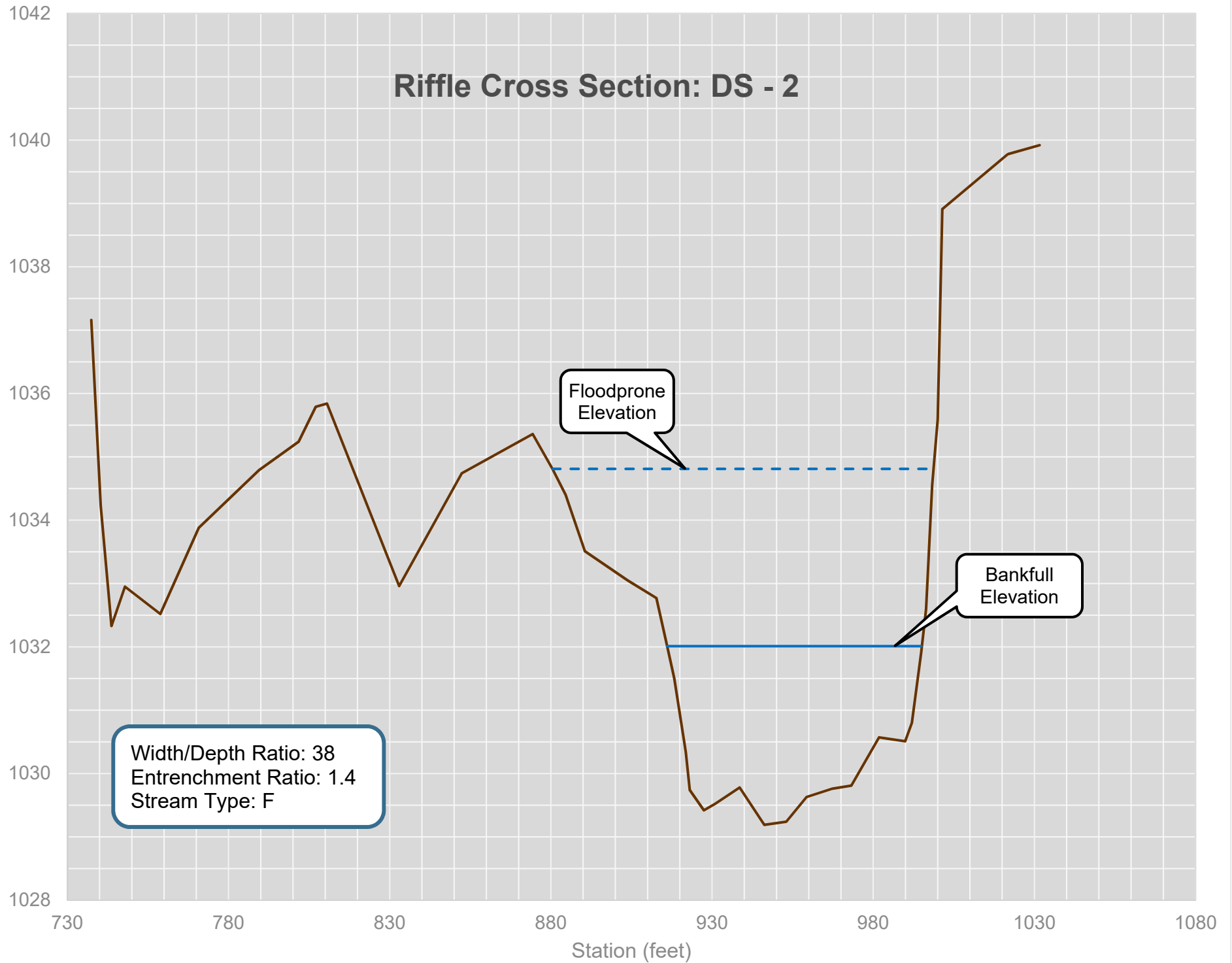
Riffle Cross Section: DS - 2

Elevation feet (NAVD 88)

Width/Depth Ratio: 38
Entrenchment Ratio: 1.4
Stream Type: F

Floodprone
Elevation

Bankfull
Elevation



Riffle Cross Section: DS - 3

Elevation feet (NAVD 88)

Floodprone
Elevation

Bankfull
Elevation

Width/Depth Ratio: 20
Entrenchment Ratio: 2.0
Stream Type: C/F

Station (feet)

1032

1030

1028

1026

1024

1022

1020

1018

1016

110

130

150

170

190

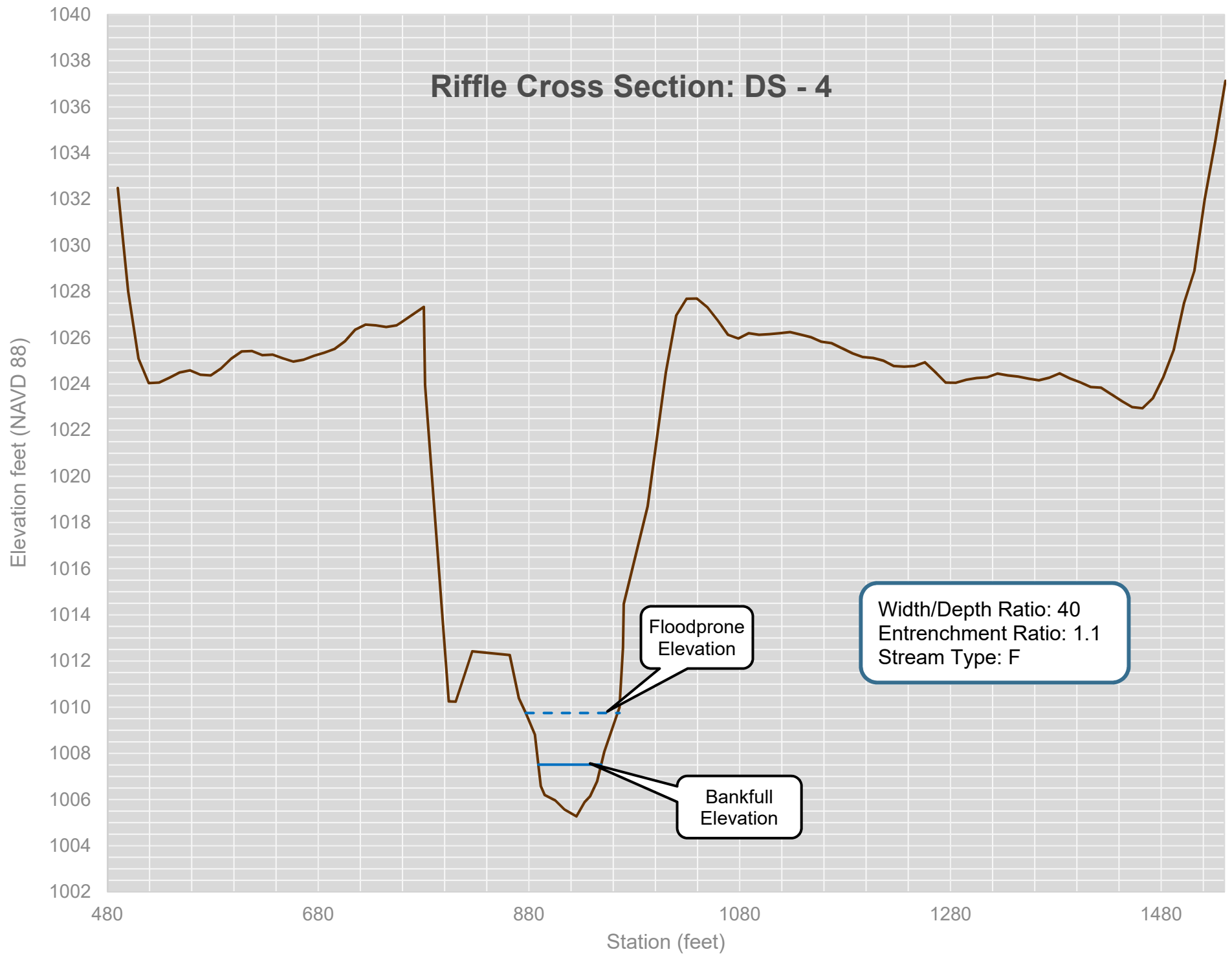
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230

250

270

Riffle Cross Section: DS - 4



Pool Cross Section: DS - 5

Elevation feet (NAVD 88)

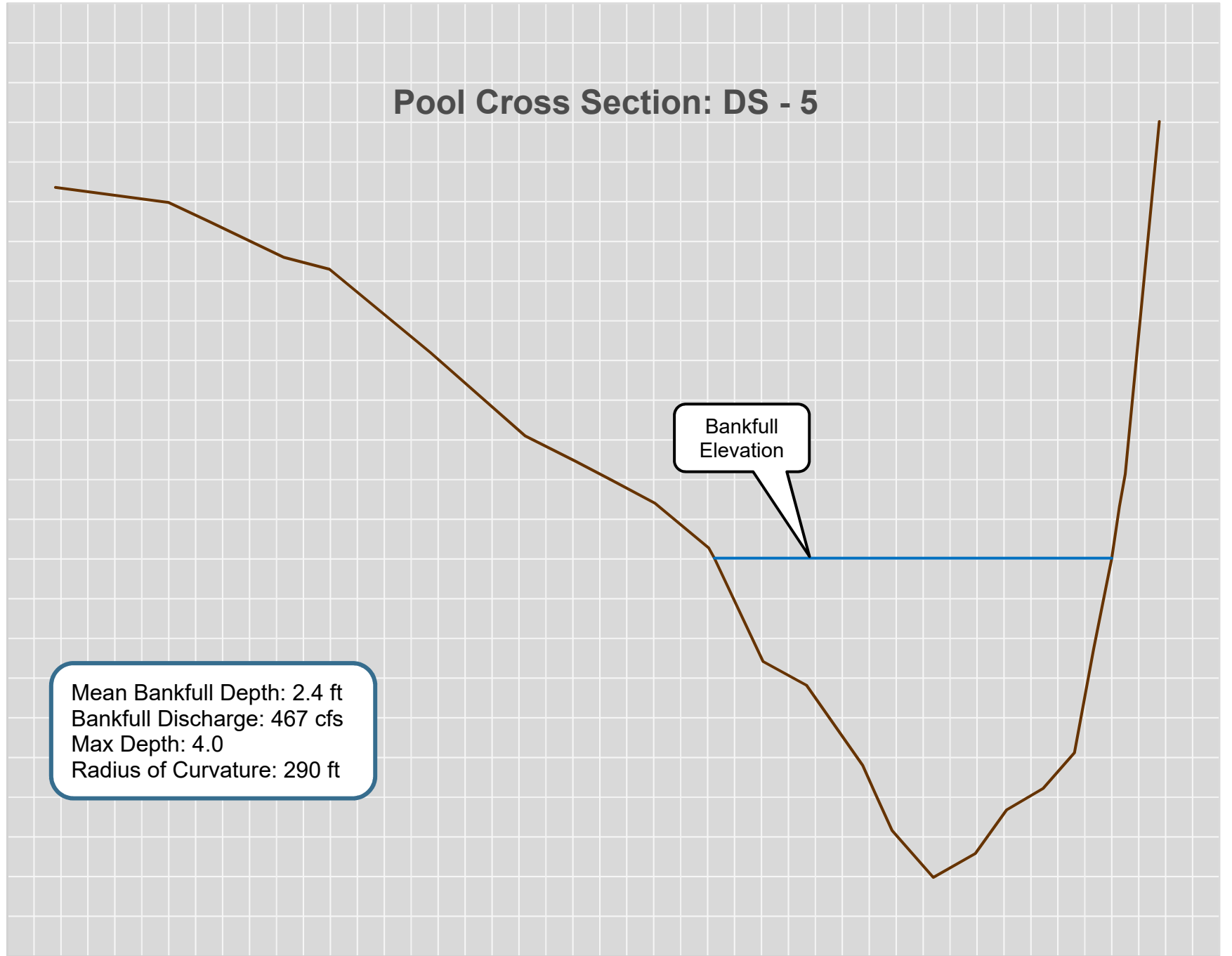
Bankfull
Elevation

Mean Bankfull Depth: 2.4 ft
Bankfull Discharge: 467 cfs
Max Depth: 4.0
Radius of Curvature: 290 ft

1004
1002
1000
998
996
994
992

400 420 440 460 480 500 520 540 560 580

Station



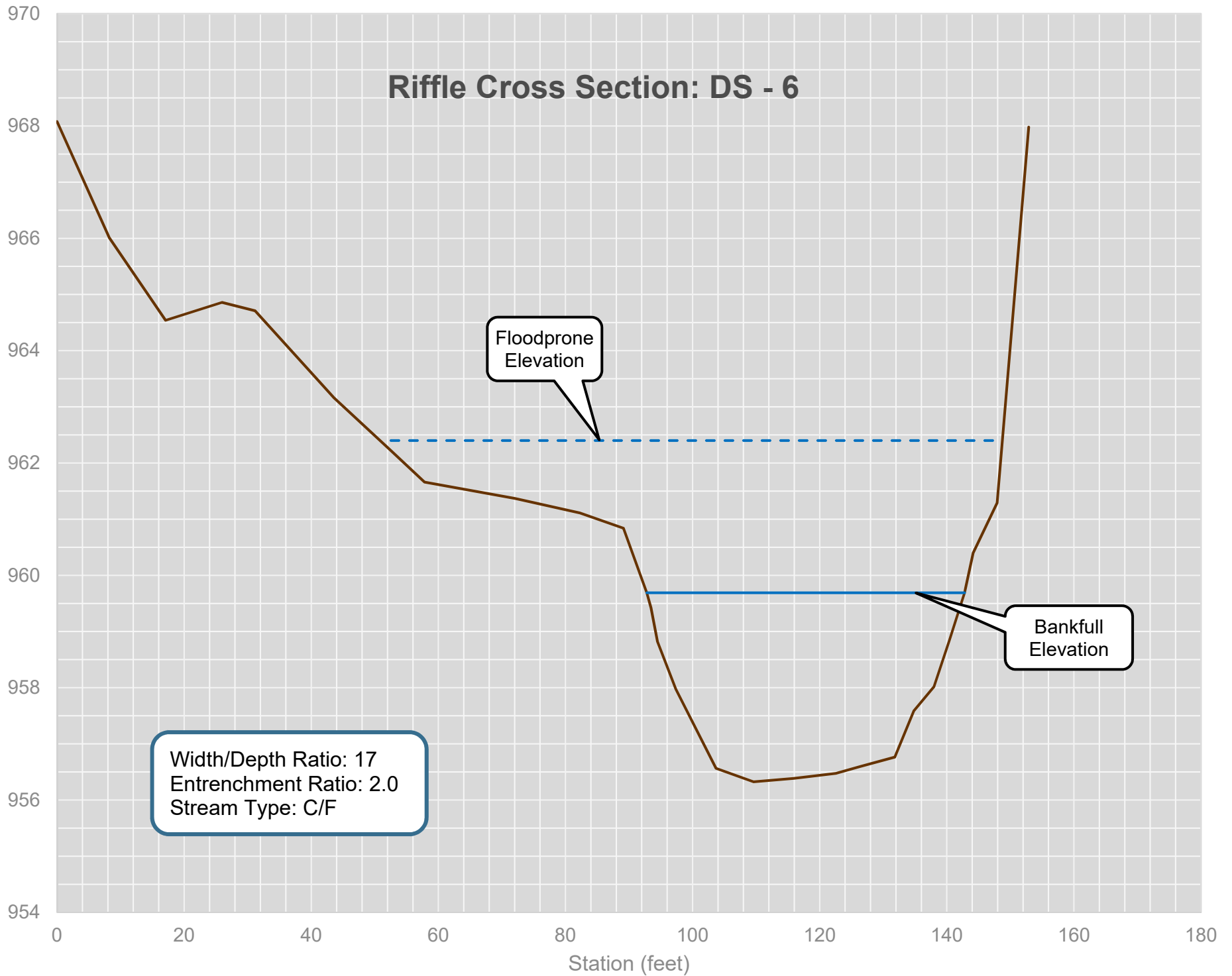
Riffle Cross Section: DS - 6

Elevation feet (NAVD 88)

Floodprone
Elevation

Bankfull
Elevation

Width/Depth Ratio: 17
Entrenchment Ratio: 2.0
Stream Type: C/F



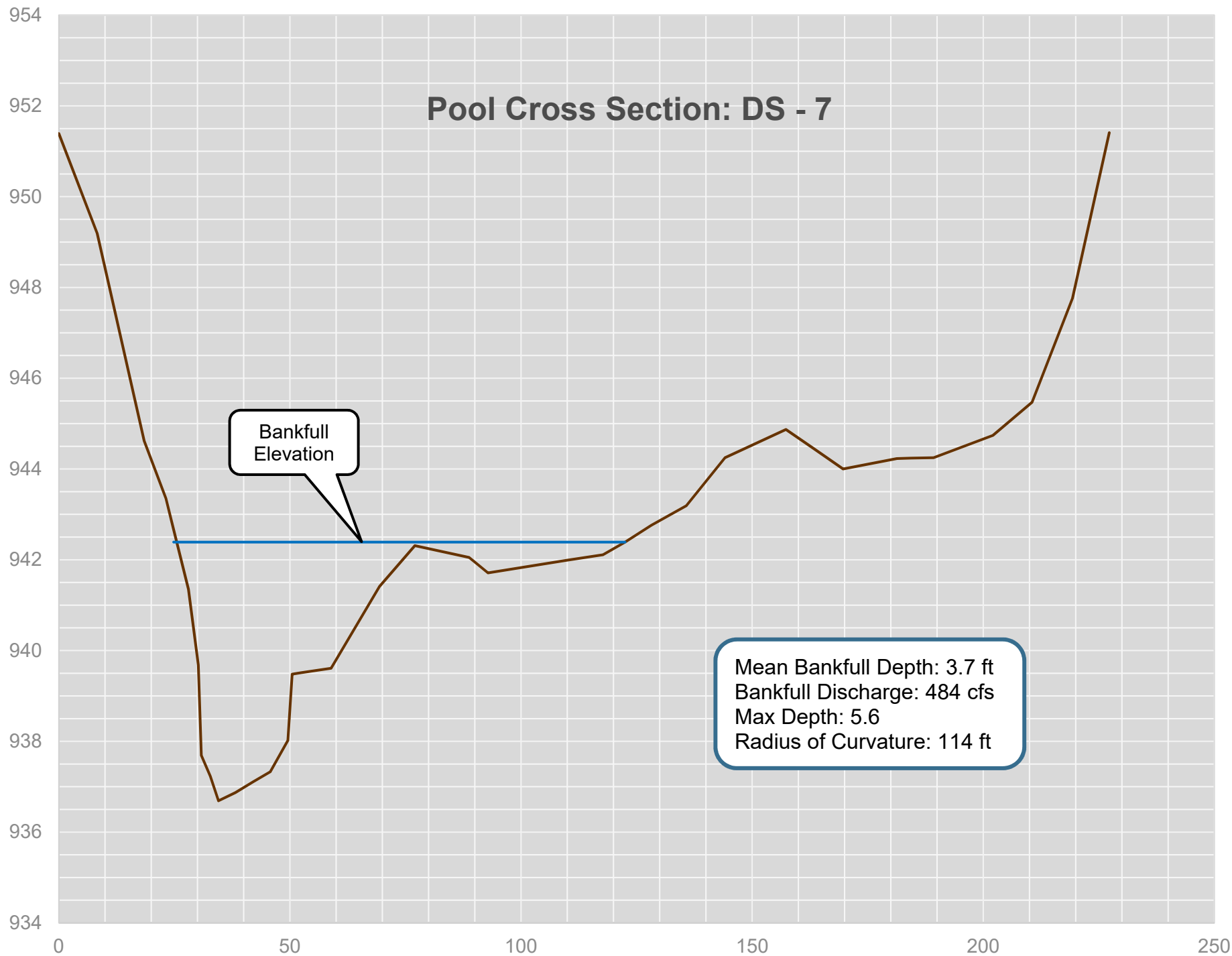
Pool Cross Section: DS - 7

Elevation feet (NAVD 88)

Bankfull
Elevation

Mean Bankfull Depth: 3.7 ft
Bankfull Discharge: 484 cfs
Max Depth: 5.6
Radius of Curvature: 114 ft

Station

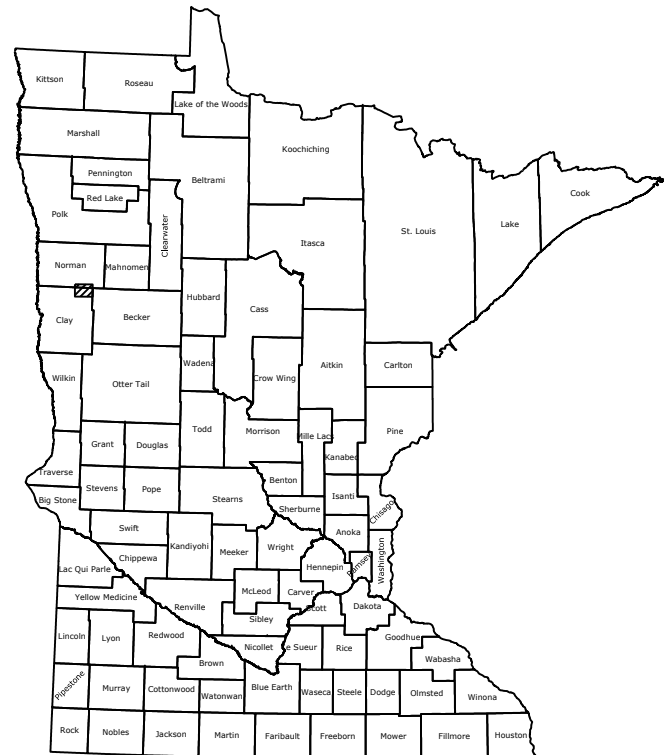




APPENDIX D

Feasibility Study Plans

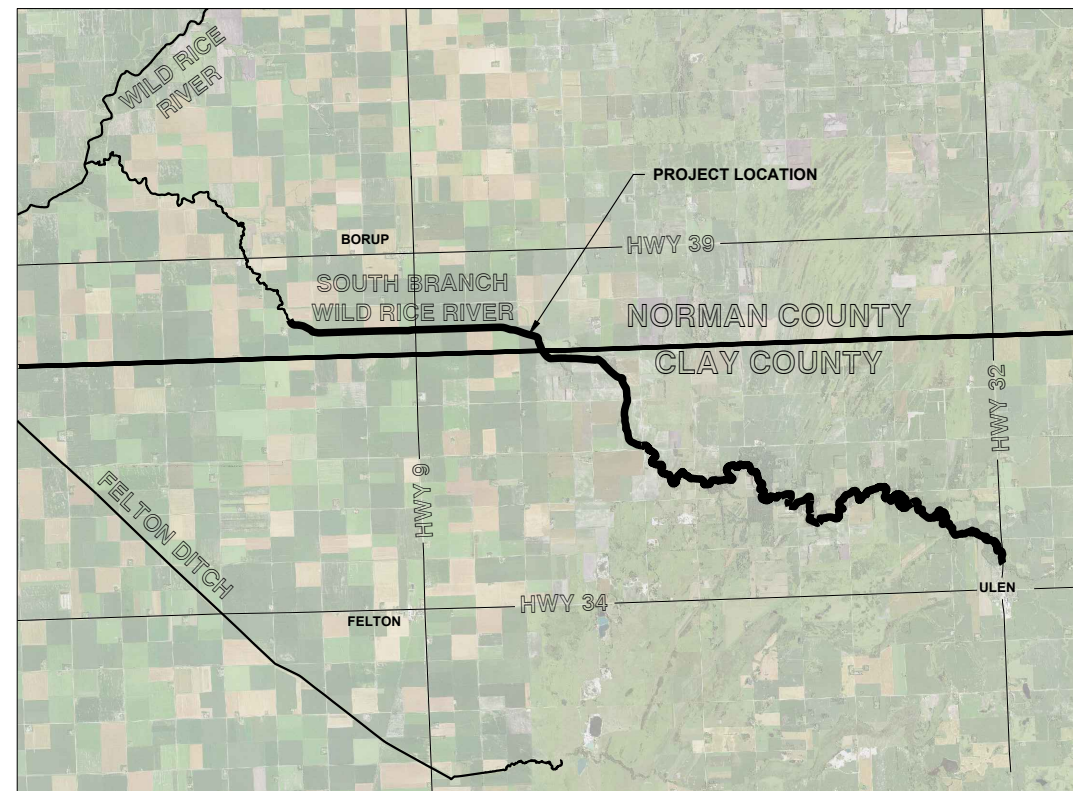
FEASIBILITY STUDY PLANS FOR SOUTH BRANCH WILD RICE RIVER RESTORATION & SEDIMENT REDUCTION PROJECT WILD RICE WATERSHED DISTRICT ADA, MINNESOTA 2020



STATE COUNTY MAP

GENERAL NOTES:

1. PROJECT LIMITS TO BE VERIFIED DURING FINAL DESIGN. PROJECT LIMITS SHOWN ON THE PLAN SHEETS ARE PRELIMINARY.
2. CHANNEL ALIGNMENT SUBJECT TO CHANGE.
3. ANY ABOVE GROUND OR UNDERGROUND UTILITIES SHOWN HAVE BEEN LOCATED FROM FIELD SURVEY, GIS DATA, OR AERIAL IMAGERY. THERE IS NO GUARANTEE THAT THE UNDERGROUND UTILITIES SHOWN COMPRISE ALL SUCH UTILITIES IN THE AREA, EITHER IN SERVICE OR ABANDONED, NOR IS THERE A GUARANTEE THAT THE UTILITIES SHOWN ARE IN THE EXACT LOCATION INDICATED.
4. ALL ELEVATIONS LISTED ARE BASED ON 1988 DATUM (NAVD).
5. THE HORIZONTAL DATUM IS UTM ZONE 14N.



INDEX OF DRAWINGS:

SHT. 1	COVER SHEET
SHT. 2	PROJECT LOCATION
SHT. 3	INDEX MAP - CHANNELIZED REACH
SHT. 4	INDEX MAP - BEACH RIDGE ROCK ARCH RAPIDS
SHT. 5	INDEX MAP - UPPER RIDGE ROCK ARCH RAPIDS
SHT. 6	LEGENDS AND NOTES
SHT. 7-16	CHANNELIZED REACH PLAN AND PROFILES
SHT. 17-20	CHANNELIZED REACH DETAILS
SHT. 21-26	BEACH RIDGE ARCH RAPIDS PLAN AND PROFILES
SHT. 27-34	UPPER RIDGE ARCH RAPIDS PLAN AND PROFILES
SHT. 35	ROCK ARCH RAPIDS DETAILS
SHT. 36-73	CROSS SECTIONS

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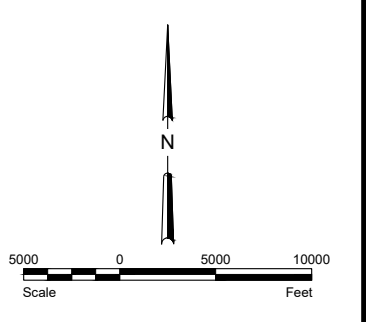
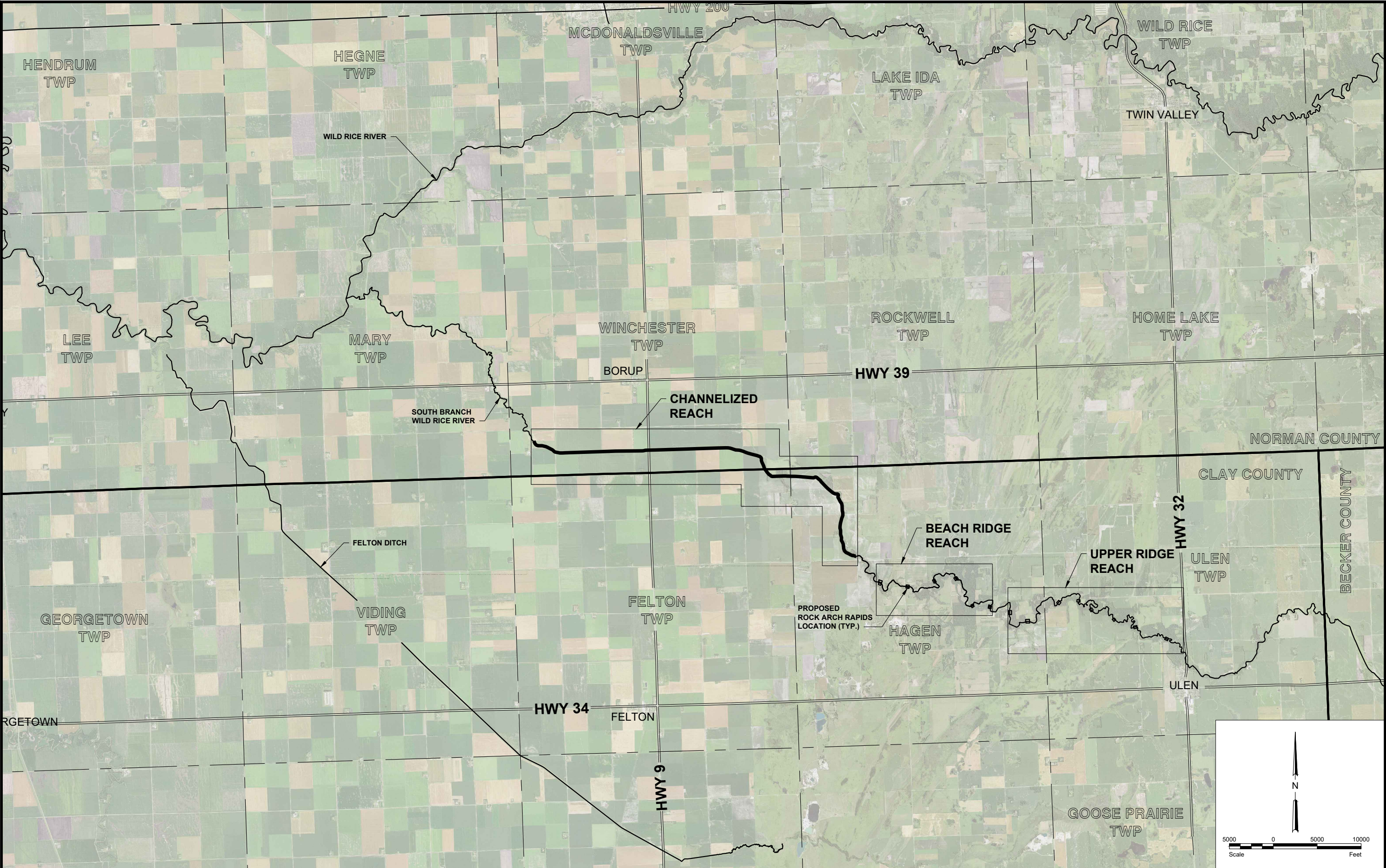
PREPARED BY:



Houston
Engineering Inc.

FARGO, NORTH DAKOTA

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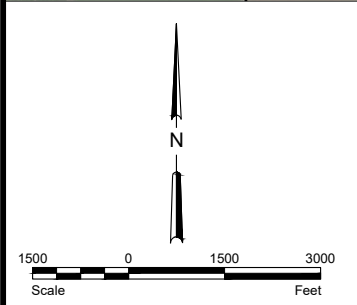
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Date
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

PROJECT LOCATION
PROJECT NO. 1432-0365

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No.	Revision	Date	By

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F: 701.237.5101

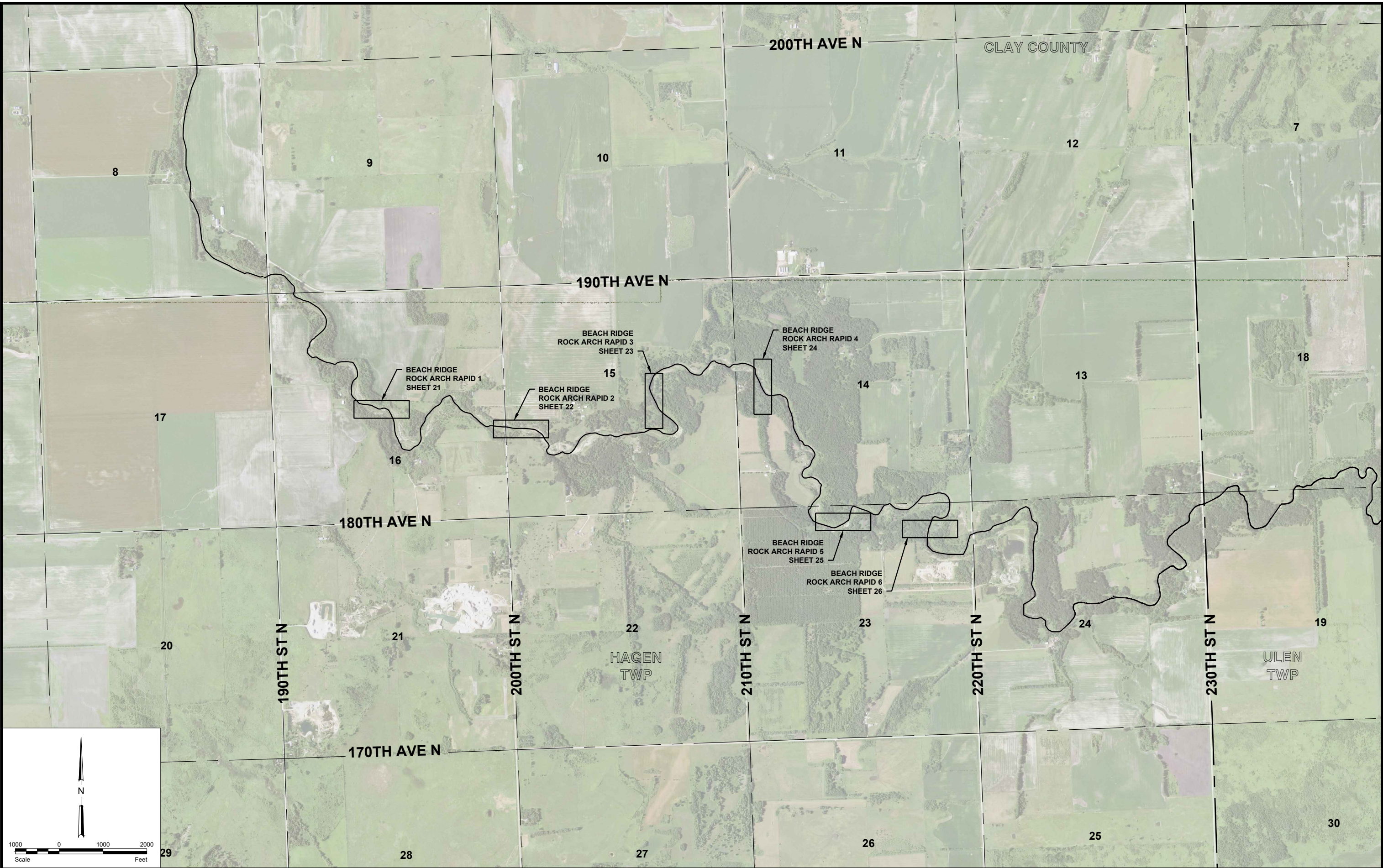
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AJK
Checked by
GLB/HRR
Date
4-28-2020
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

INDEX MAP - LAKE PLAIN
REACH
PROJECT NO. 1432-0365

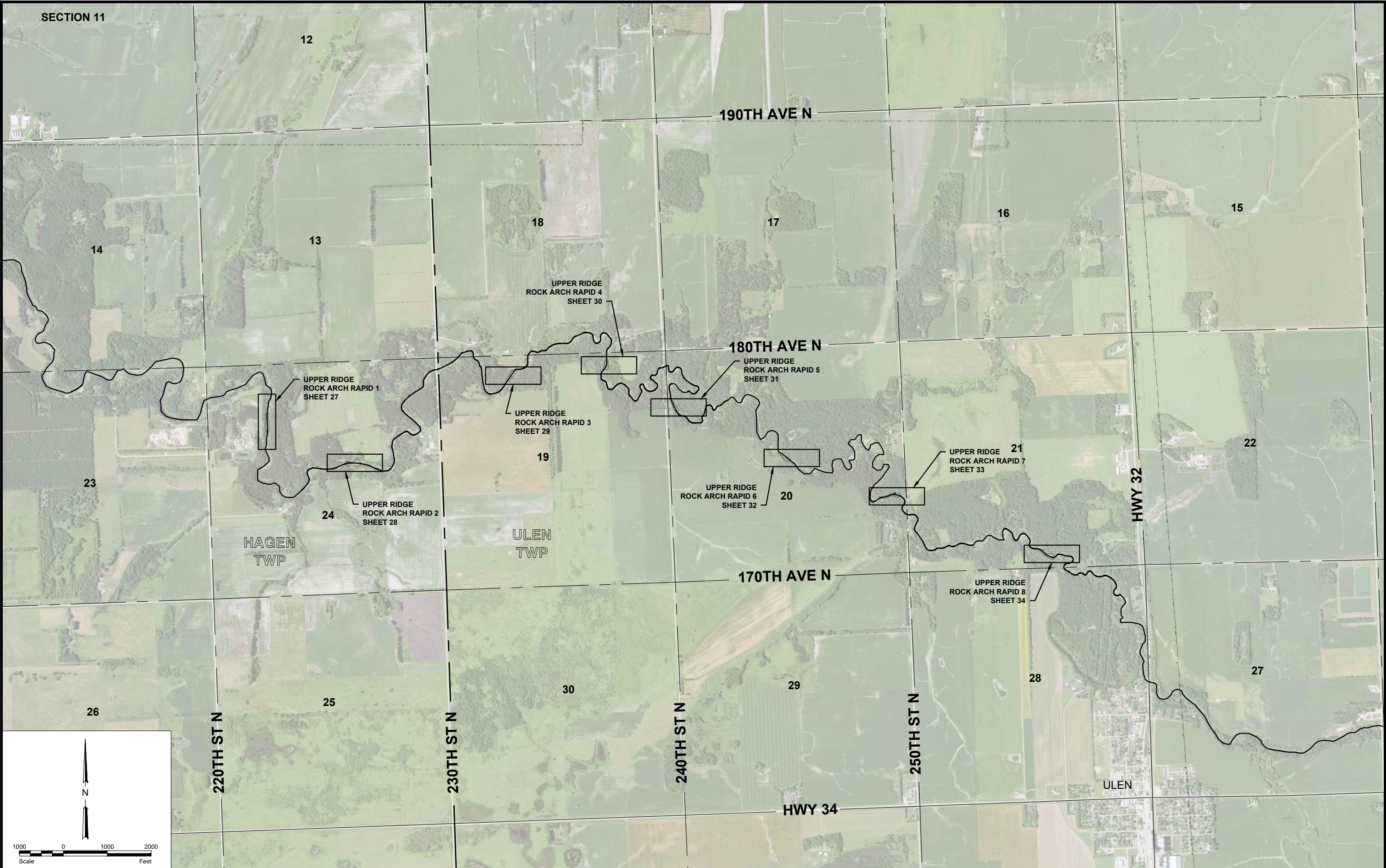
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No.	Revision	Date	By				P: 701.237.5065 F: 701.237.5101	Checked by GLB/HRR	Scale NTS			

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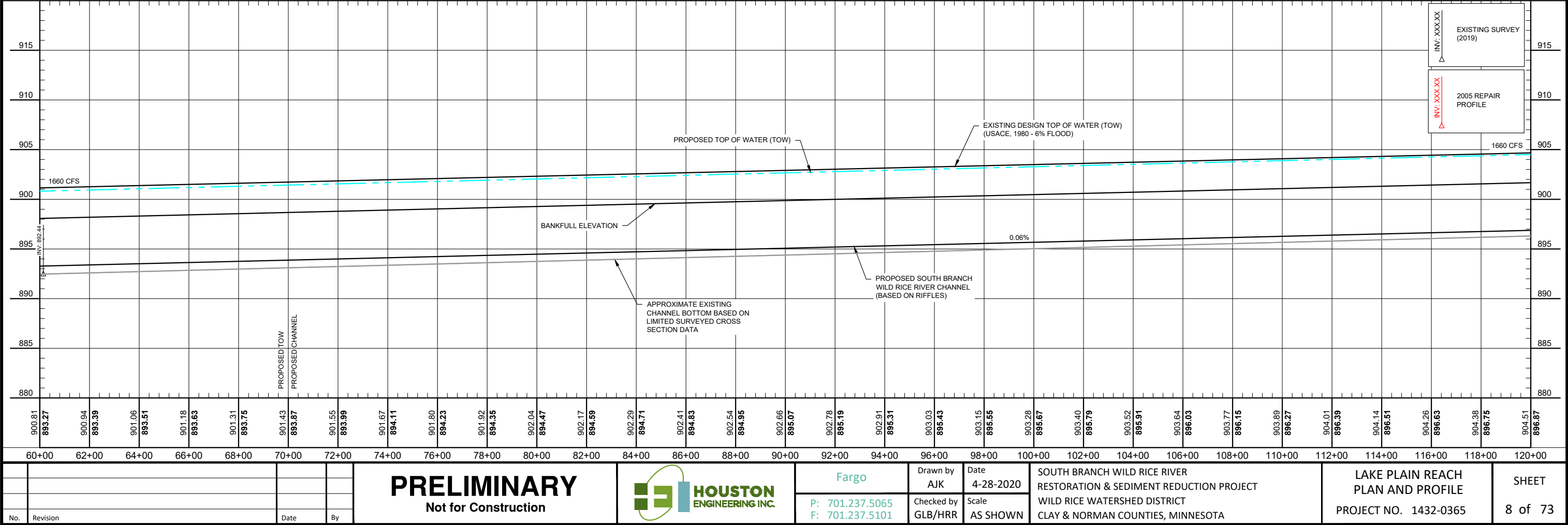
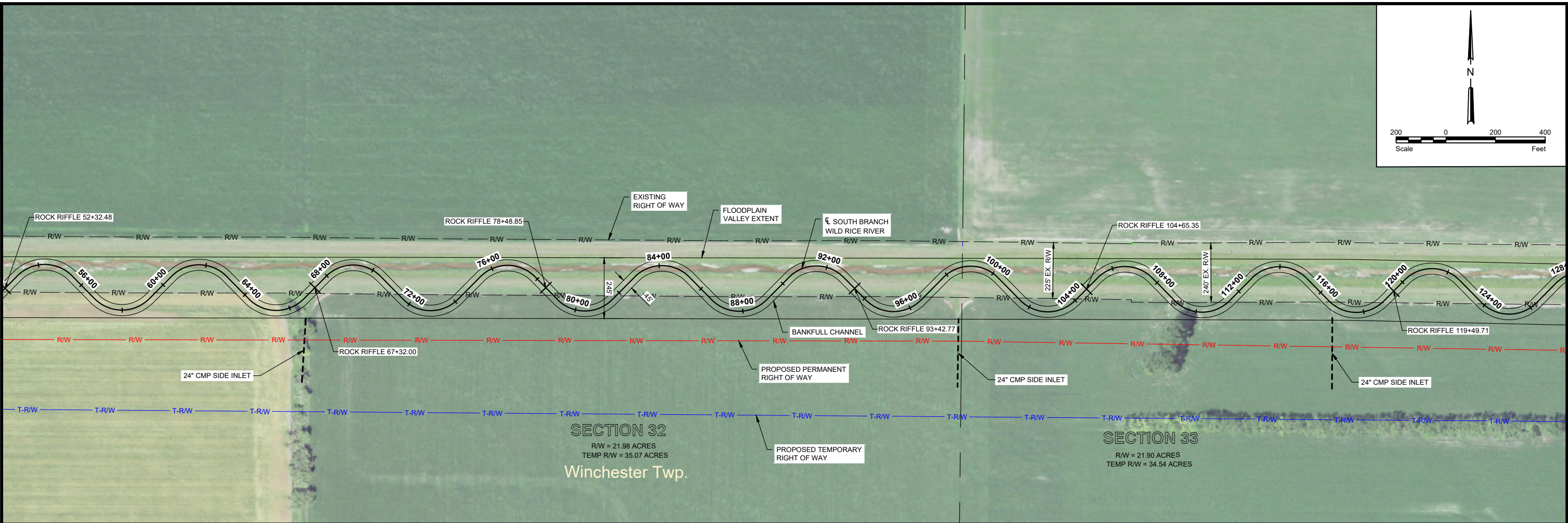
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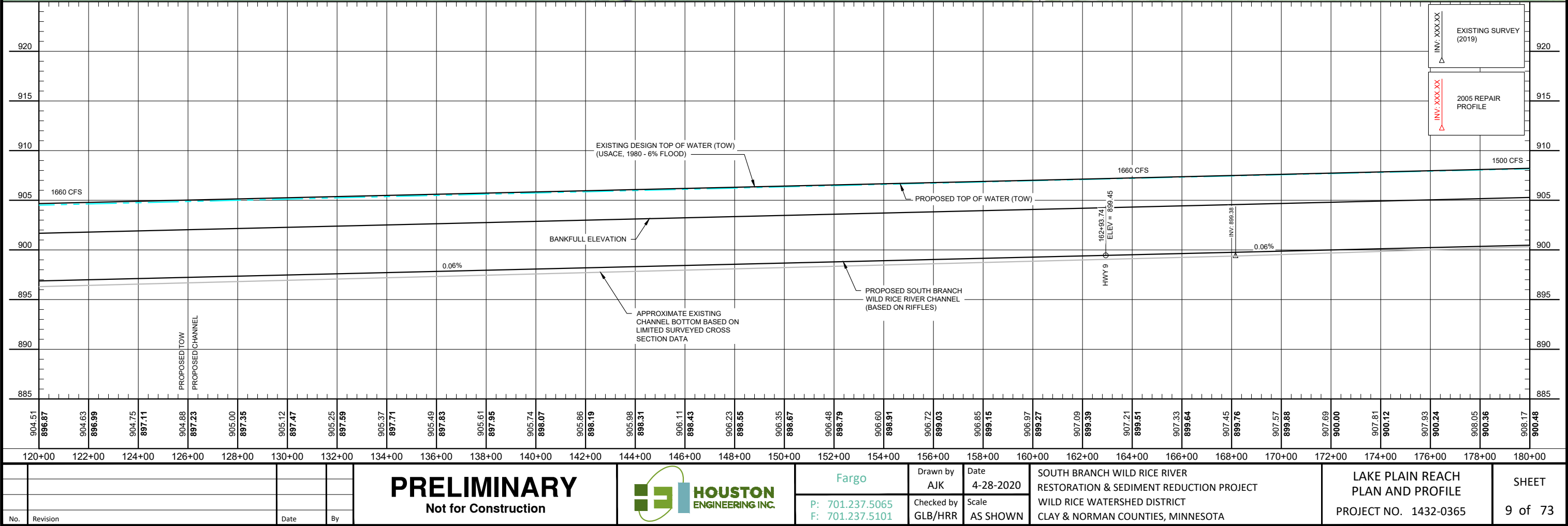
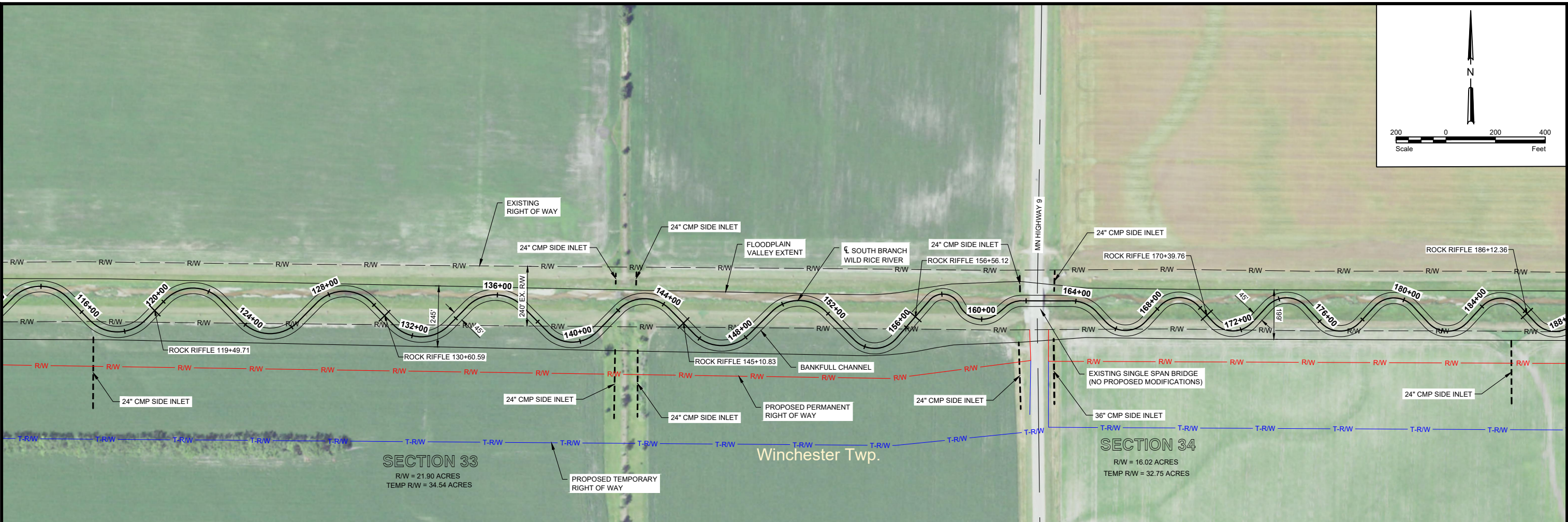
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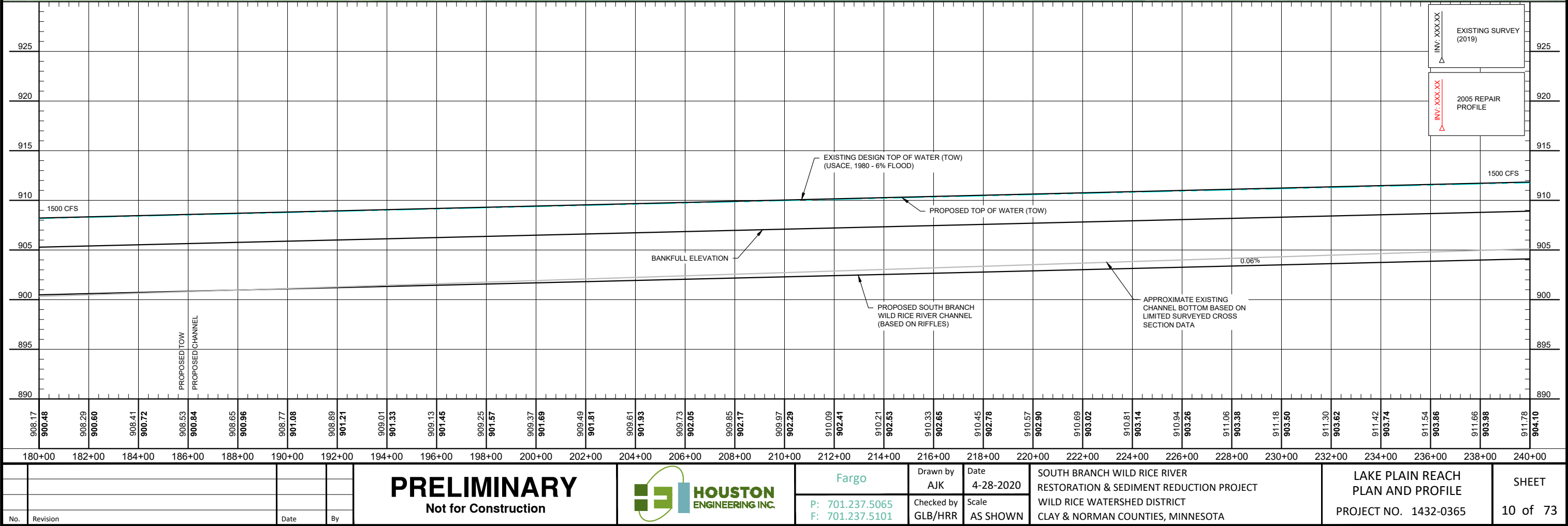
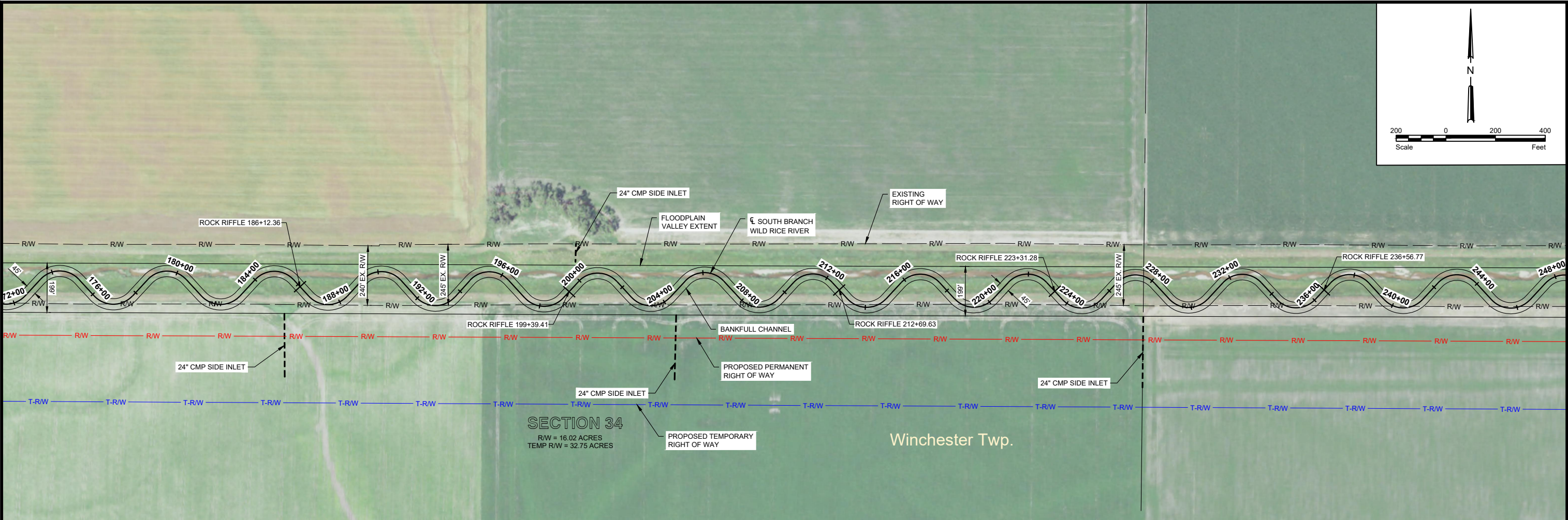
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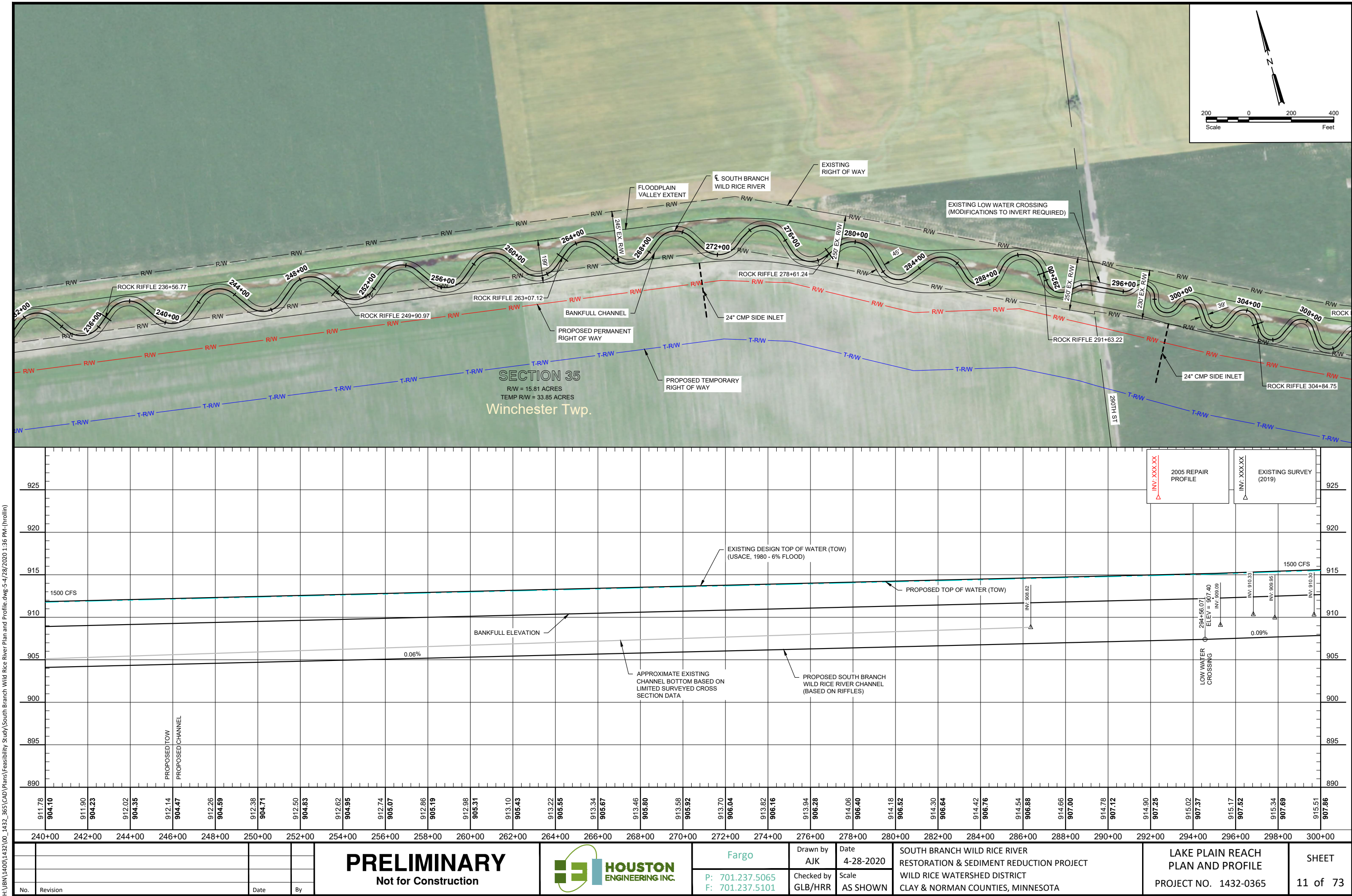
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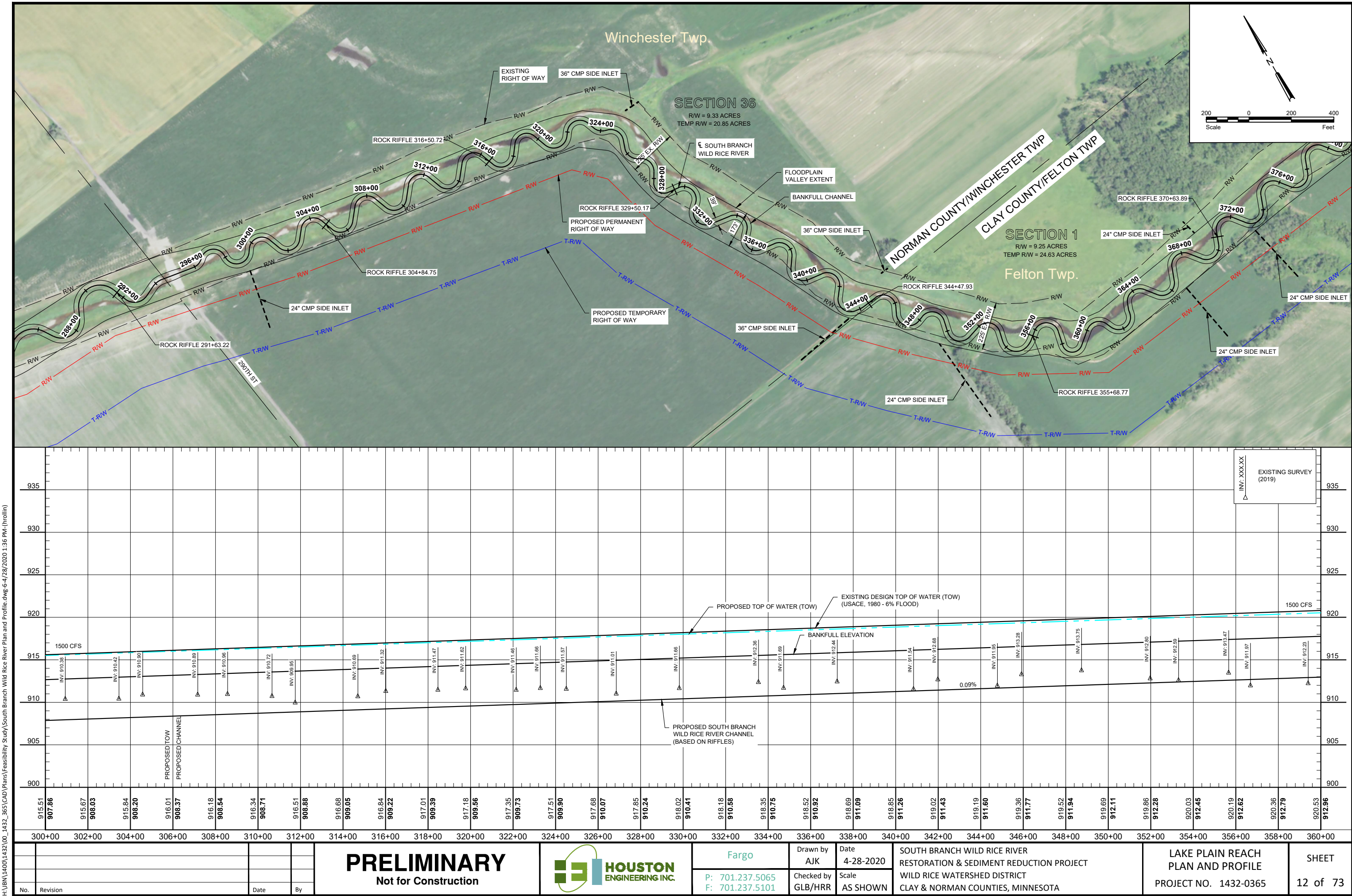
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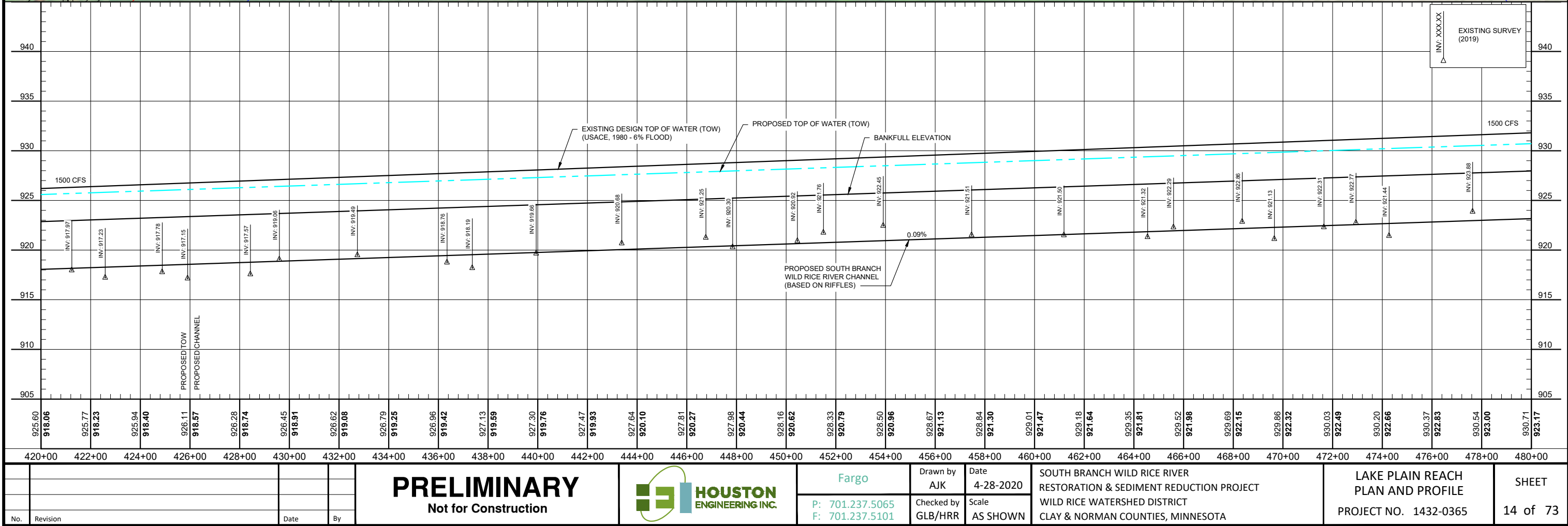
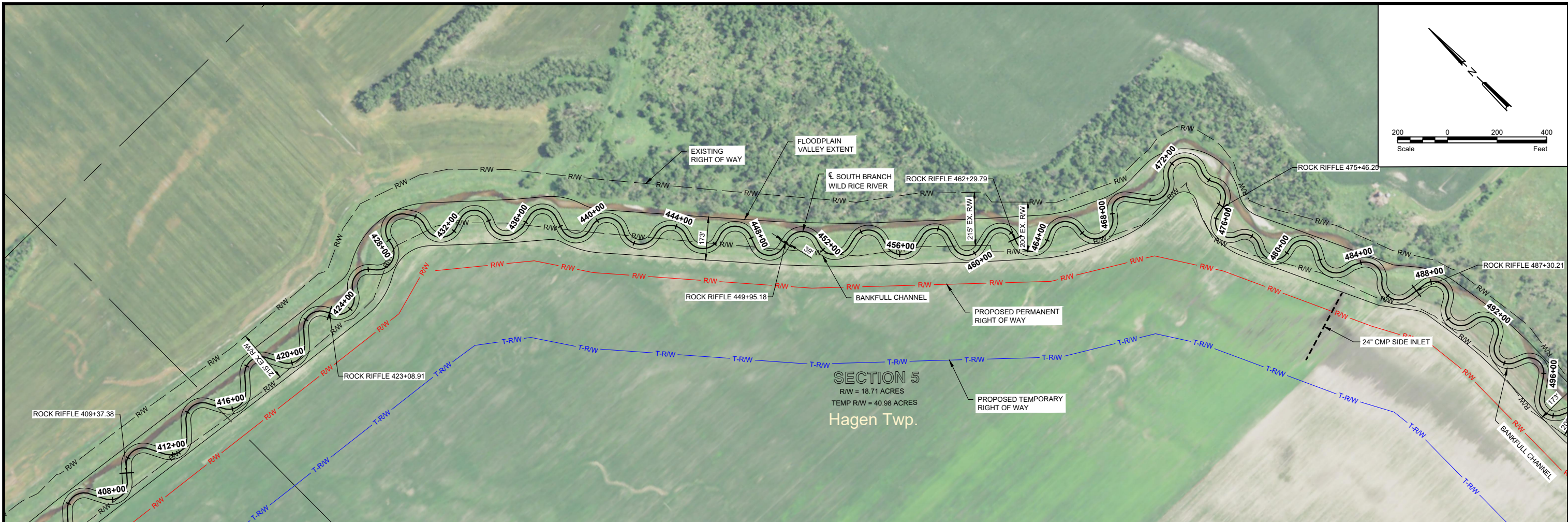
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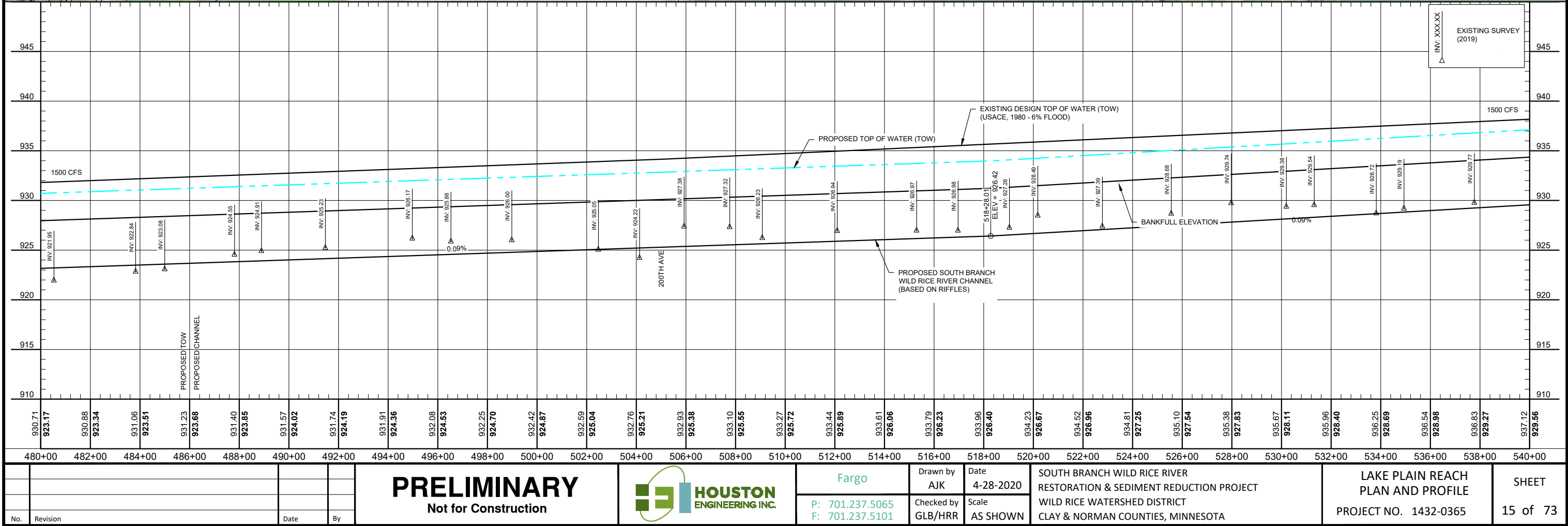
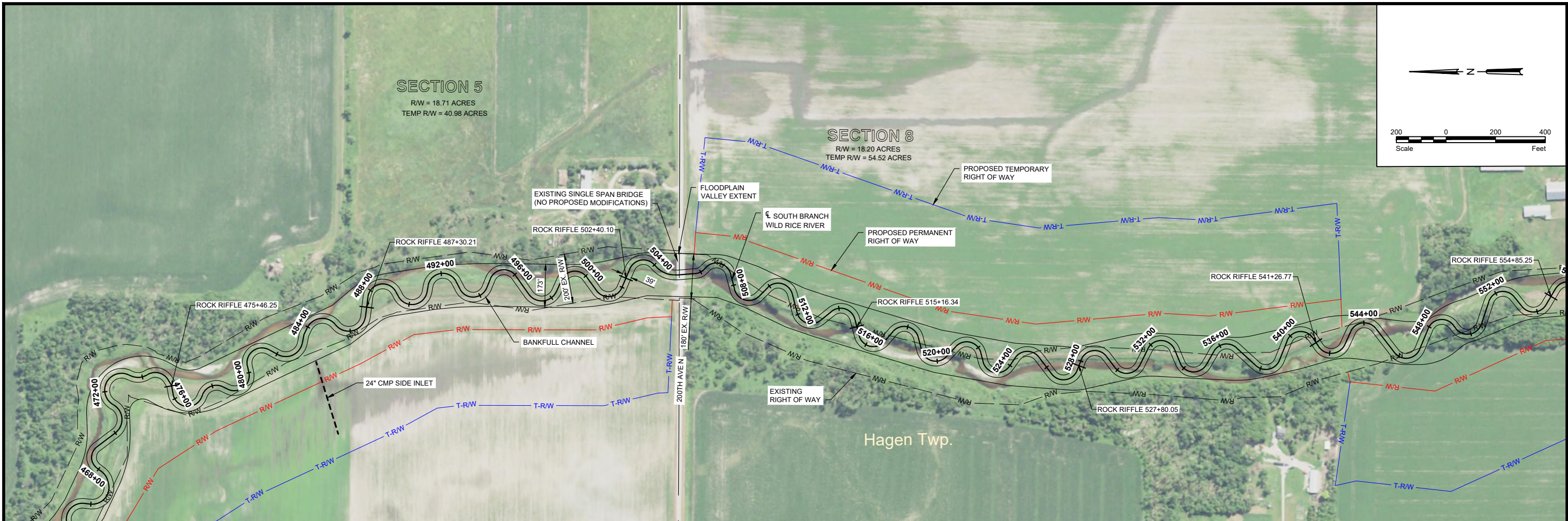
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GLB/HRR
Date
4-28-2020
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RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

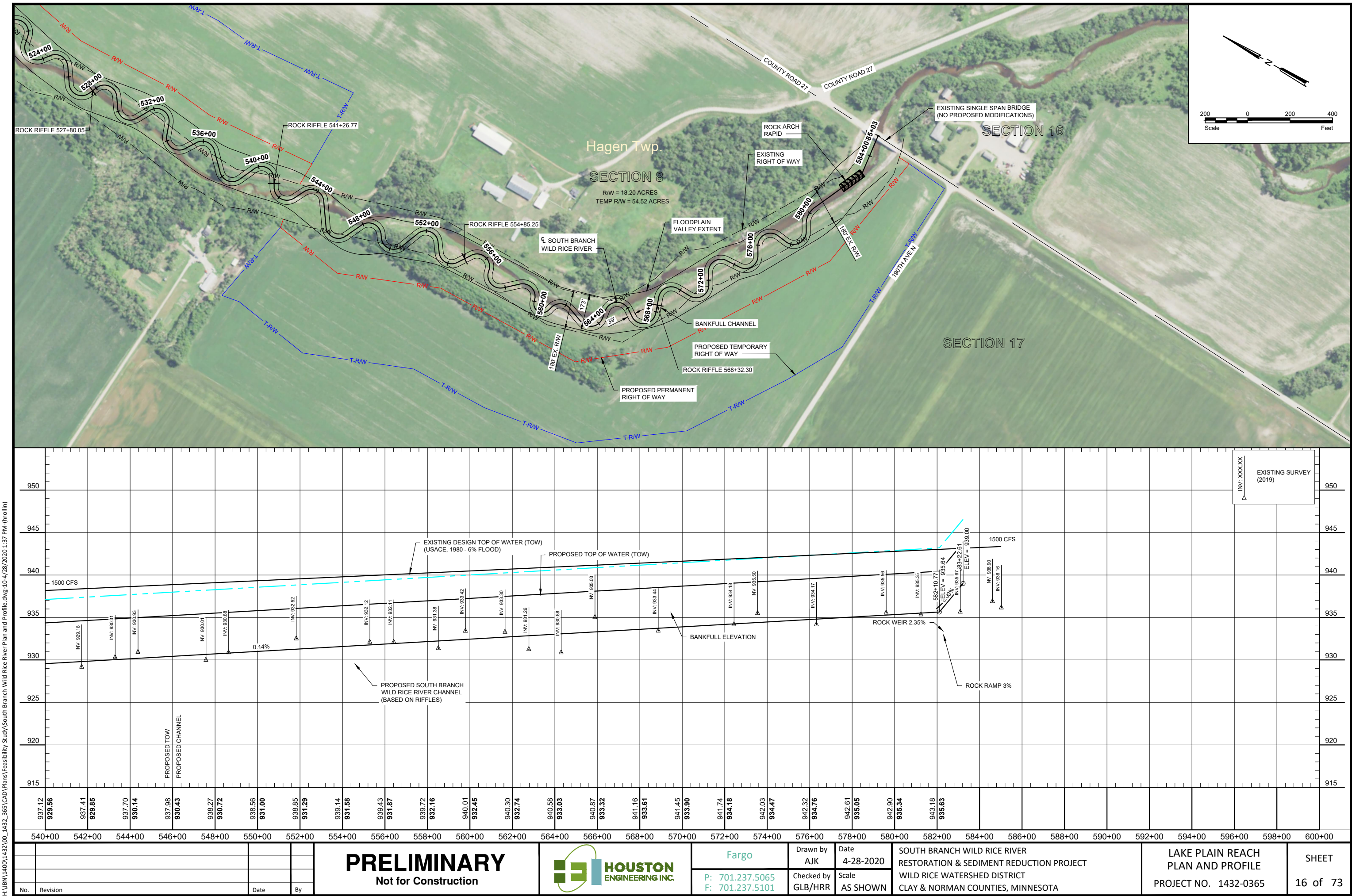
LAKE PLAIN REACH
PLAN AND PROFILE
PROJECT NO. 1432-0365

SHEET
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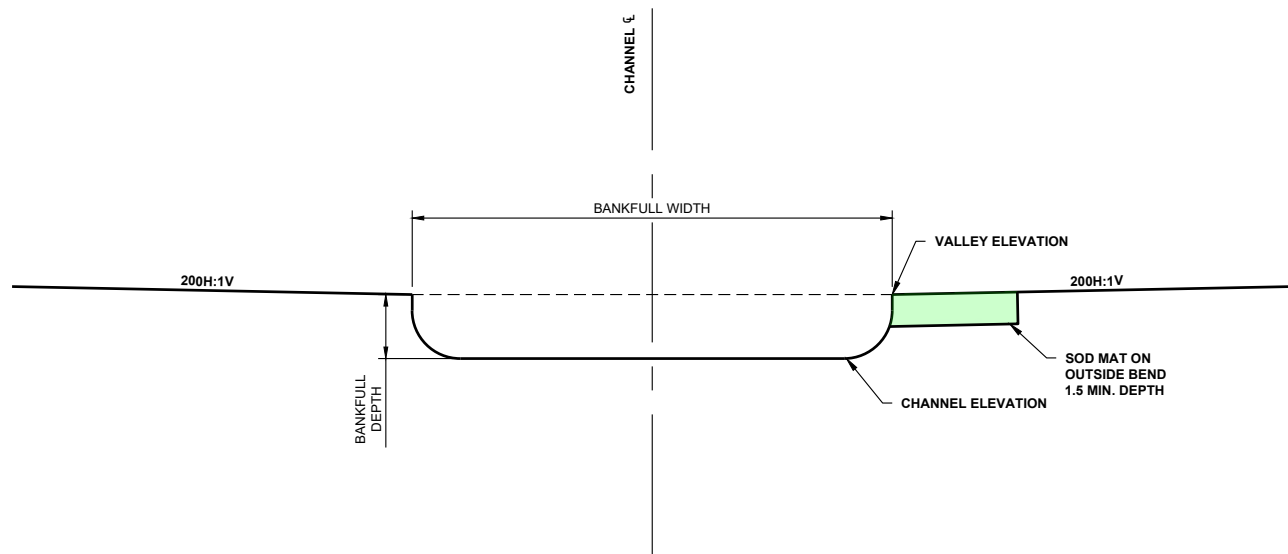
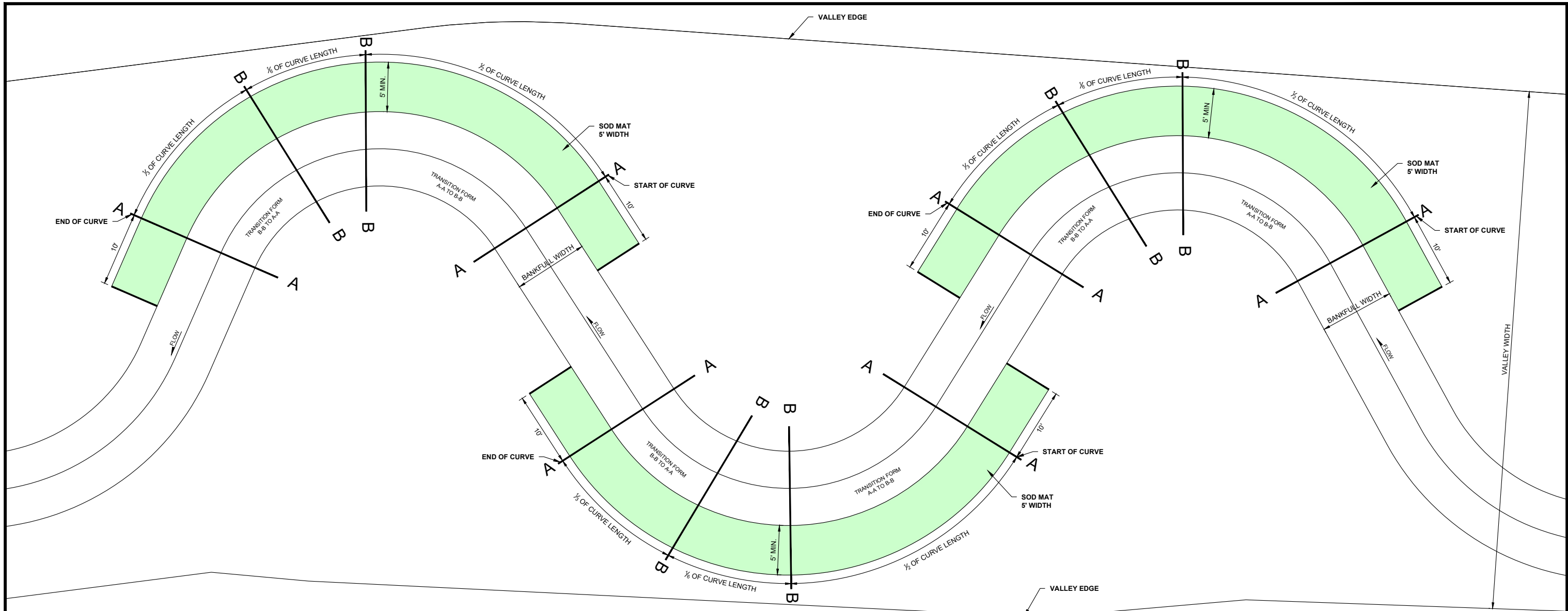
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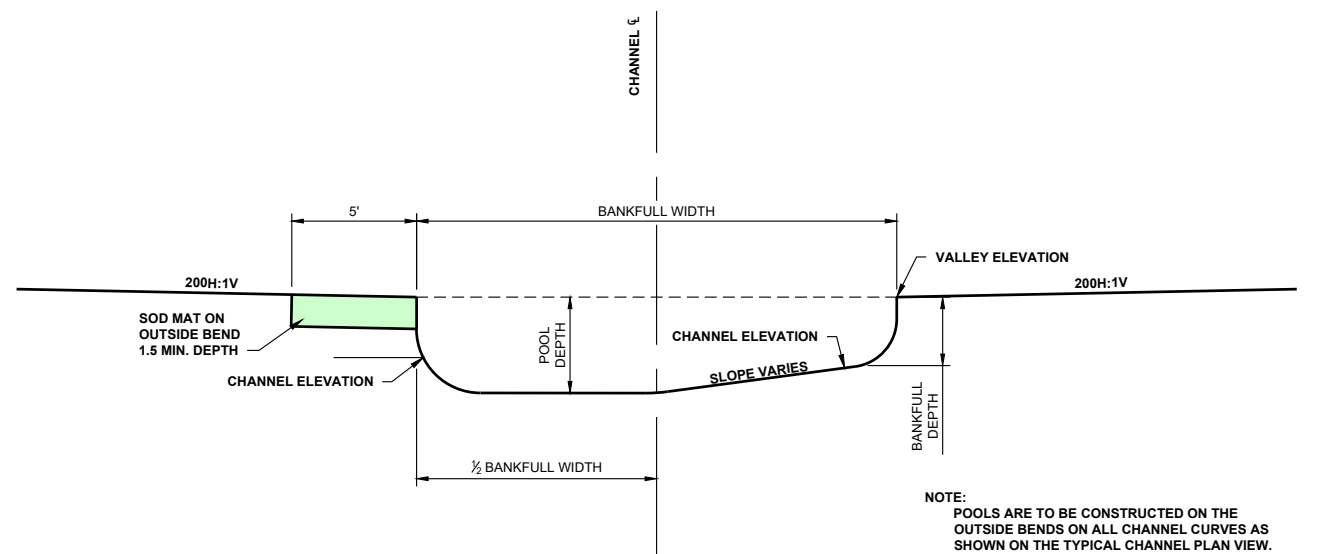
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A-A TYPICAL SECTION
NOT TO SCALE



B-B TYPICAL SECTION
NOT TO SCALE

NOTE:
POOLS ARE TO BE CONSTRUCTED ON THE
OUTSIDE BENDS ON ALL CHANNEL CURVES AS
SHOWN ON THE TYPICAL CHANNEL PLAN VIEW.

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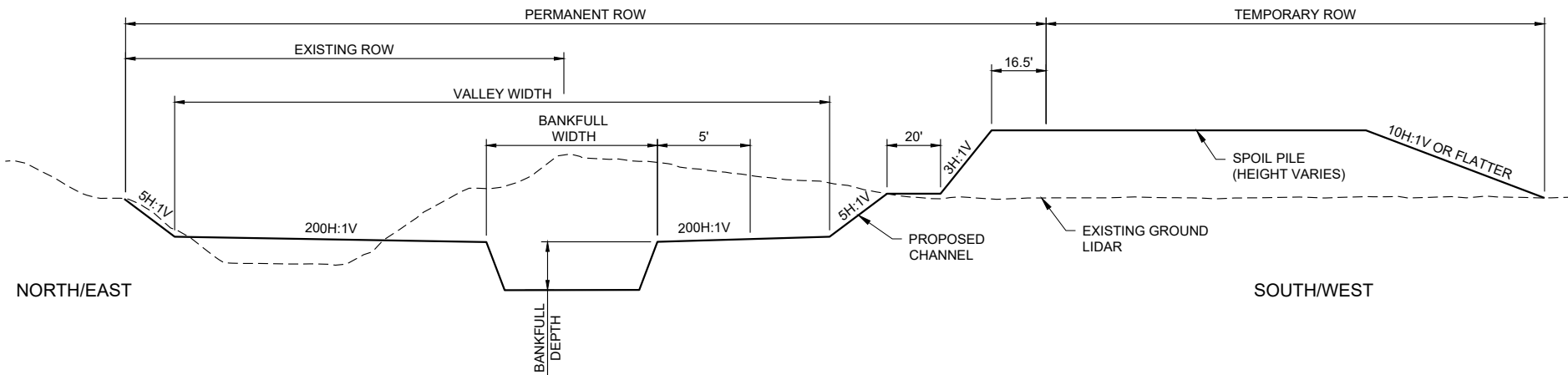
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

LAKE PLAIN REACH TYPICAL
CHANNEL PLAN VIEW
PROJECT NO. 1432-0365

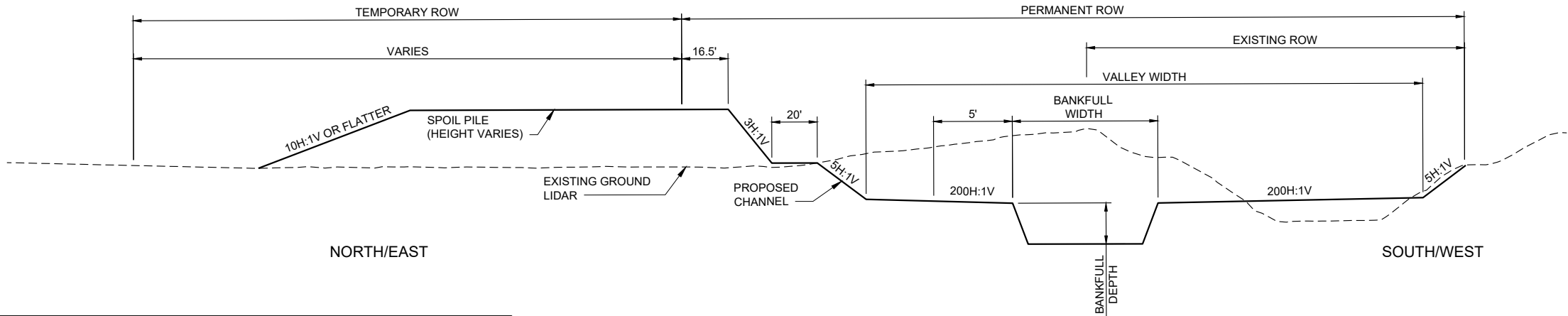
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- NOTES:
- 1. SOD MATERIAL SHALL CONSIST OF SUFFICIENT PLANT GROWTH TO BIND THE SOD MAT TOGETHER. SOD MATS CONTAINING WILLOWS AND/OR DENSE STANDS OF GRASSES ARE CONSIDERED IDEAL. ACCEPTABLE SOD MATERIAL SHALL BE DETERMINED BY THE ENGINEER OR FIELD REPRESENTATIVE. SOD MAT SHALL BE INSTALLED ON THE OUTSIDE BENDS ONLY.
 - 2. THE CONTRACTOR SHALL FILL ABANDONED CHANNEL TO THE VALLEY ELEVATION OR MATCH THE ADJACENT GROUND ELEVATION, WHICHEVER IS LOWER.
 - 3. CONTRACTOR SHOULD SALVAGE EXISTING TOPSOIL FOR LATER REUSE ON SITE IN EXCAVATION AREA AS WELL AS IN AREAS WHERE EMBANKMENTS ARE PLACED.
 - 4. DRAINAGE SHALL BE MAINTAINED ON THE OUTSIDE OF THE SPOIL PILE. AREAS OUTSIDE OF THE SPOIL PILES SHALL BE GRADED TO DRAIN.
 - 5. MINIMUM OF 6" TOPSOIL SHALL BE SPREAD BELOW THE PROPOSED CHANNEL CROSS SECTION EXCEPT CHANNEL BOTTOM.

TYPICAL CHANNEL SECTION (STA. 0+00 TO 503+13 AND 542+54 TO 579+60)
NOT TO SCALE



PROPOSED CHANNEL GEOMETRY				
STATION	BANKFULL WIDTH (FT)	BANKFULL DEPTH (FT)	VALLEY WIDTH (FT)	POOL DEPTH (FT)
0+00 TO 35+94	49	4.8	209	7.3
35+94 TO 162+96	45	4.8	239	7.1
162+96 TO 295+45	45	4.8	199	7.1
295+45 TO 393+17	39	4.8	173	6.7

TYPICAL CHANNEL SECTION (STA. 505+13 TO 542+54)
NOT TO SCALE

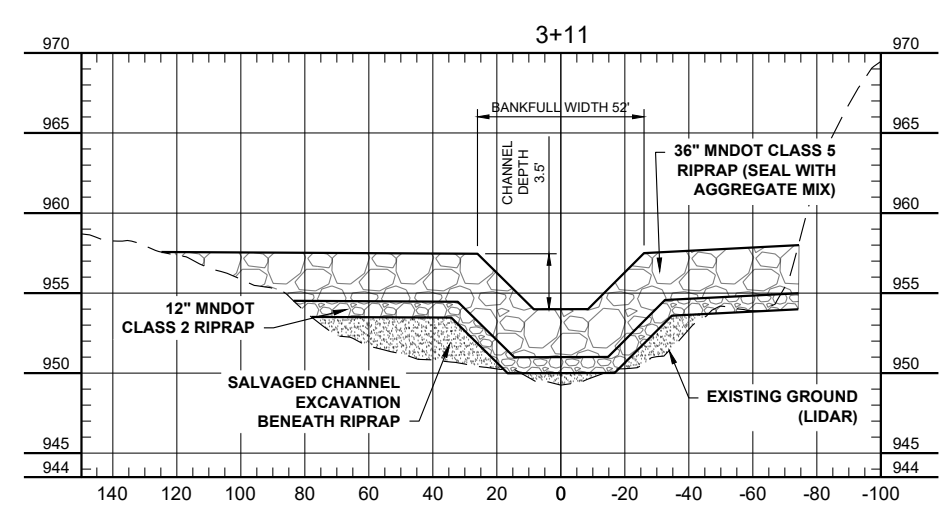
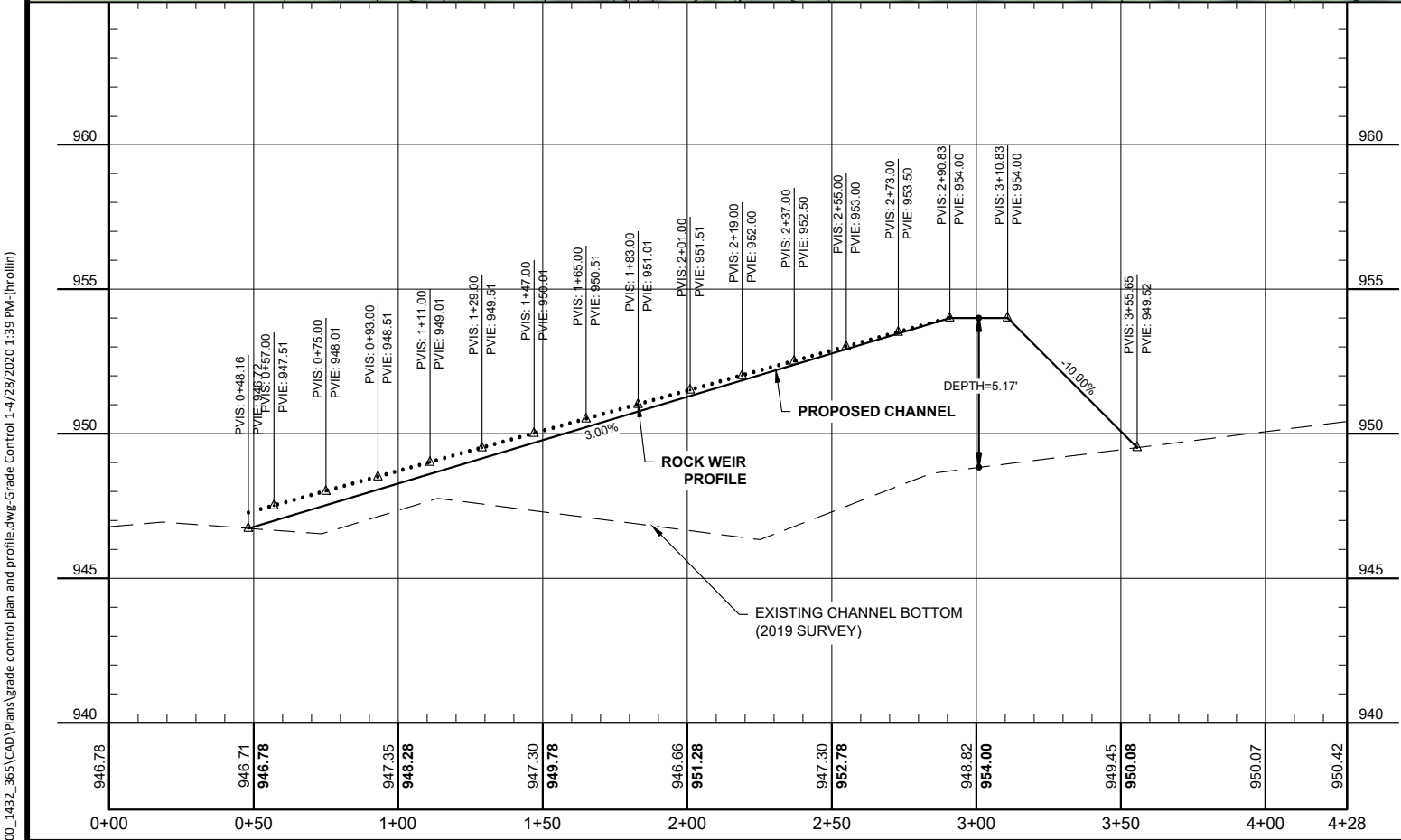
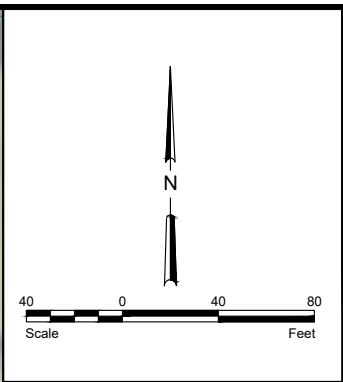
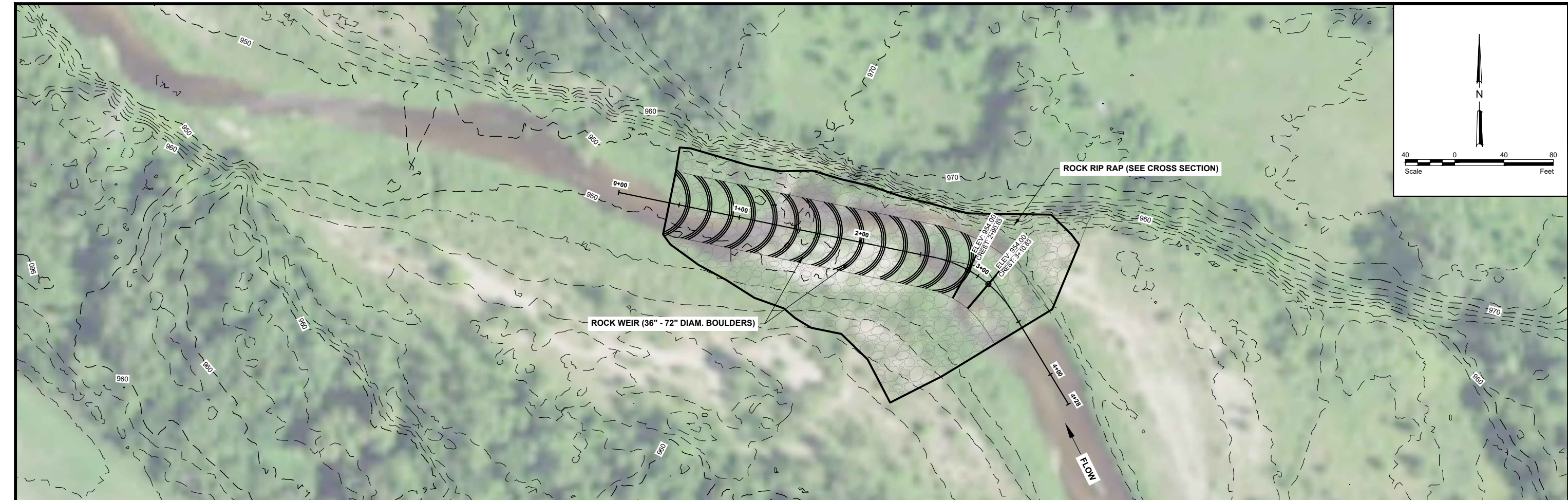
No.	Revision	Date	By

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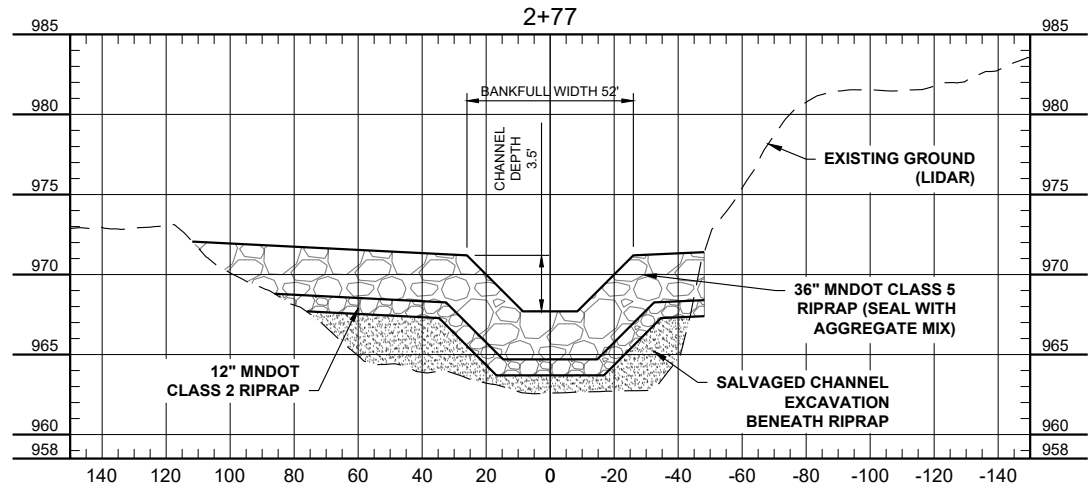
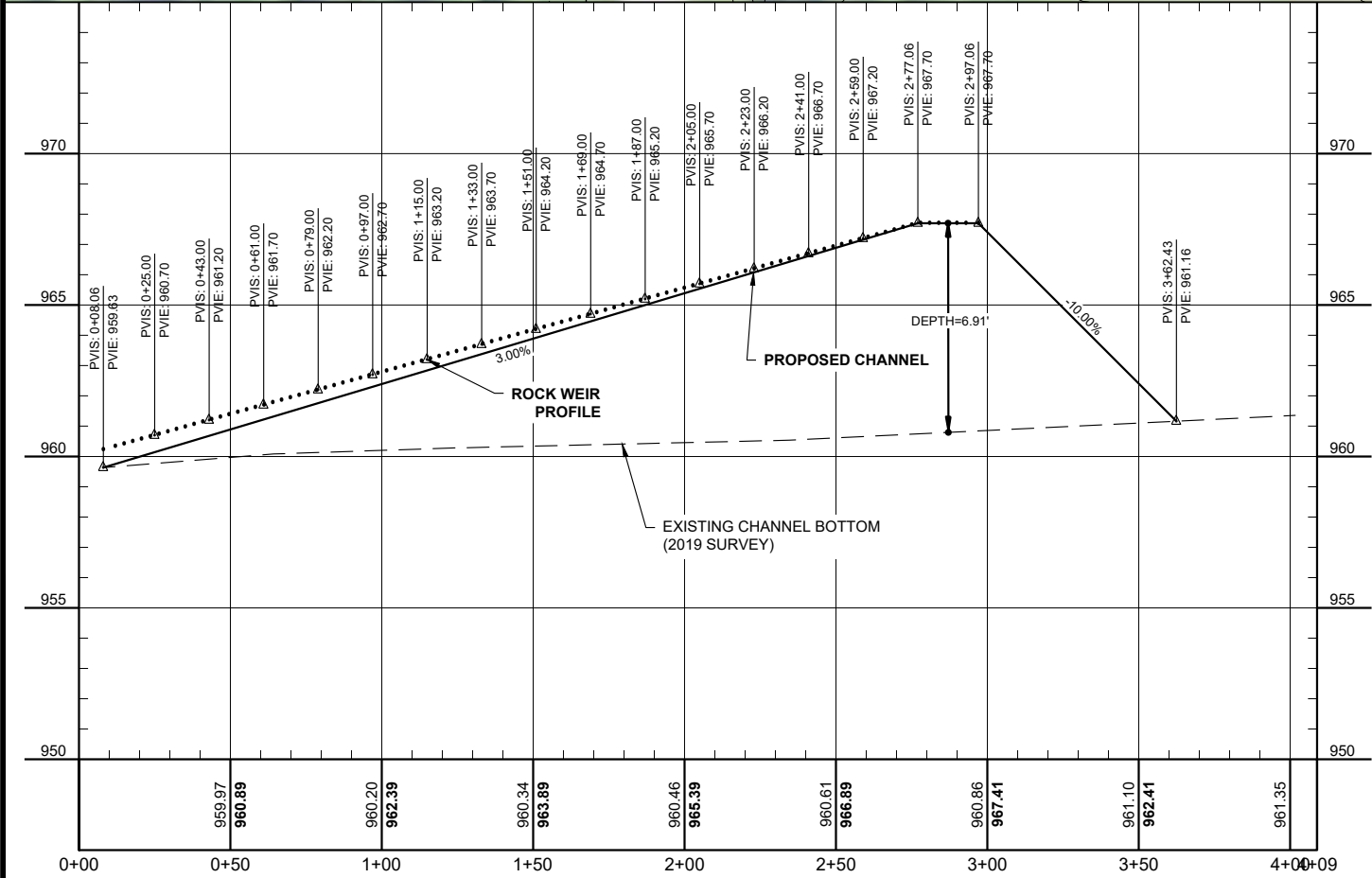
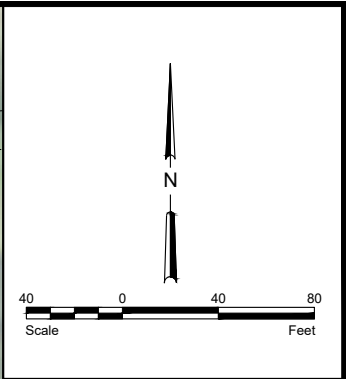
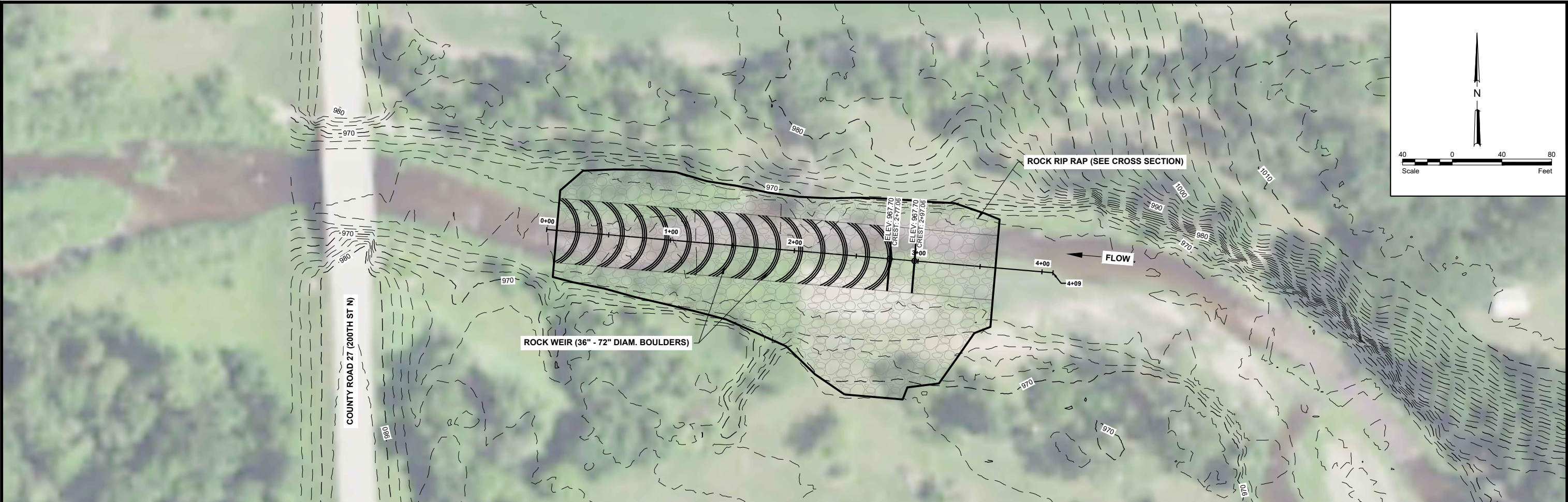
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	Checked by GLB/HRR	Scale AS SHOWN			

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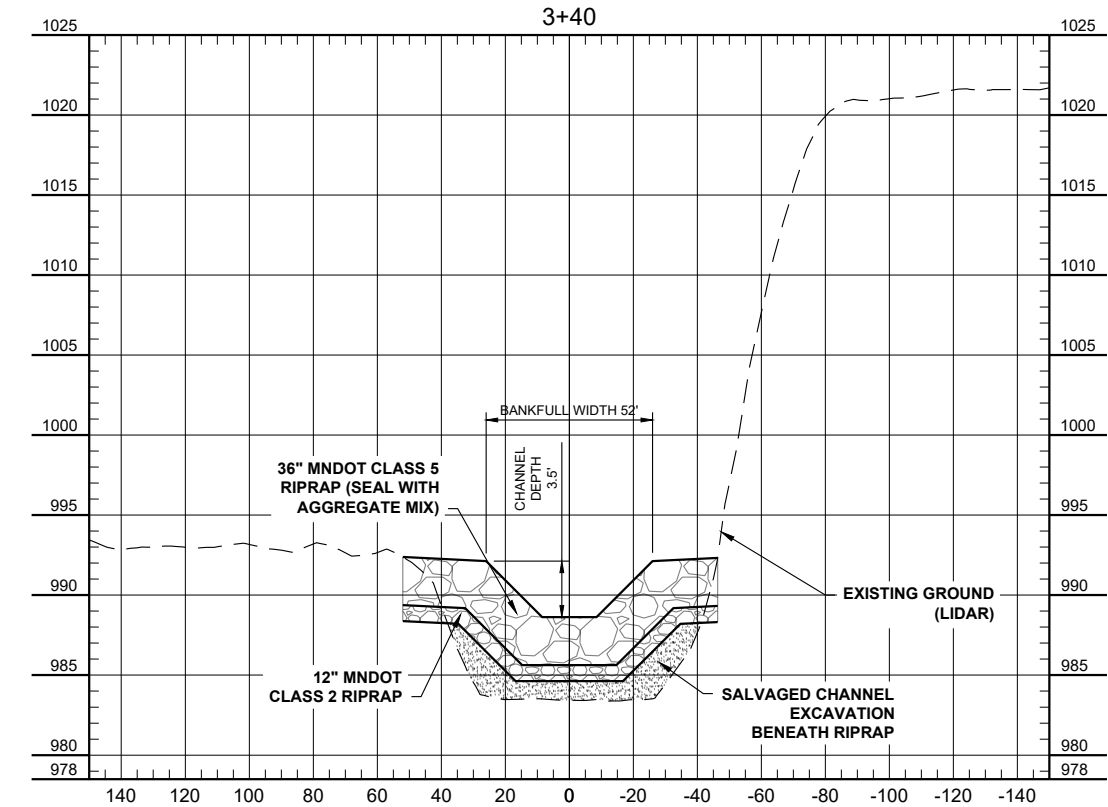
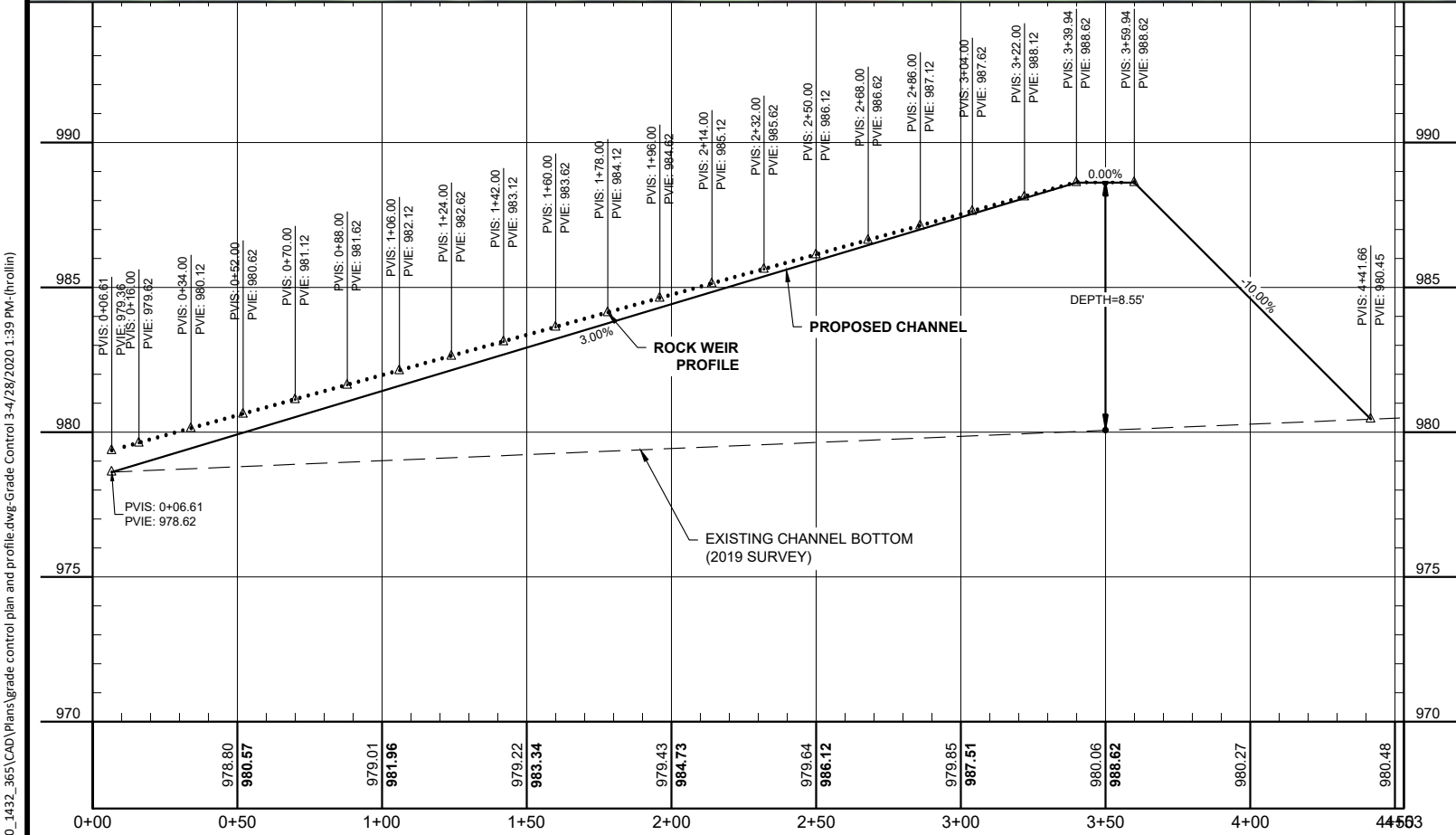
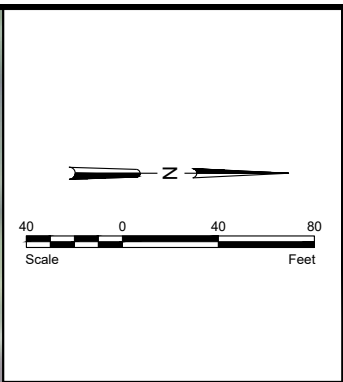
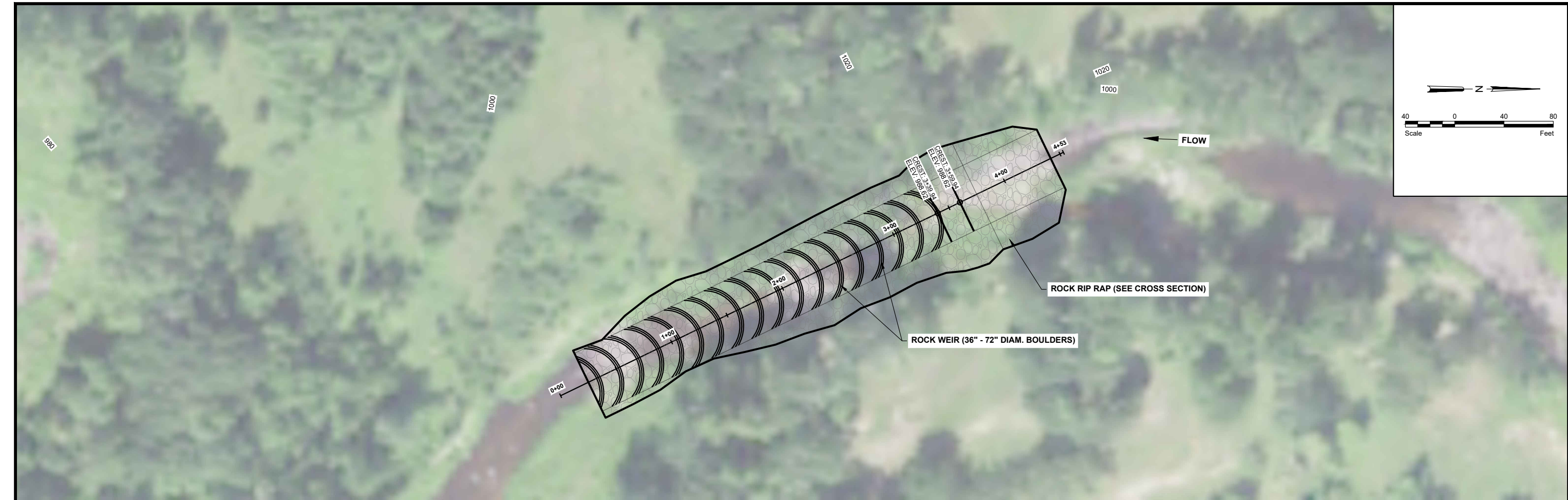
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No.	Revision	Date	By				P: 701.237.5065 F: 701.237.5101	Checked by GLB/HRR	Scale AS SHOWN			

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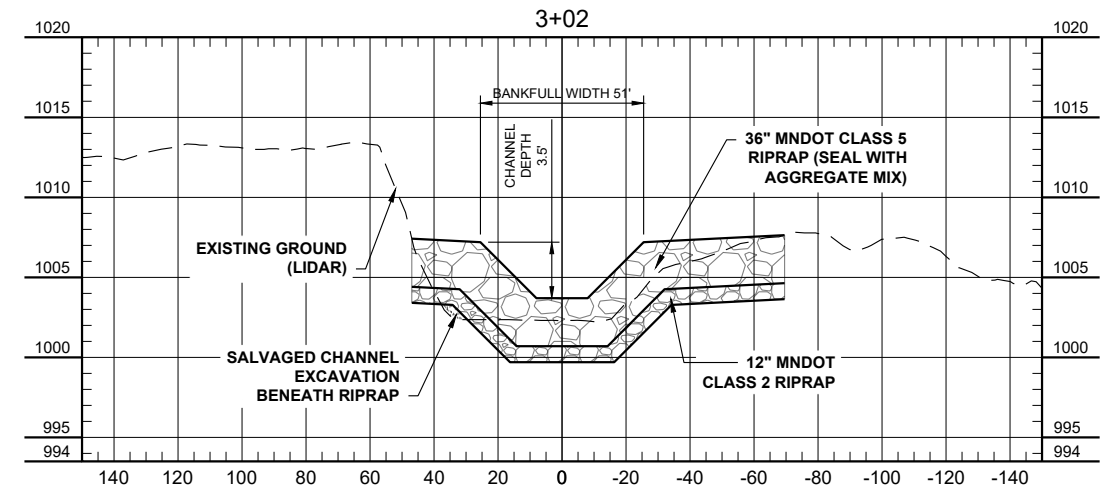
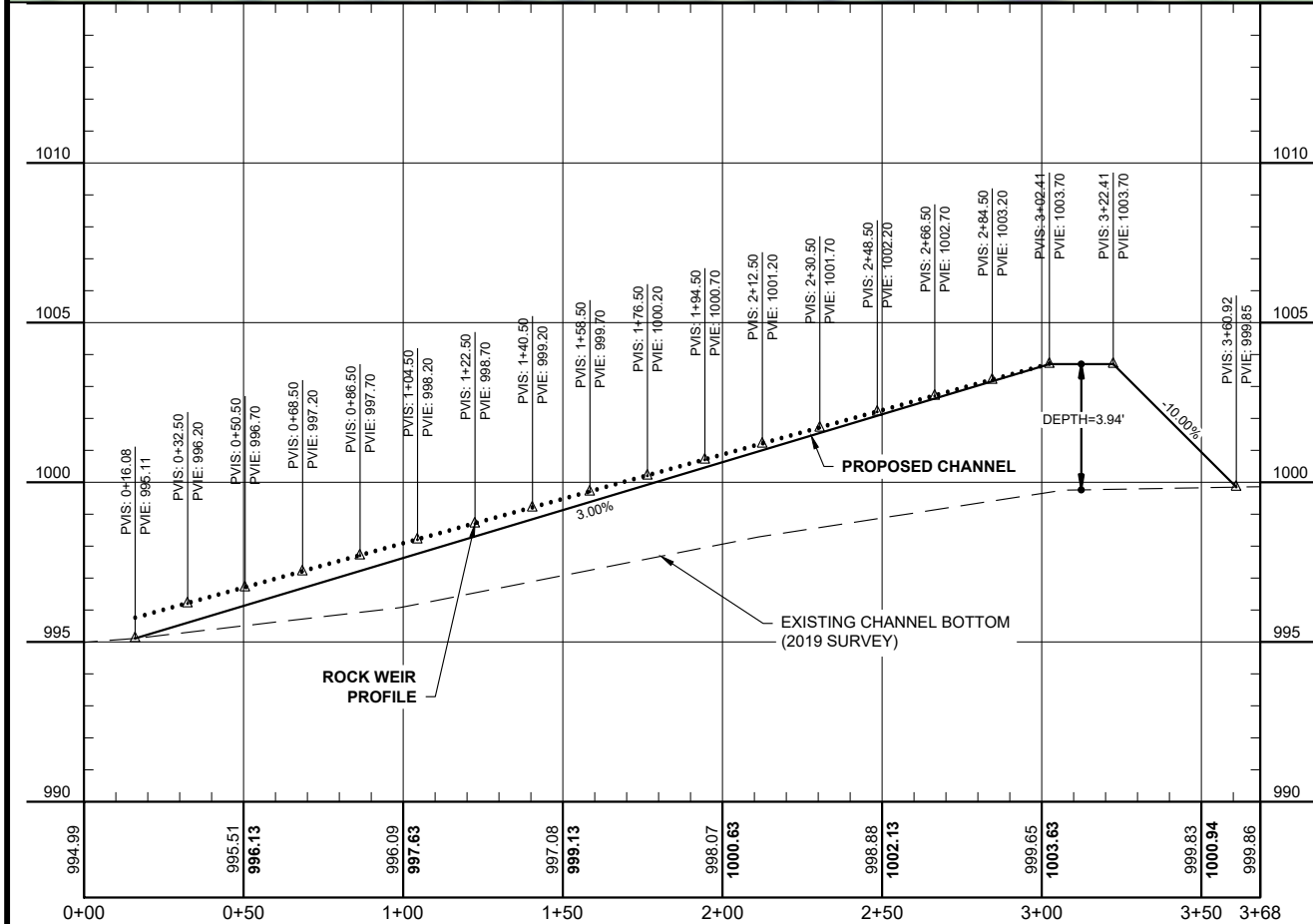
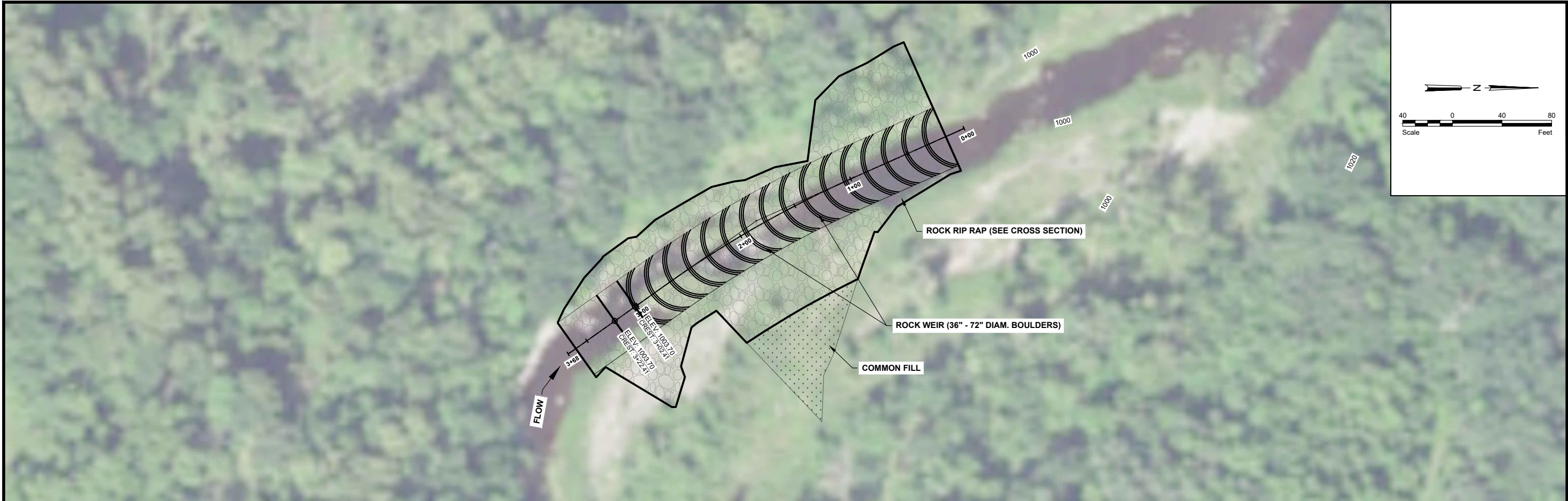
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No.	Revision	Date	By								

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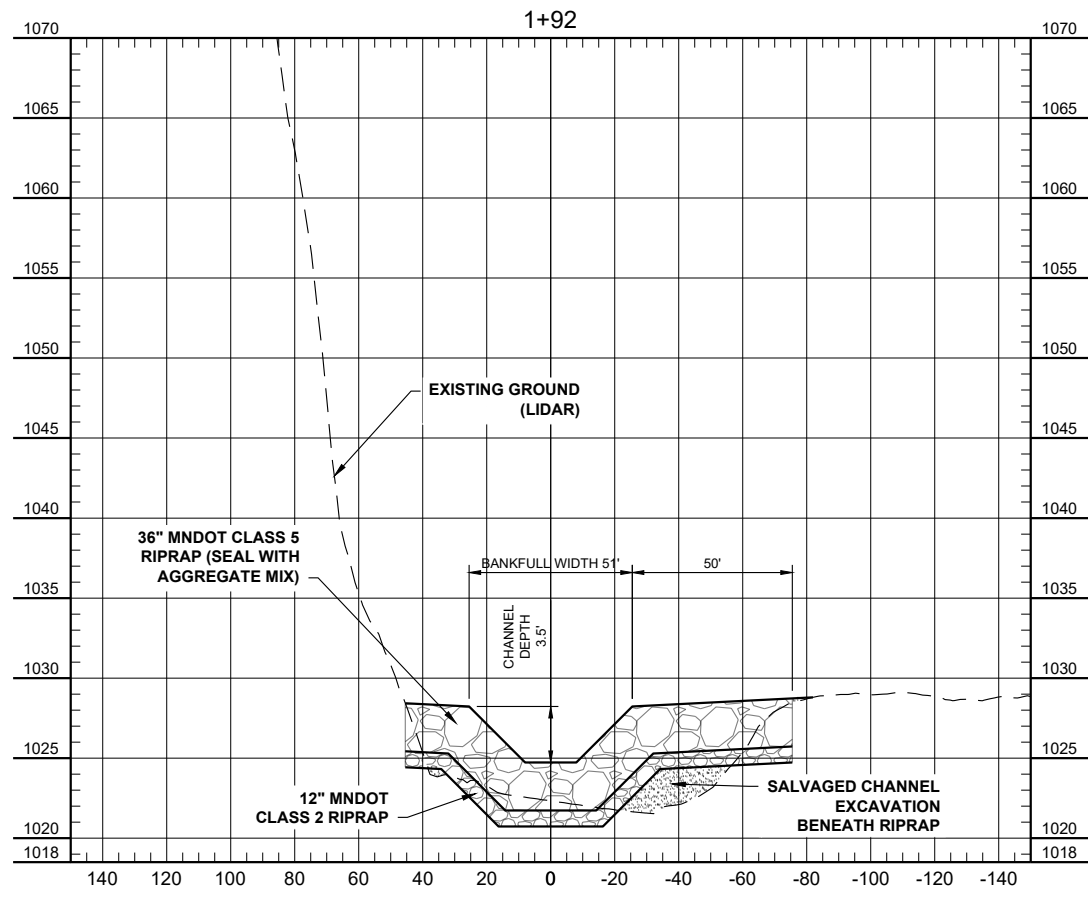
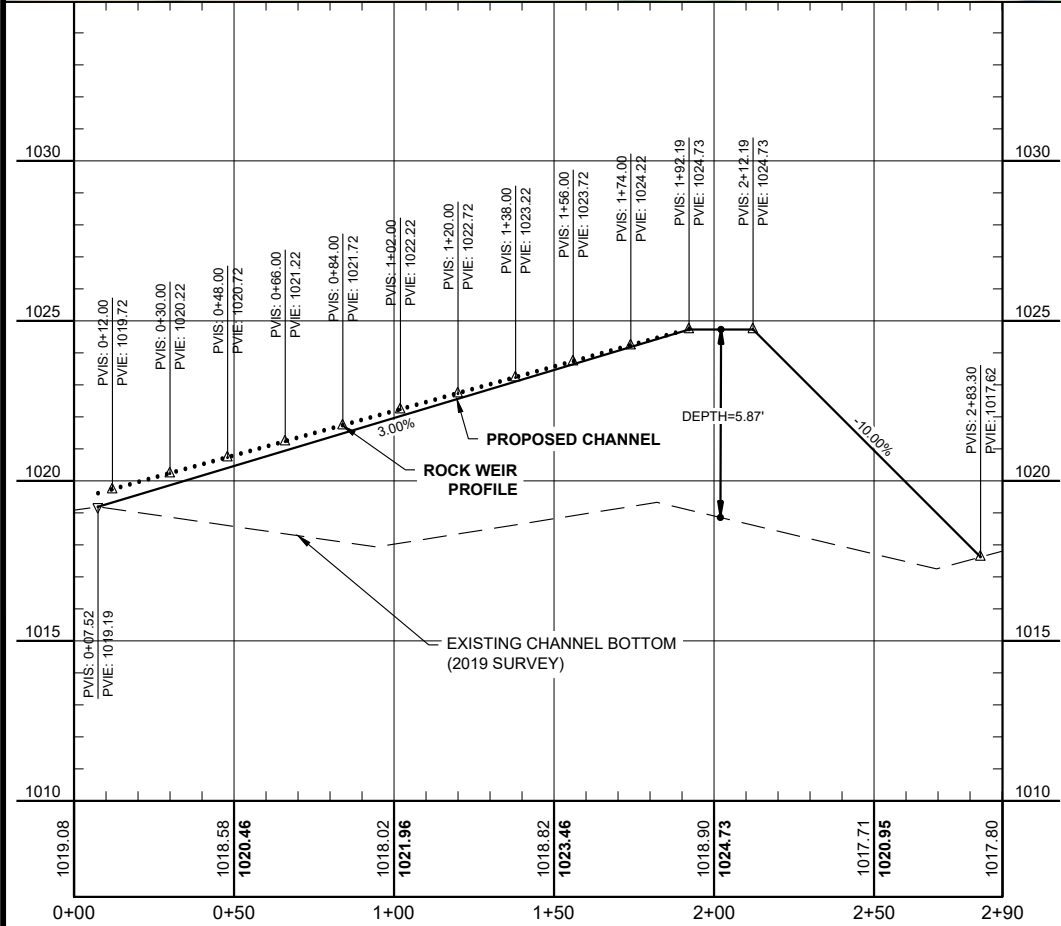
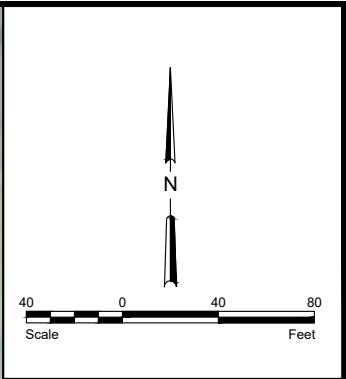
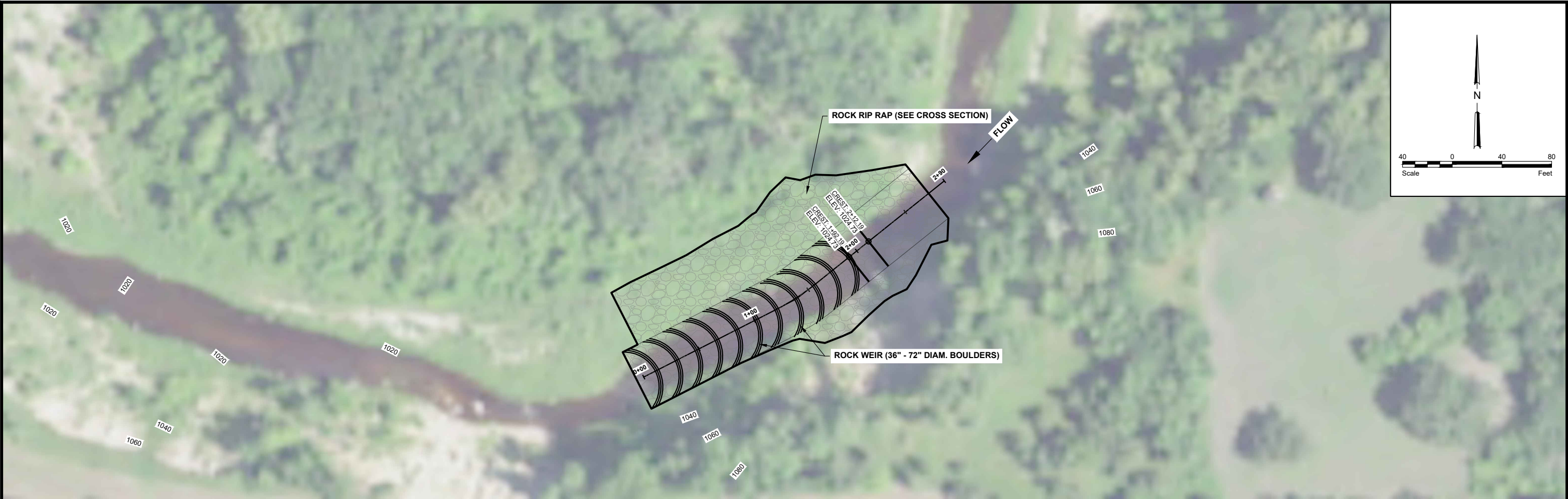
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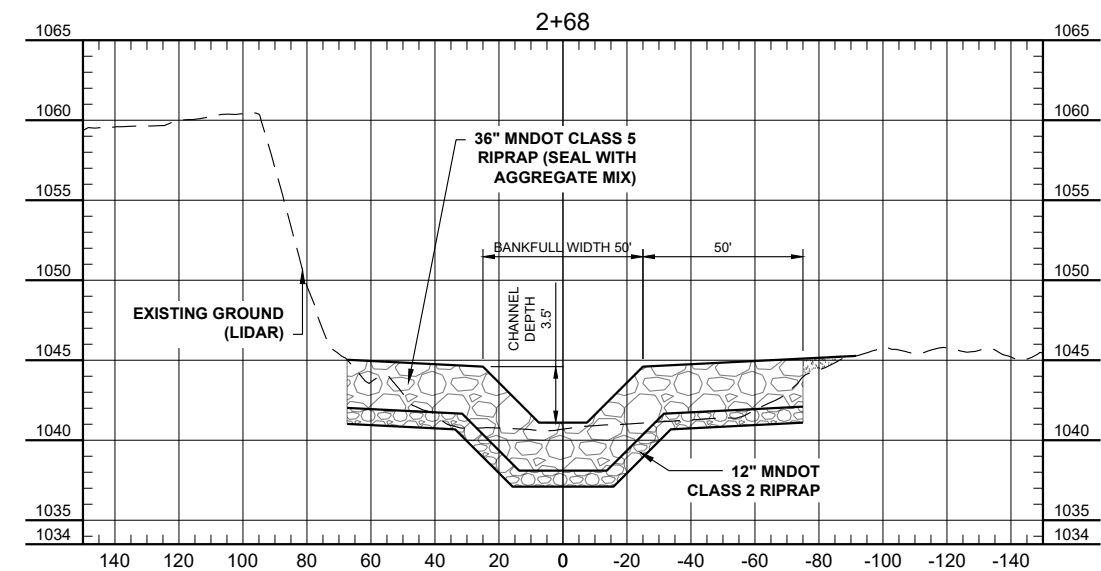
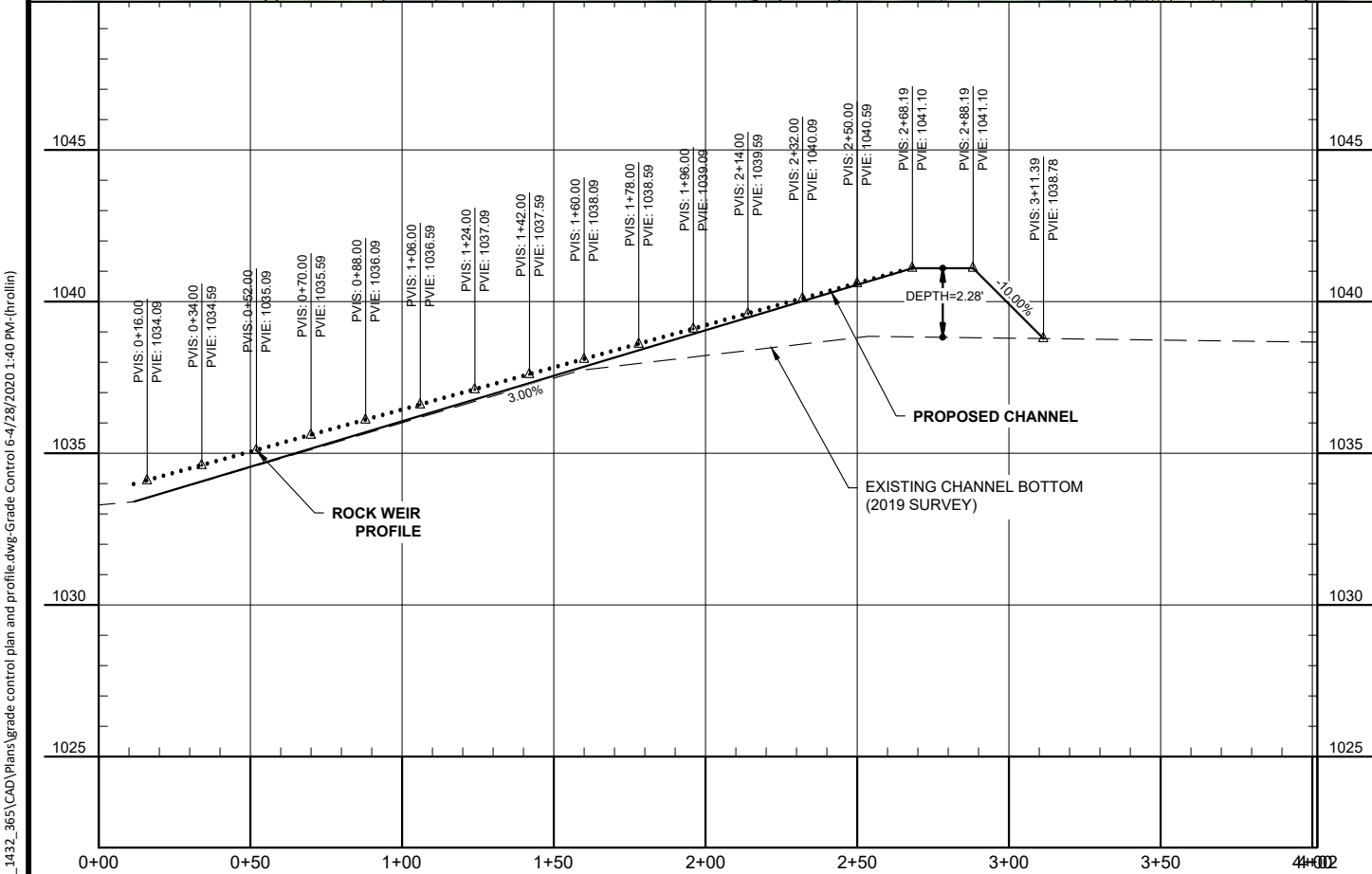
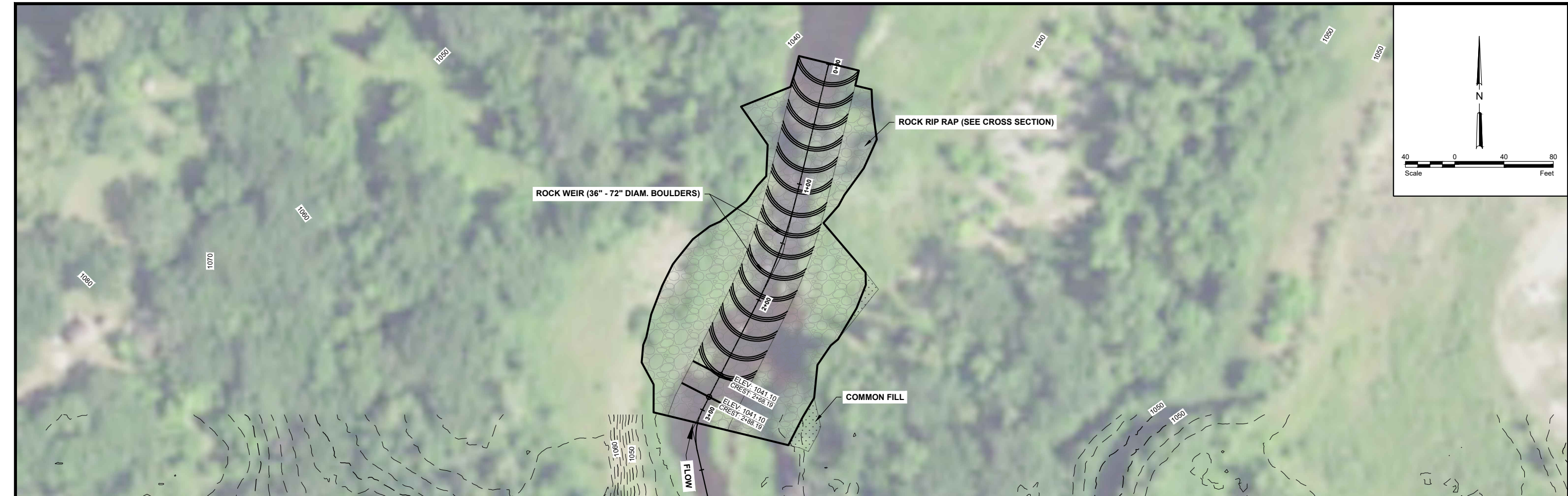


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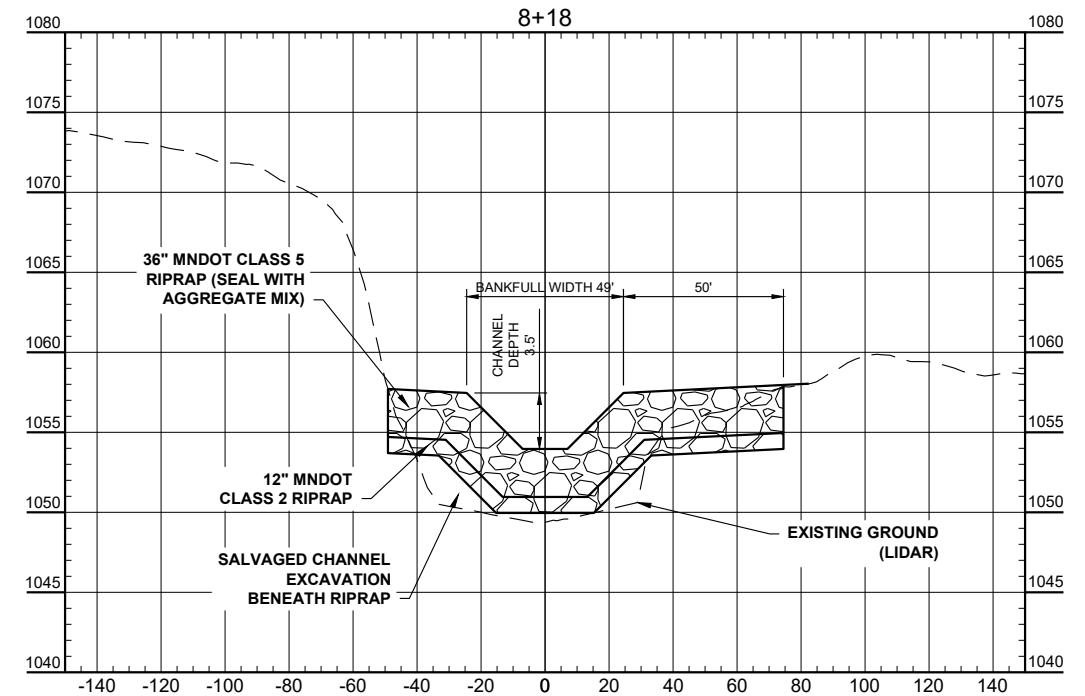
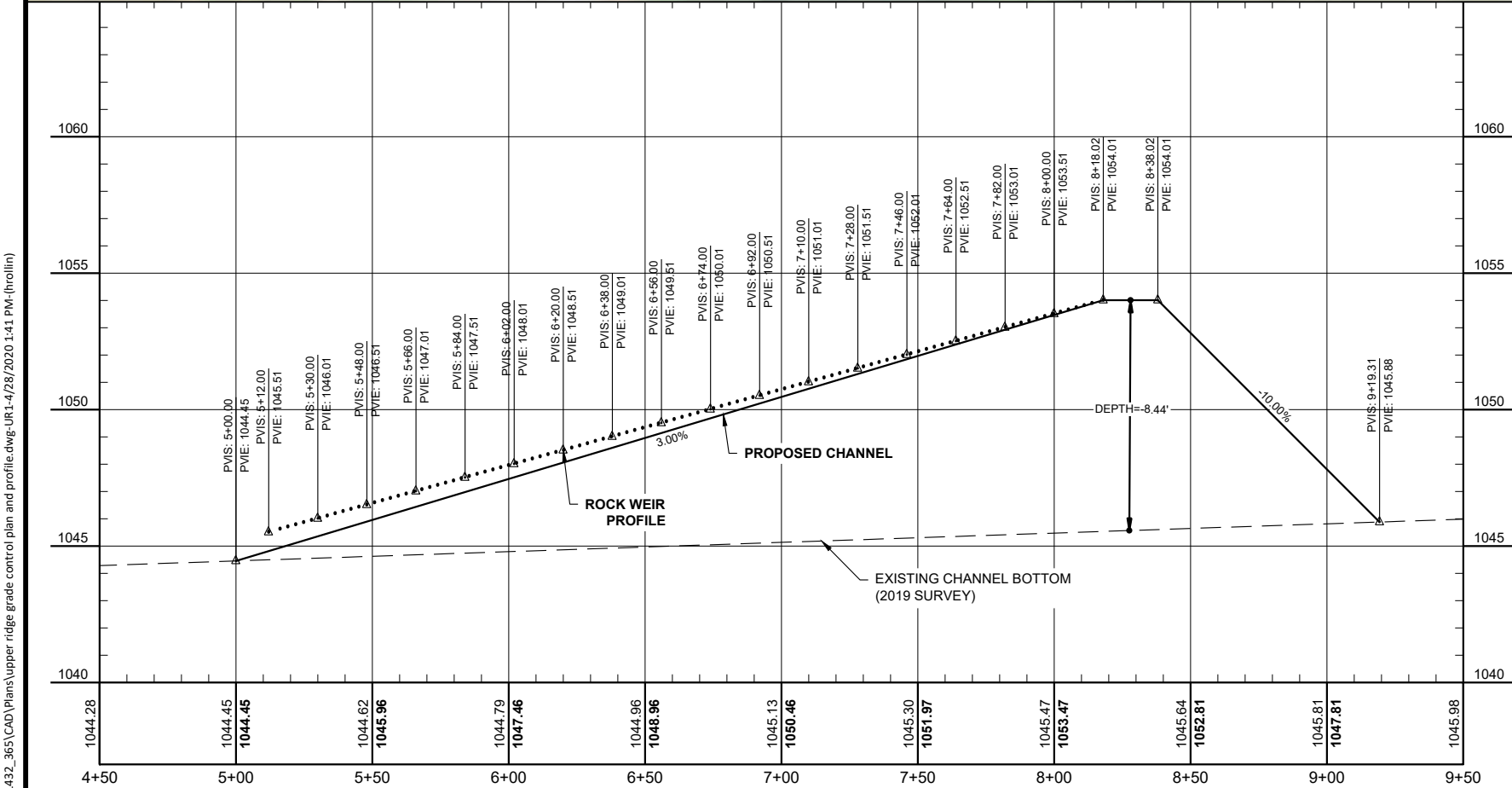
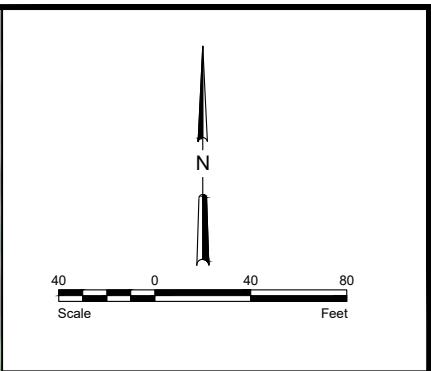
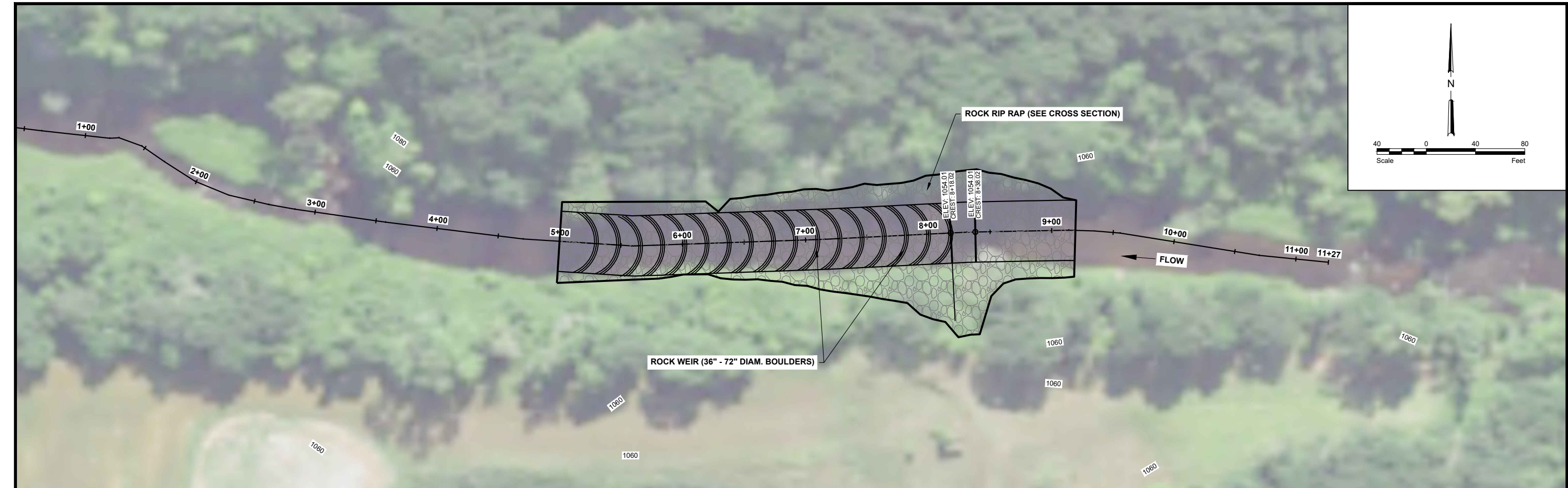


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No.	Revision	Date	By								



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No.	Revision	Date	By

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GLB/HRR

Date
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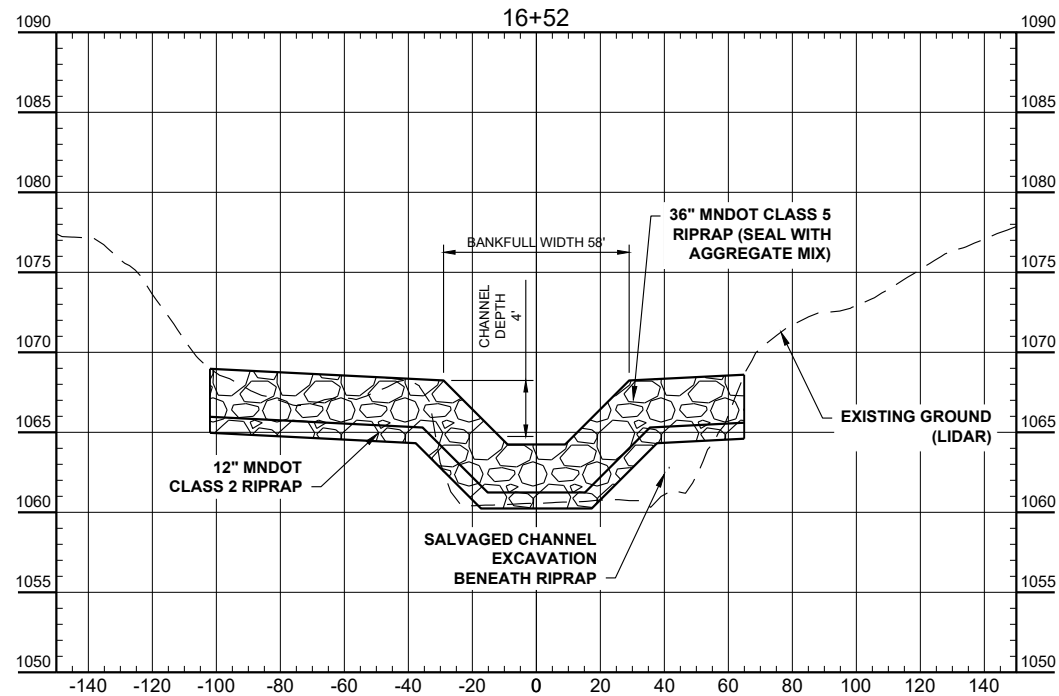
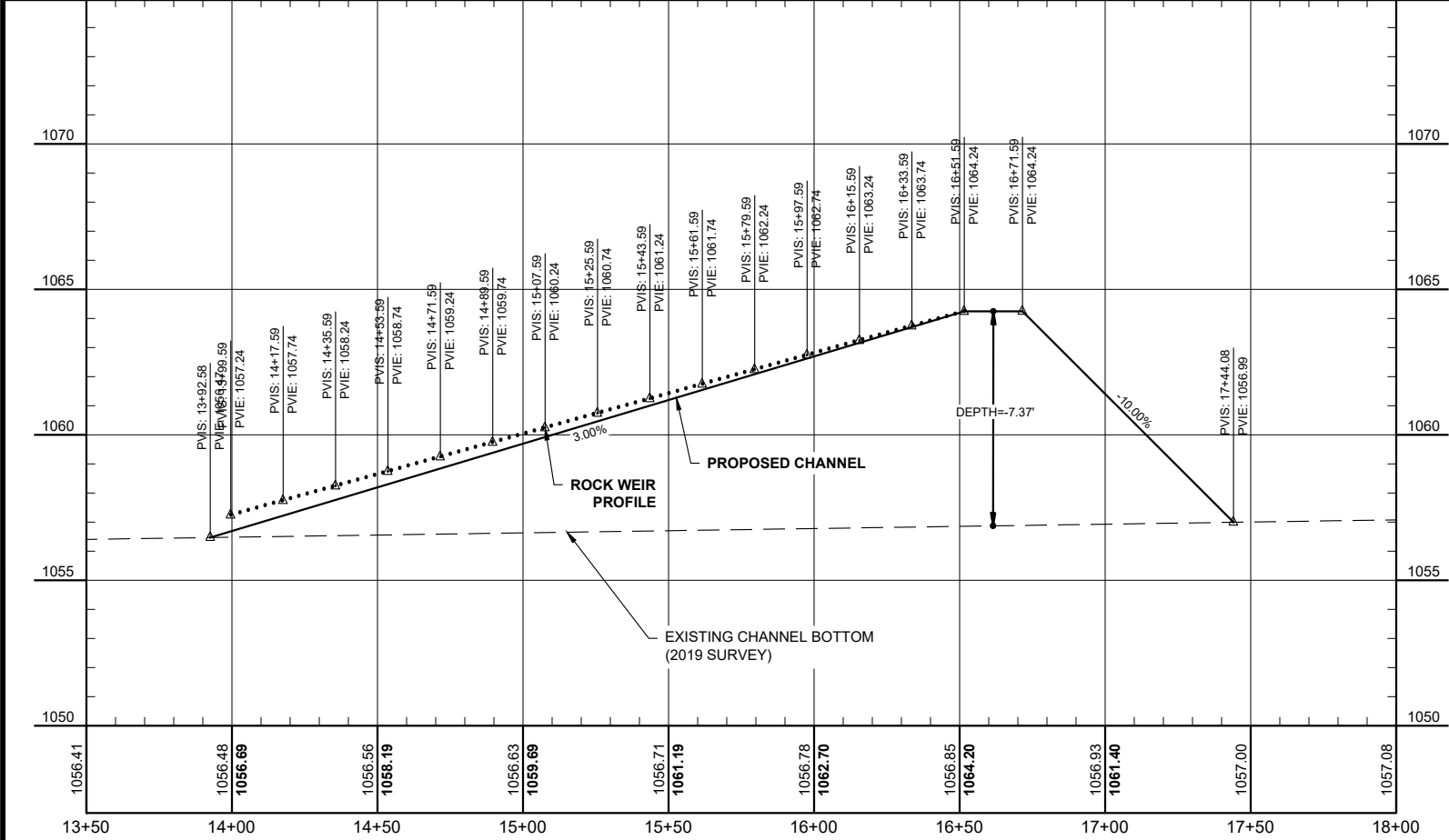
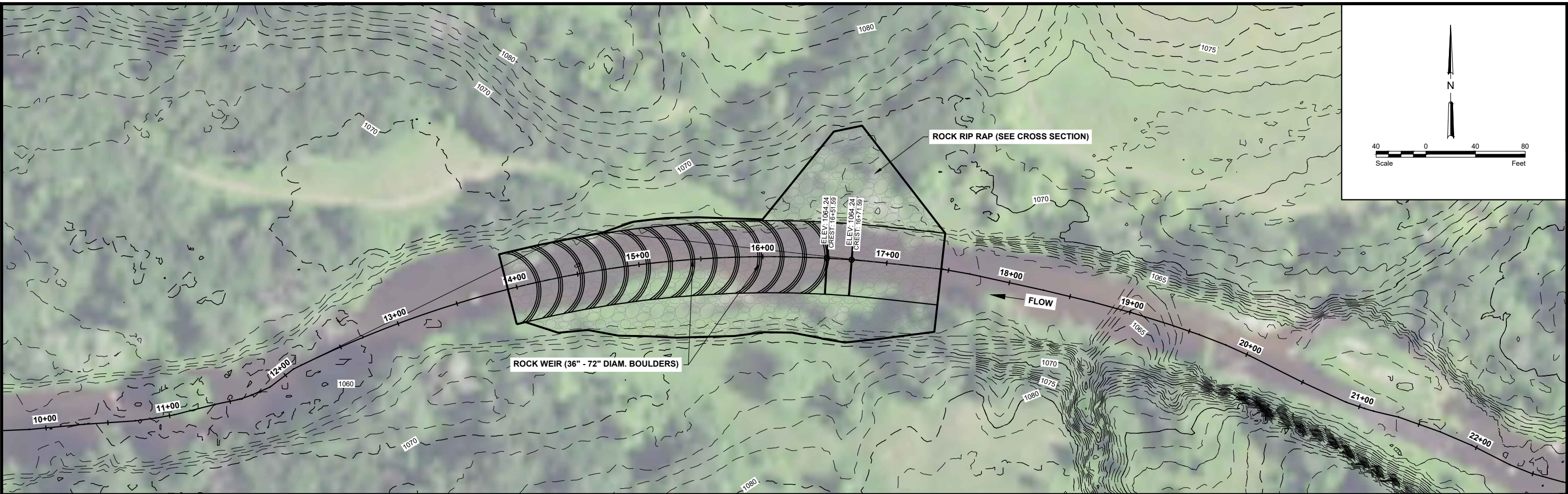
SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

UPPER RIDGE
ROCK ARCH RAPIDS 1
PLAN AND PROFILE
PROJECT NO. 1432-0365

SHEET

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No.	Revision	Date	By

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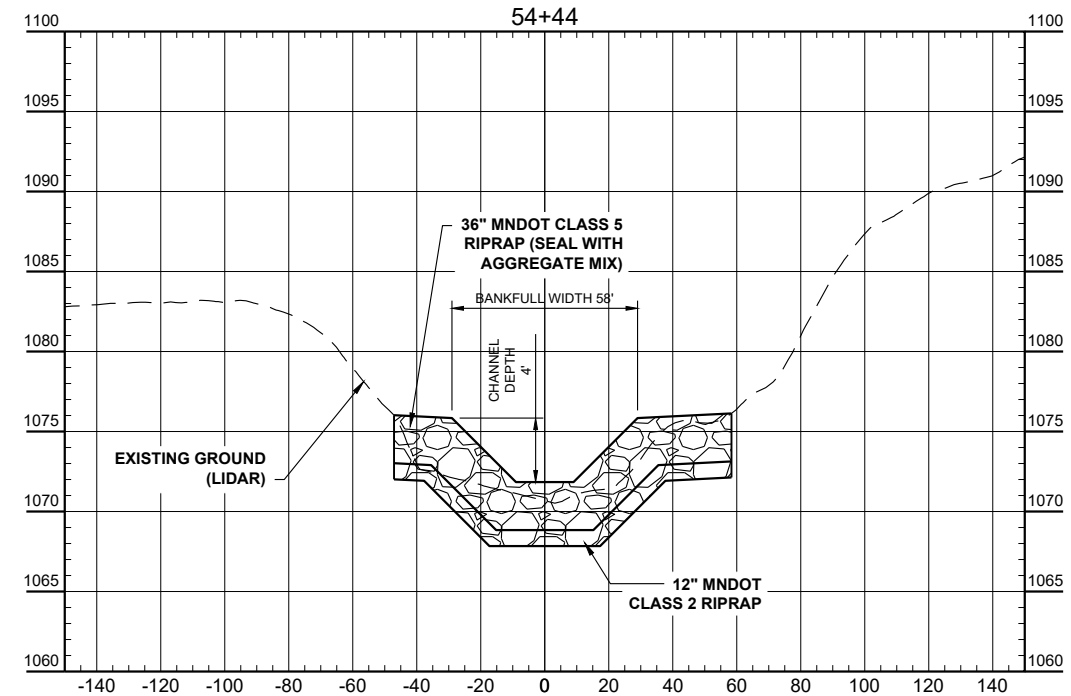
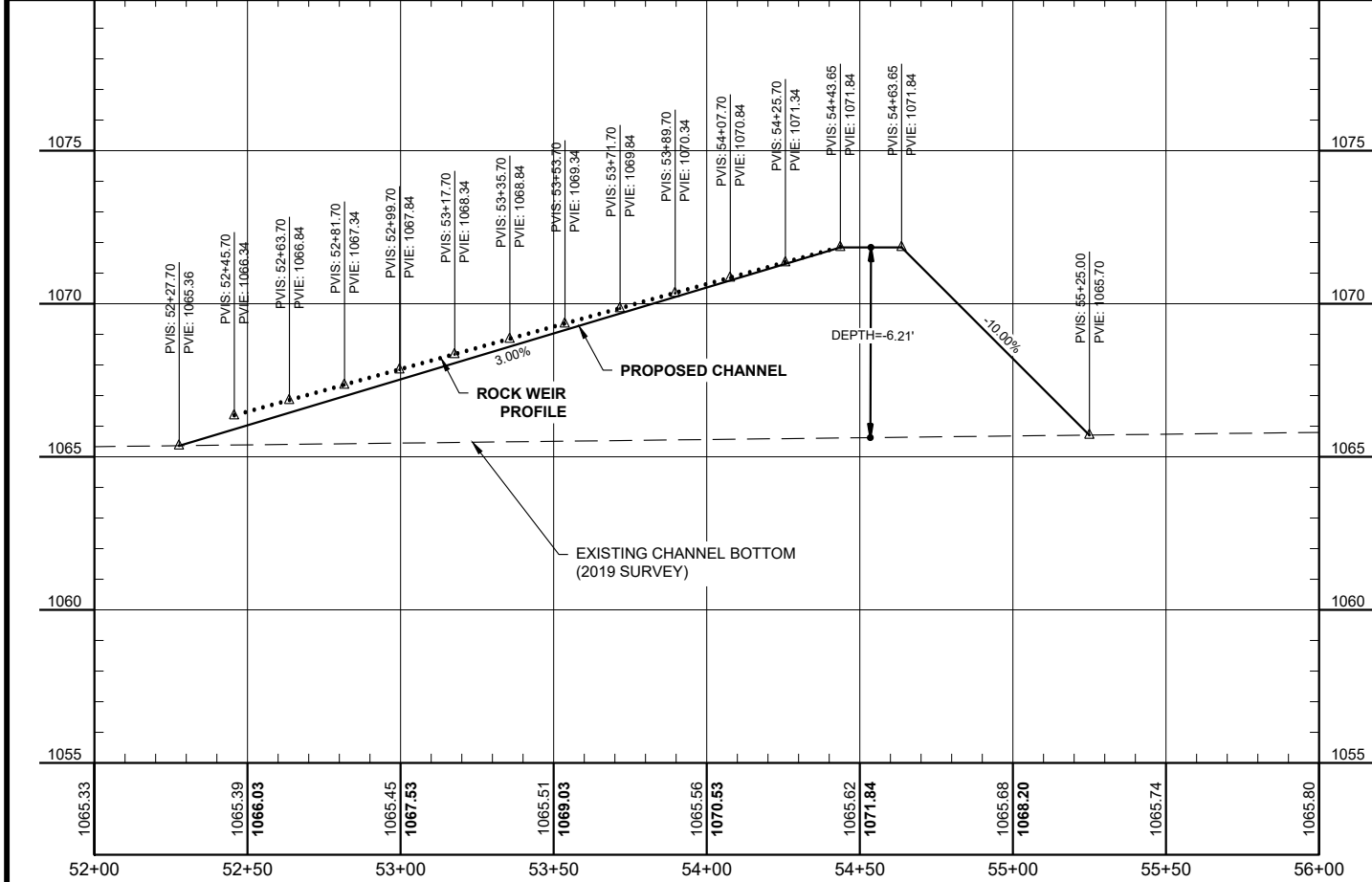
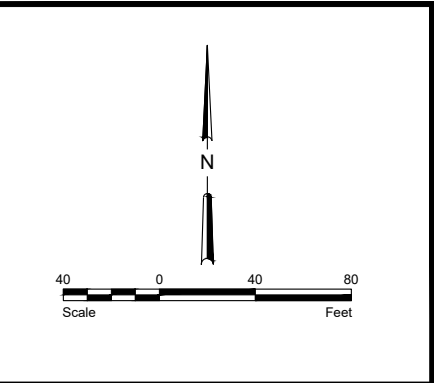
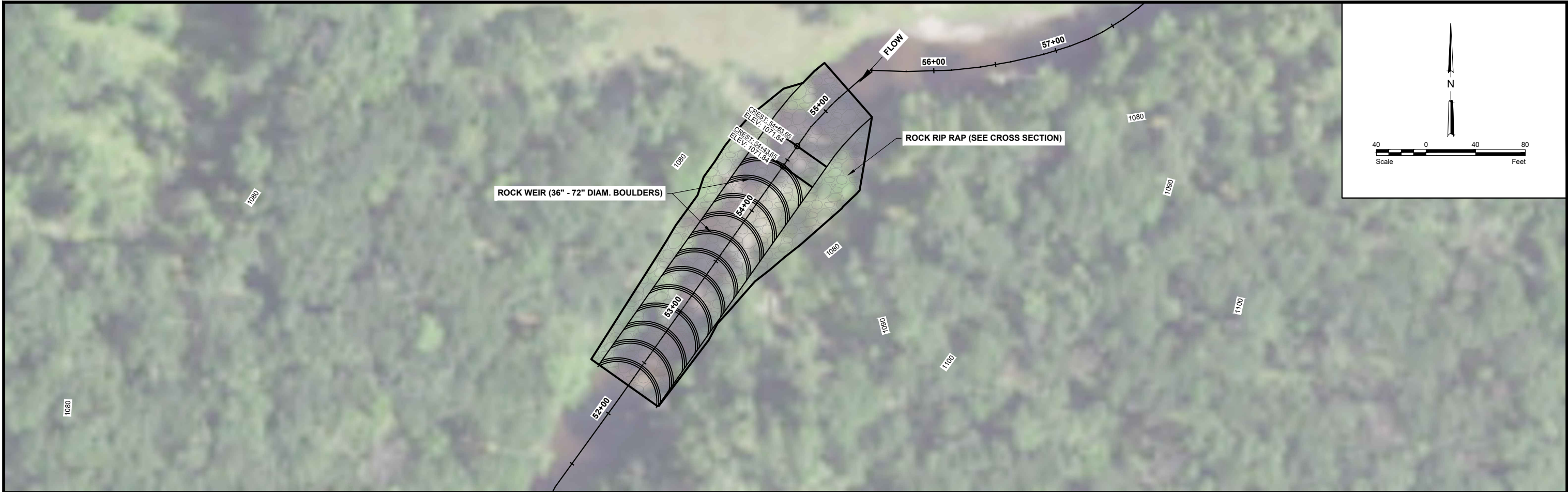
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

UPPER RIDGE
ROCK ARCH RAPIDS 2
PLAN AND PROFILE
PROJECT NO. 1432-0365

SHEET
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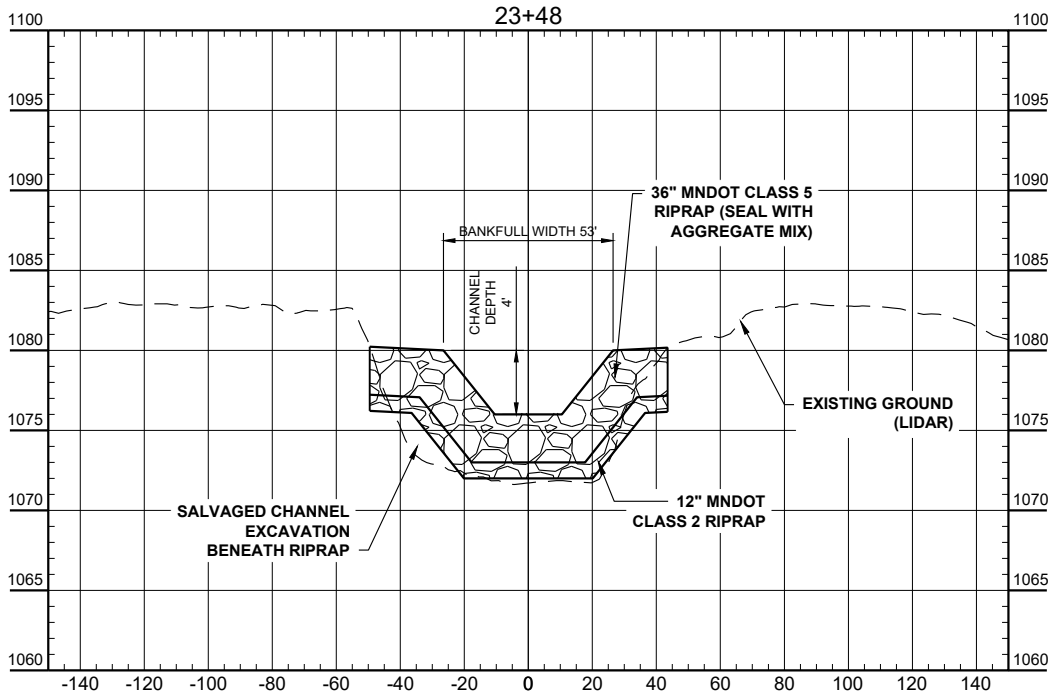
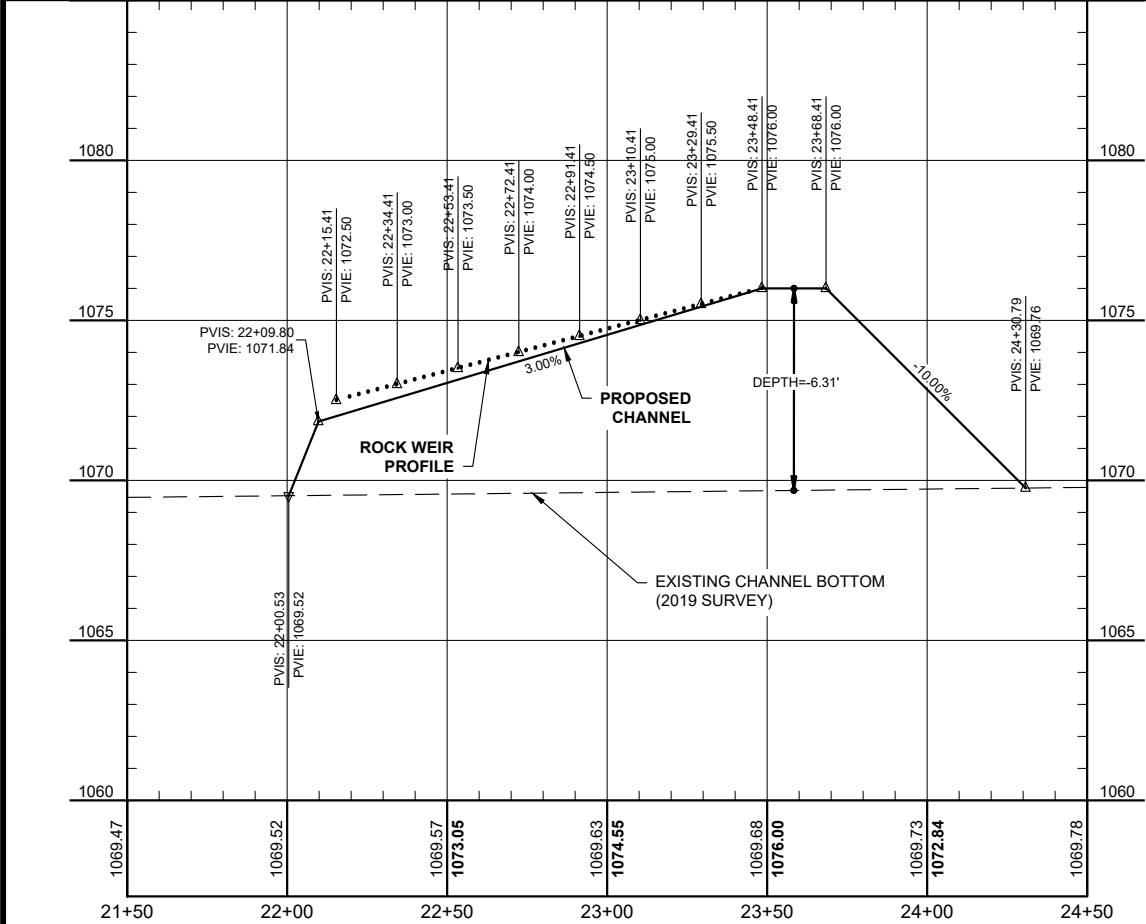
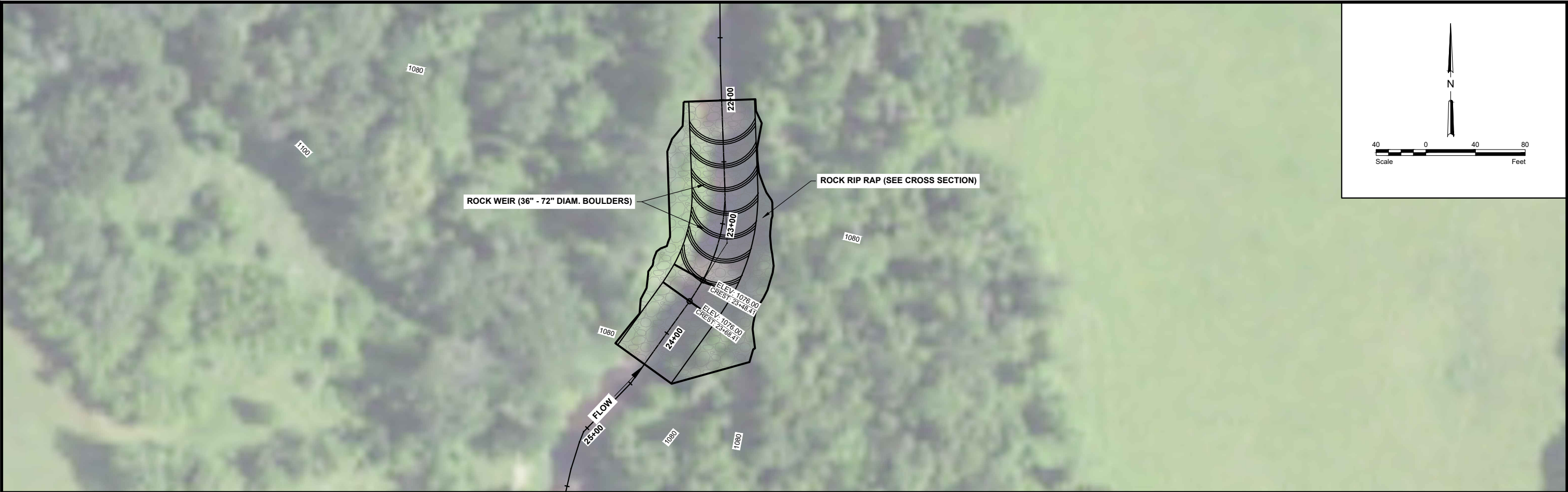
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P: 701.237.5065 F: 701.237.5101	Checked by GLB/HRR	Scale AS SHOWN

SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

UPPER RIDGE
ROCK ARCH RAPIDS 3
PLAN AND PROFILE
PROJECT NO. 1432-0365

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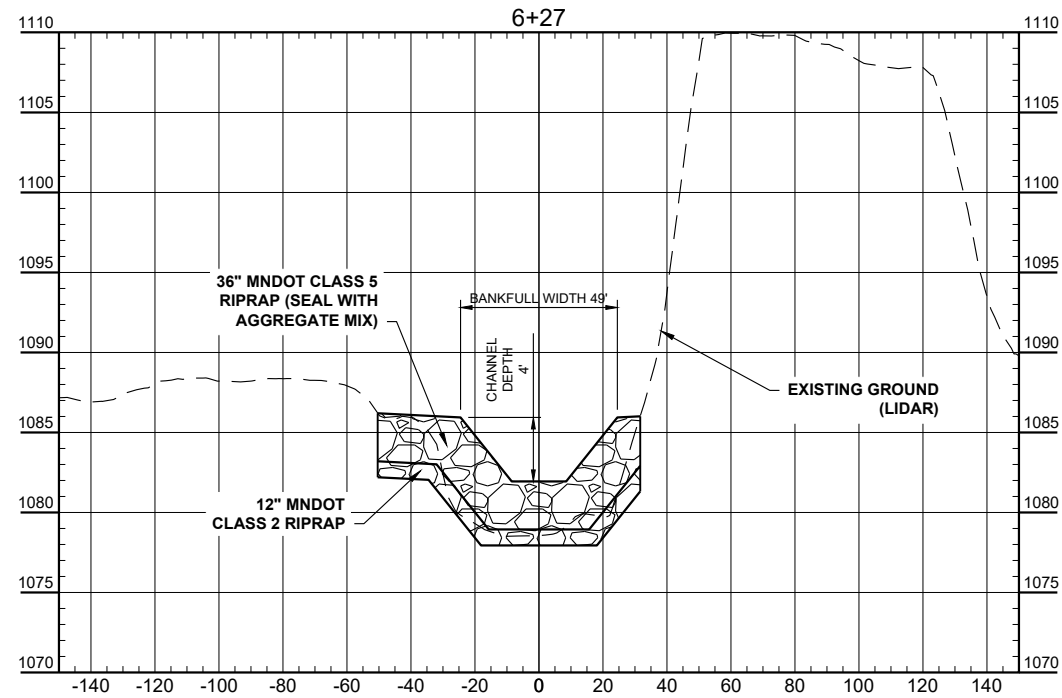
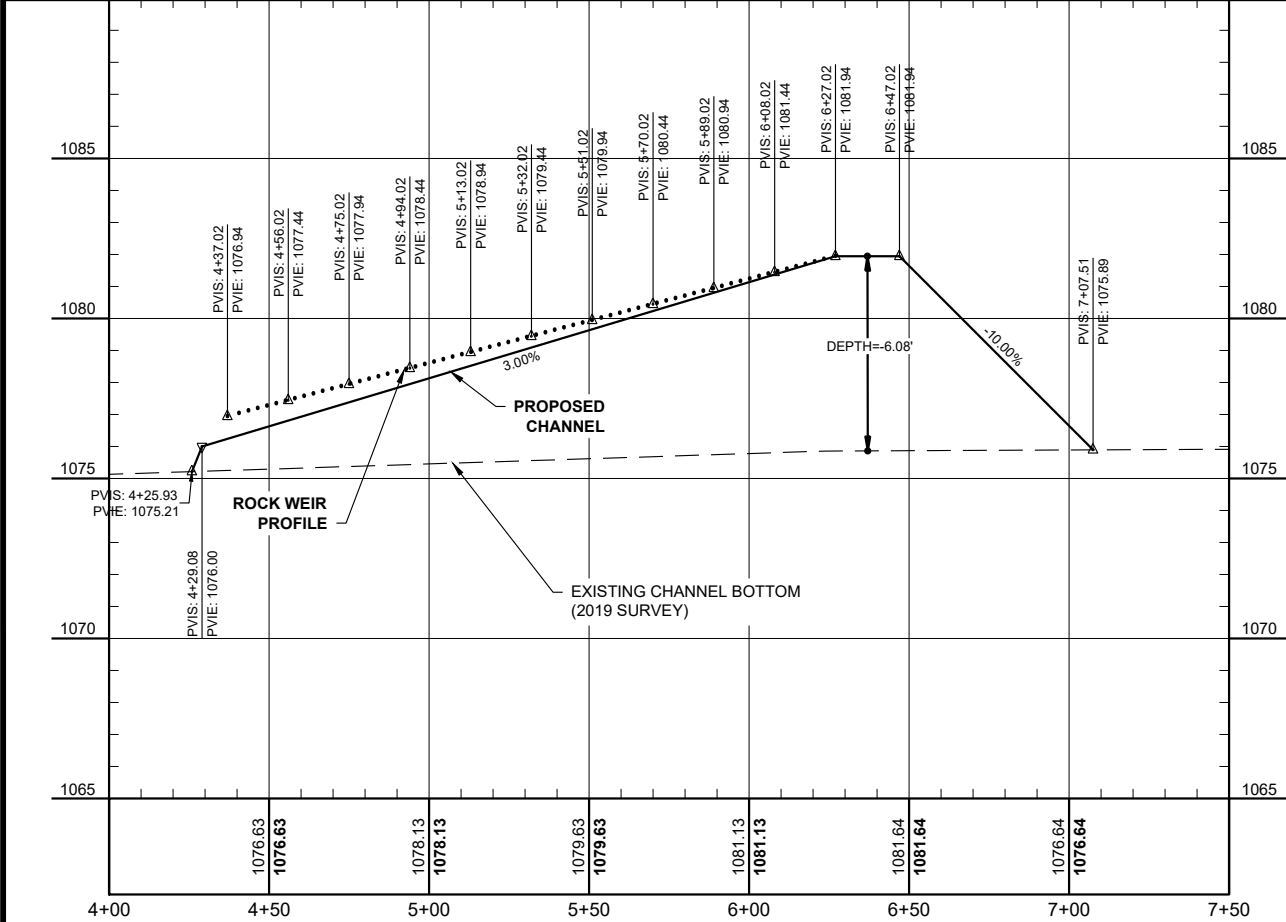
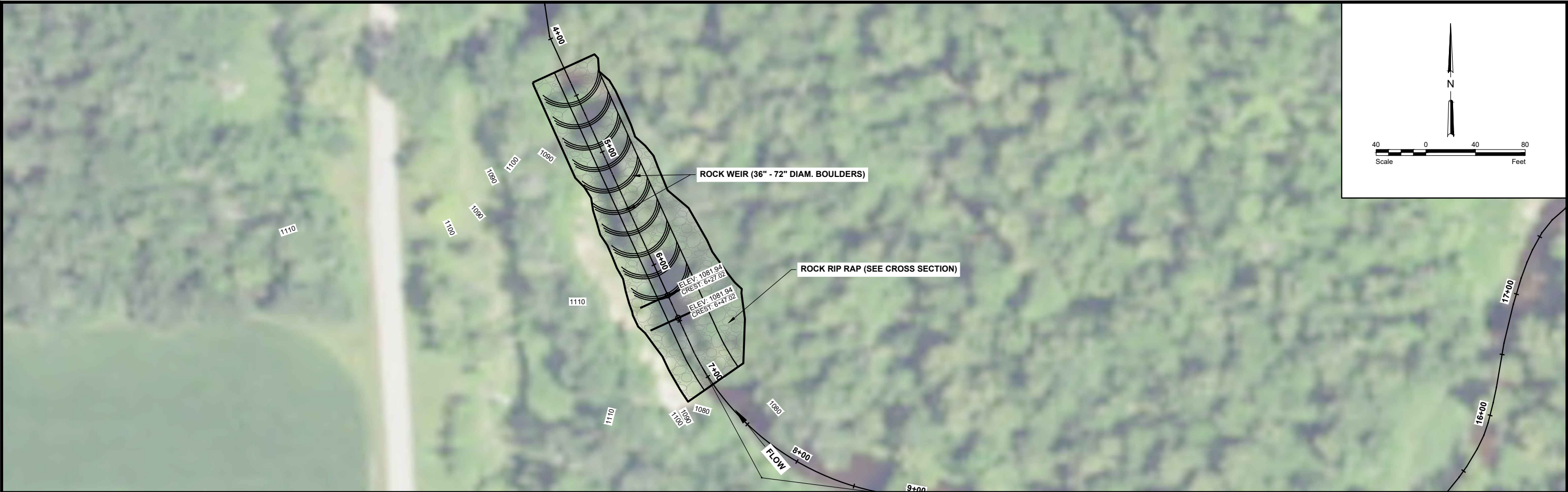
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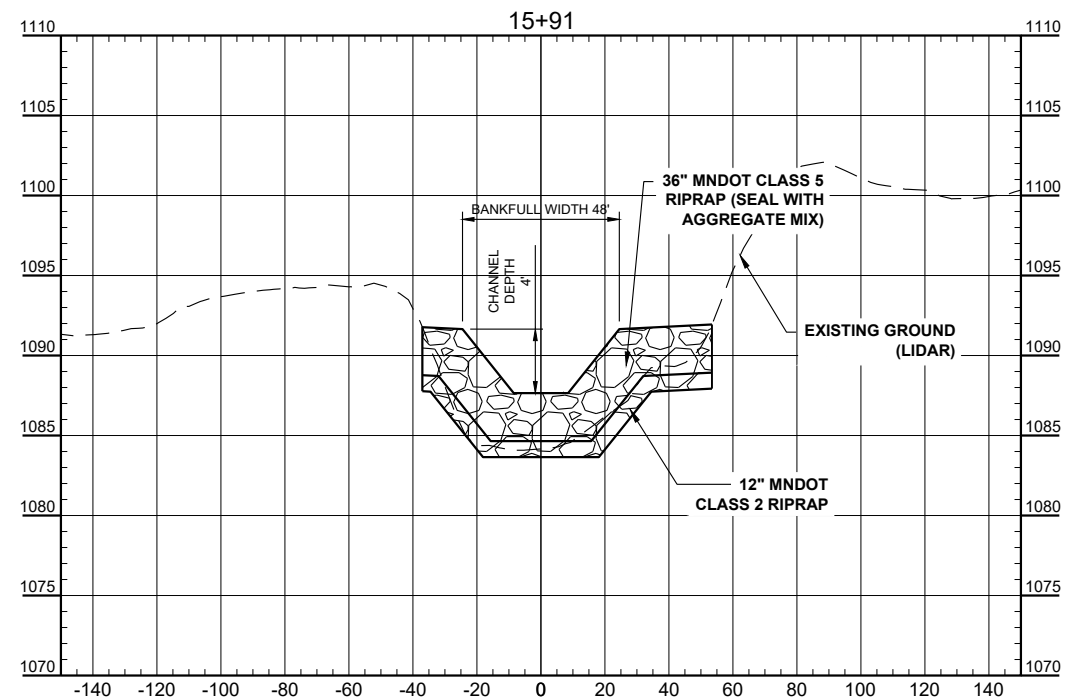
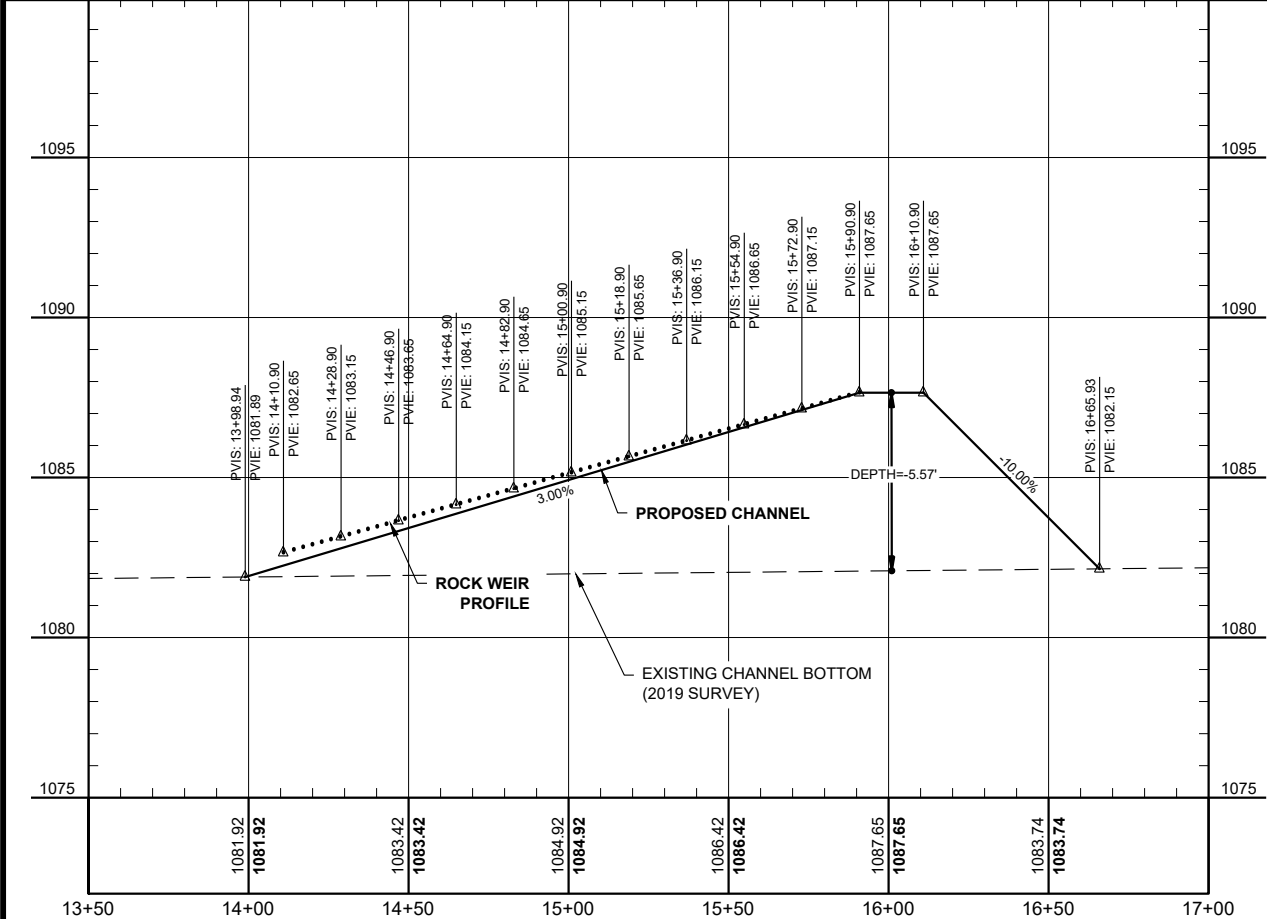
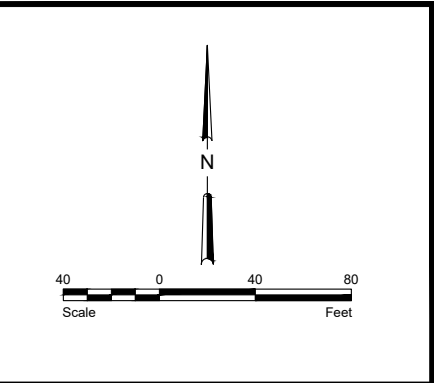
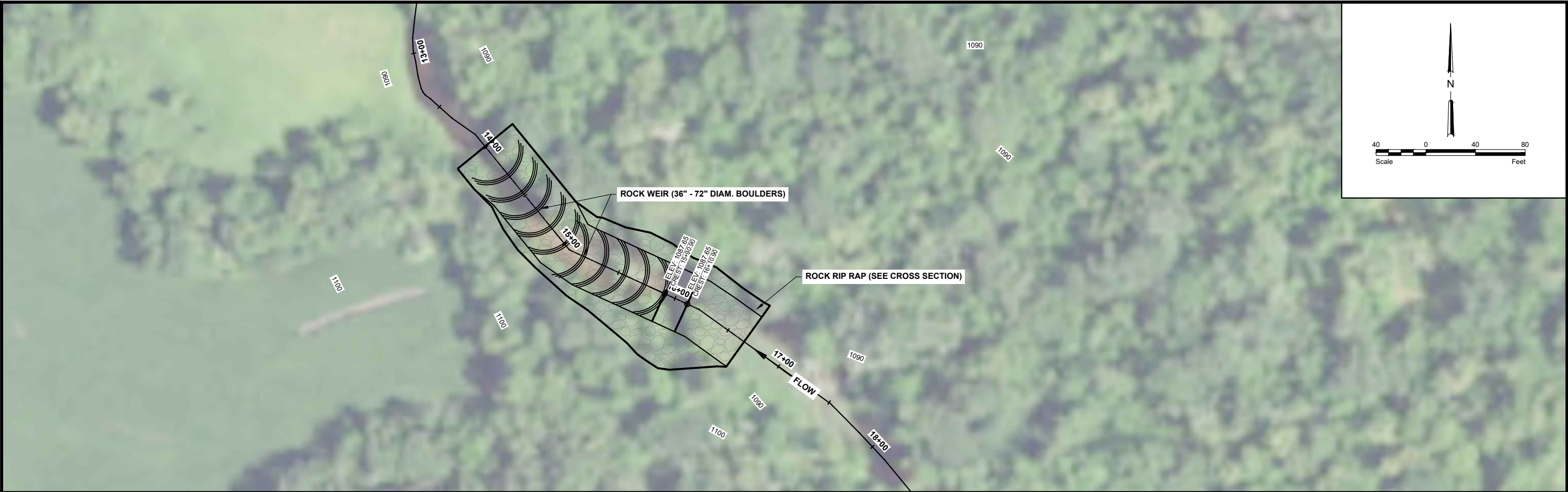
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

UPPER RIDGE
ROCK ARCH RAPIDS 5
PLAN AND PROFILE
PROJECT NO. 1432-0365

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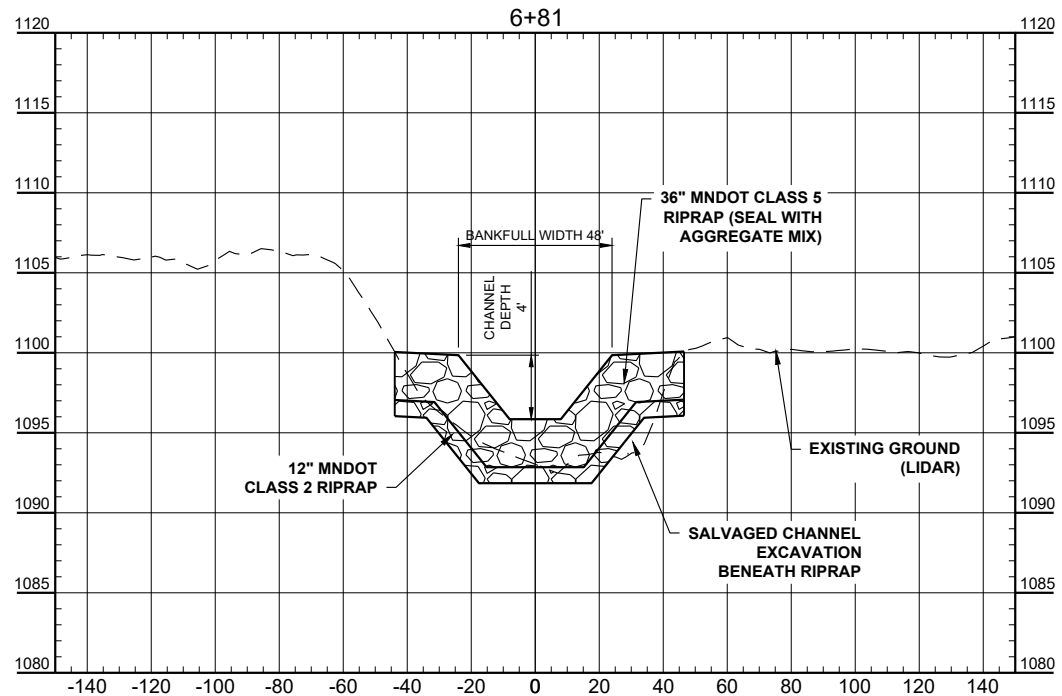
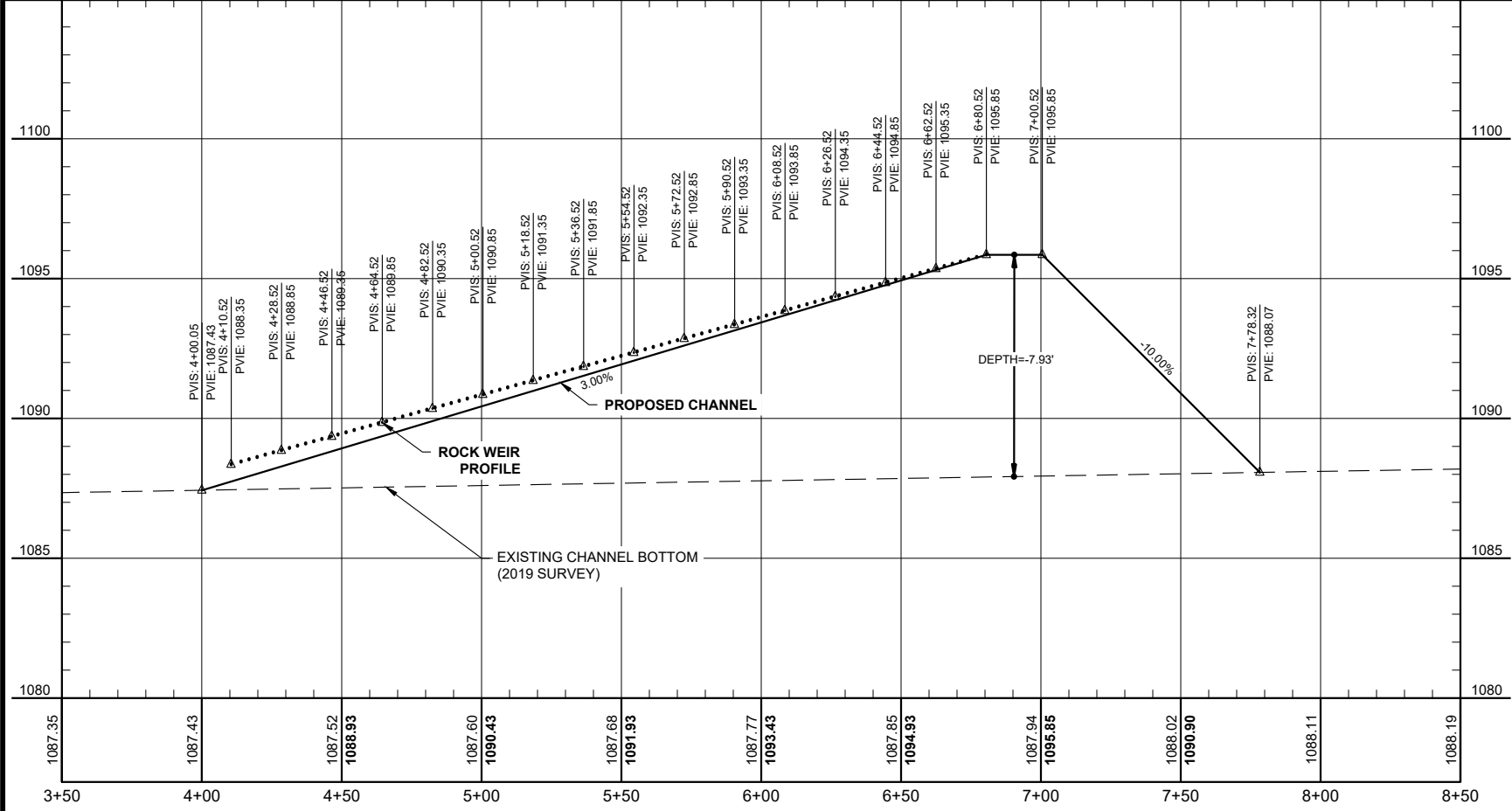
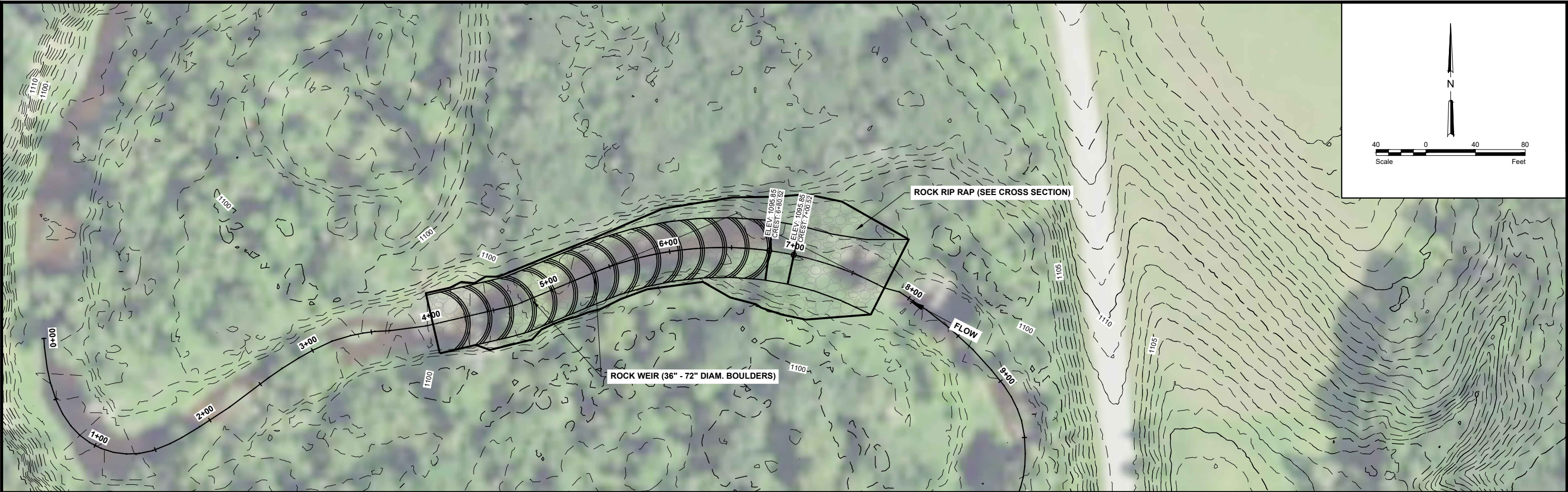
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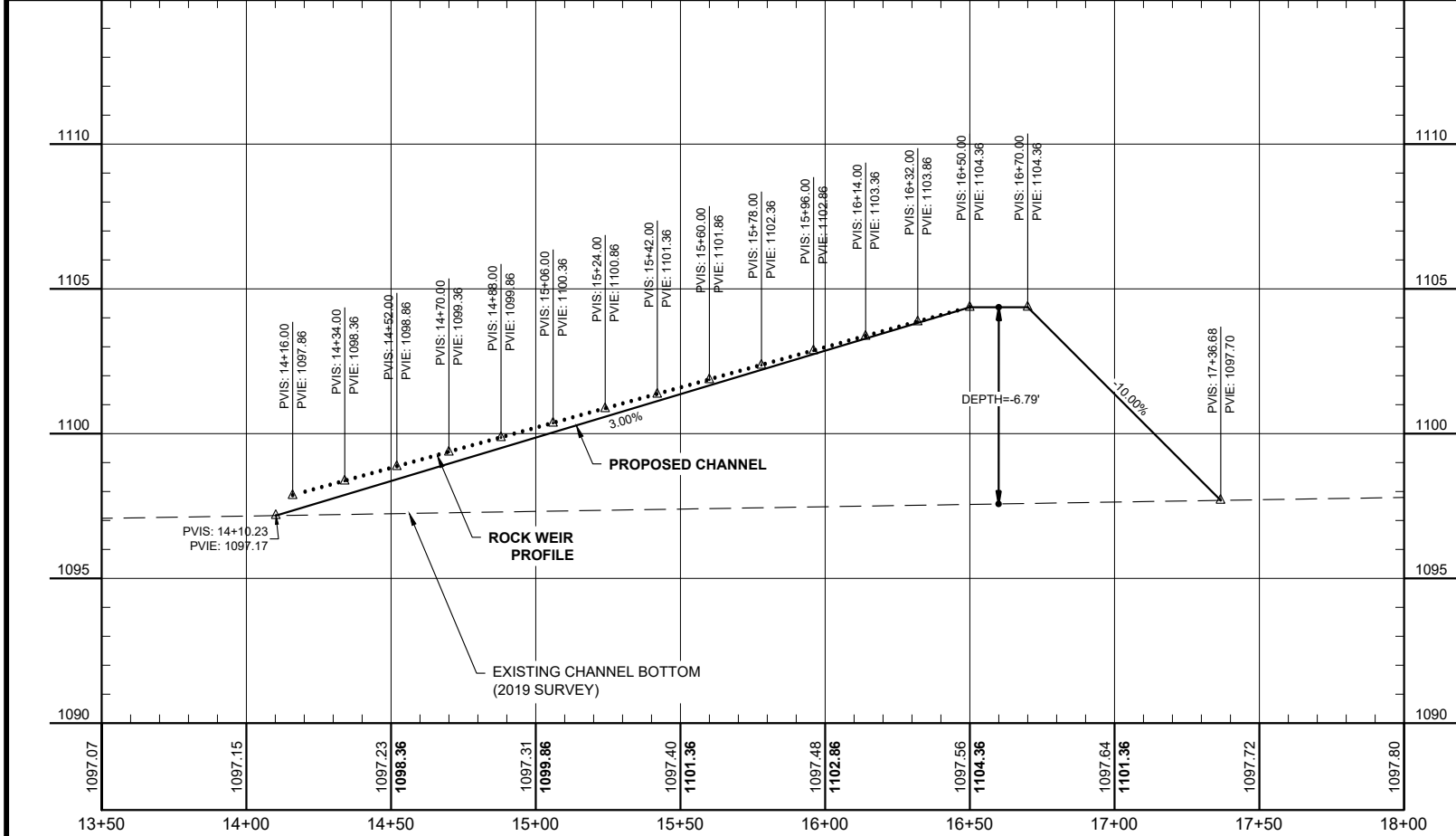
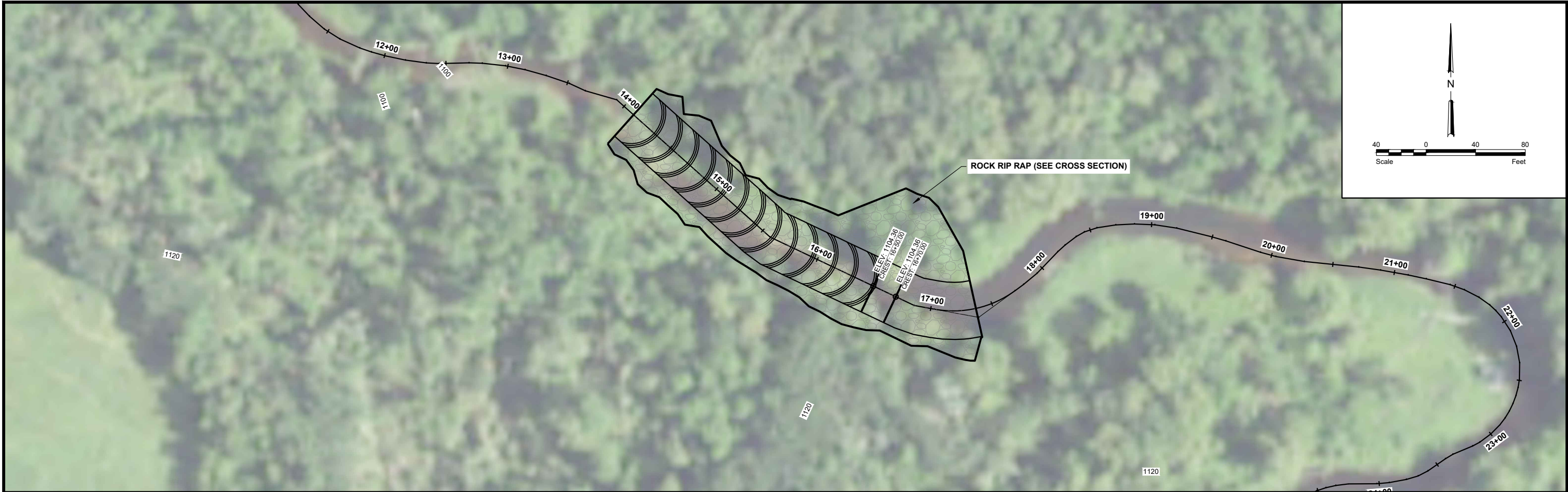
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RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

UPPER RIDGE
ROCK ARCH RAPIDS 7
PLAN AND PROFILE
PROJECT NO. 1432-0365

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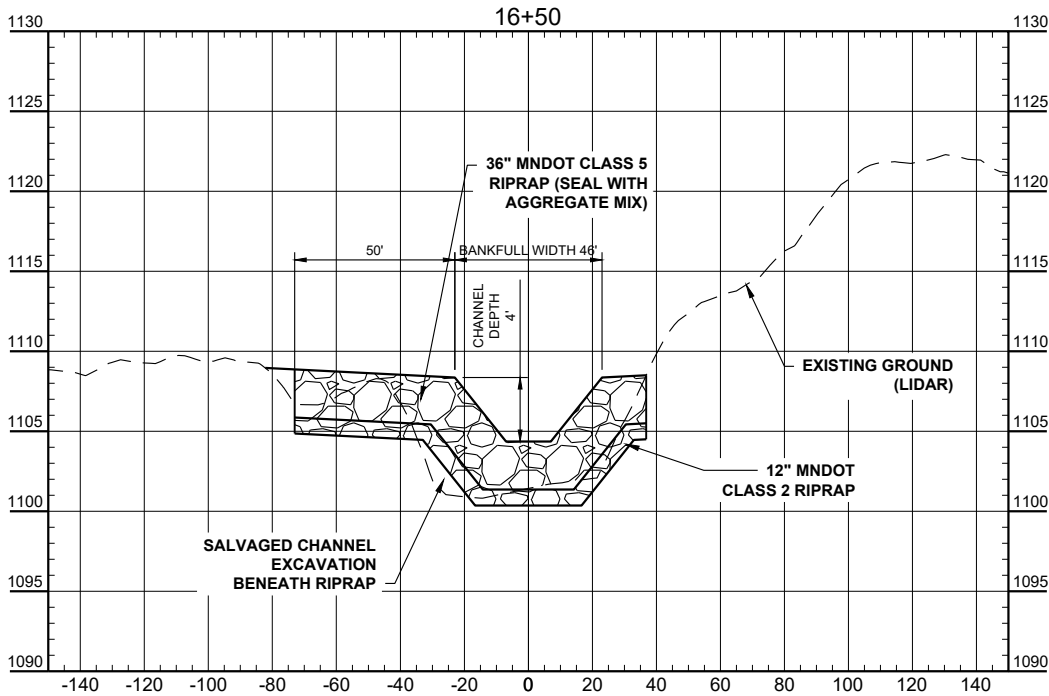
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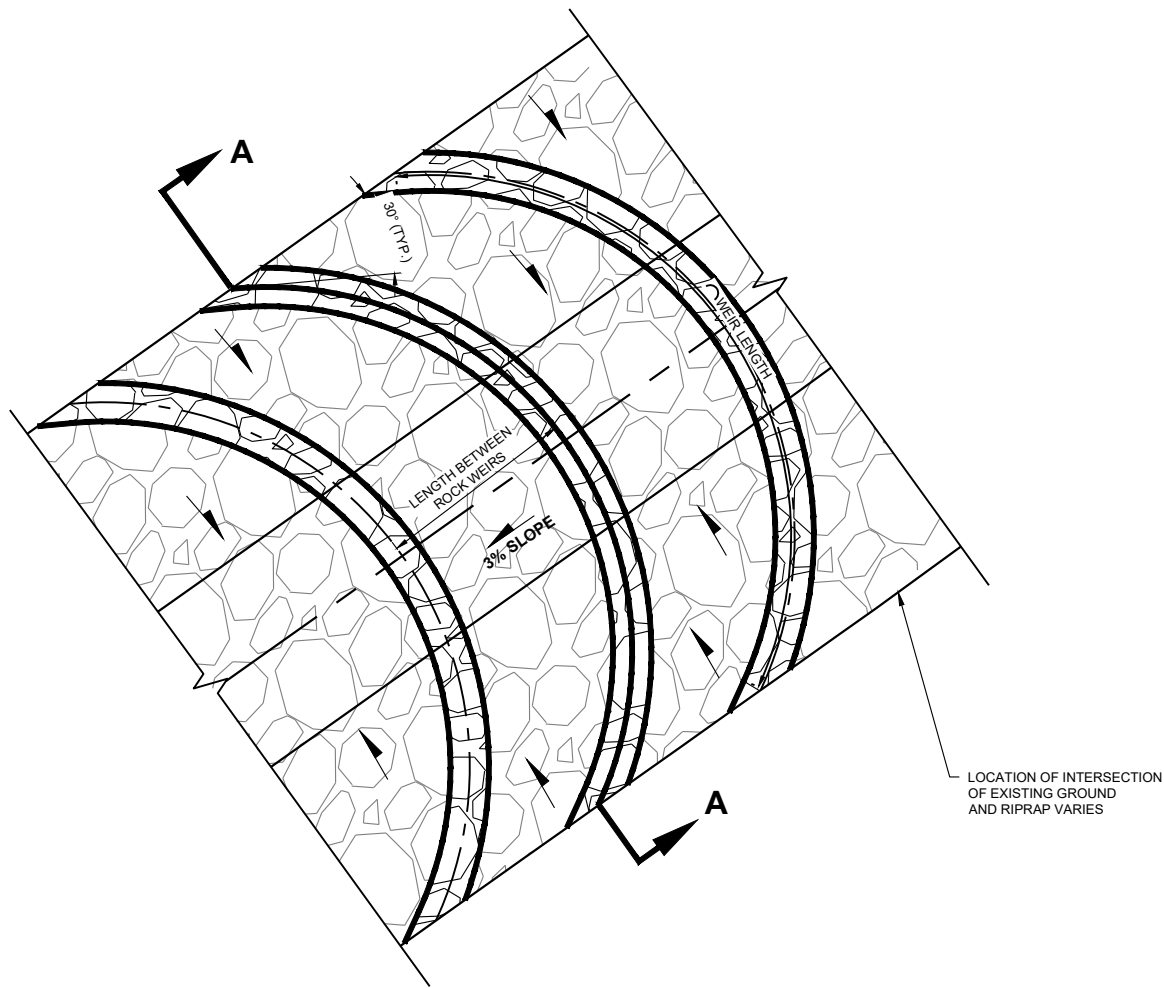
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RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

UPPER RIDGE
ROCK ARCH RAPIDS 8
PLAN AND PROFILE
PROJECT NO. 1432-0365

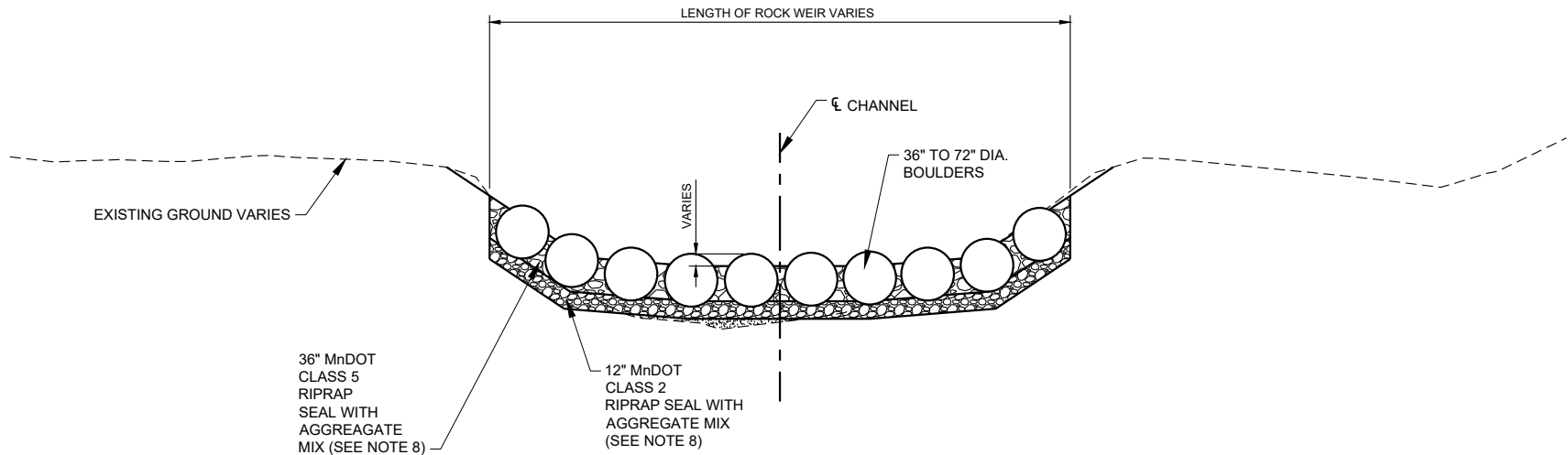
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ROCK WEIR LAYOUT
NOT TO SCALE



ROCK WEIR SECTION A - A
NOT TO SCALE

- NOTES:
1. NUMBER OF BOULDERS FOR EACH ROCK-ARCH IS DEPENDENT ON SIZE AND SPACING OF BOULDERS.
 2. ROCK WEIRS SHALL CONSIST OF 36" - 72" BOULDERS. TOP OF BOULDERS SHALL BE SET ABOVE MNDOT CL 5 RIPRAP AS SHOWN ON THE PROFILES.
 3. BOULDER WEIRS ARE TO BE FILLED WITH SMALLER STONE (MNDOT CL. 2 ROCK RIPRAP) TO REDUCE LEAKAGE AND CREATE POOLS.
 4. ADDITIONAL BOULDERS WILL BE ADDED RANDOMLY TO ADD TO AESTHETICS AS DIRECTED BY THE ENGINEER OR REPRESENTATIVE IN THE FIELD.
 5. THE WEIRS FUNCTION TO PROVIDE ADDED STABILITY TO THE RAPIDS, RESTING AREA FOR THE MIGRATION OF FISH, DIRECTING FLOW TOWARDS MID-CHANNEL (REDUCING STRESS ON BANKS) AND INCREASING SAFETY BY CREATING LOW VELOCITIES NEAR BANKS.
 6. WEIRS ARE TO BE INTEGRATED INTO THE CONSTRUCTED BANKS, THE GAPS BETWEEN BOULDERS SHALL TYPICALLY RANGE FROM 0 TO 6 INCHES. LARGER GAPS MAY BE NECESSARY DEPENDING ON SPECIES OF FISH.
 7. ALL FILL MATERIAL UNDER RIPRAP RAMP TO BE OR EXCAVATED CHANNEL MATERIAL.
 8. VOIDS IN THE PLACED RIPRAP SHALL BE FILLED WITH A WELL GRADED MIX OF AGGREGATE VARYING FROM THE NO. 40 SIEVE UP TO 3 INCH STONES. THE MIX OF AGGREGATE SHOULD BE SUCH THAT IT IS NOT BLOWN OUT OF THE RIPRAP BY THE RIVERS CURRENT BUT INSTEAD FORCES FLOW OVER THE RIPRAP. EXCESS CHANNEL EXCAVATION CAN BE USED FOR FILLING VOIDS WITH ENGINEERS APPROVAL.

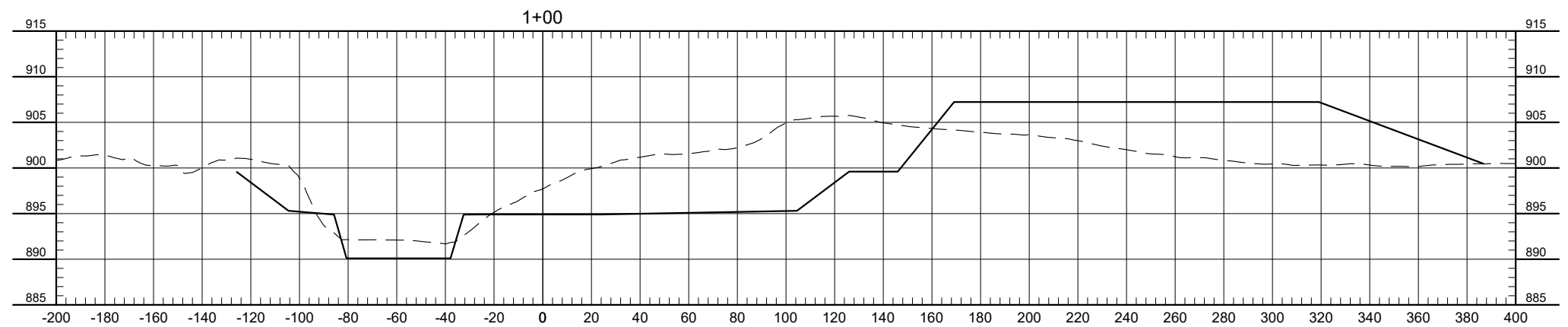
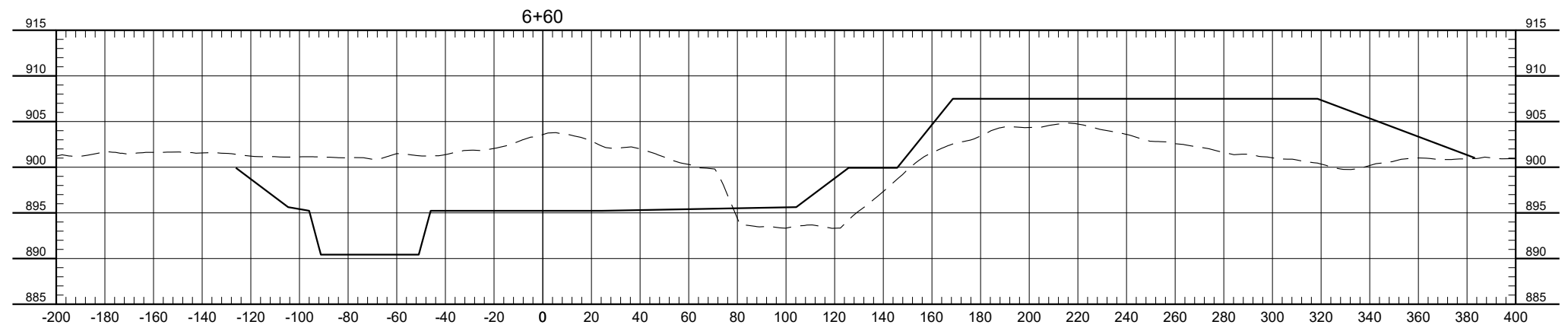
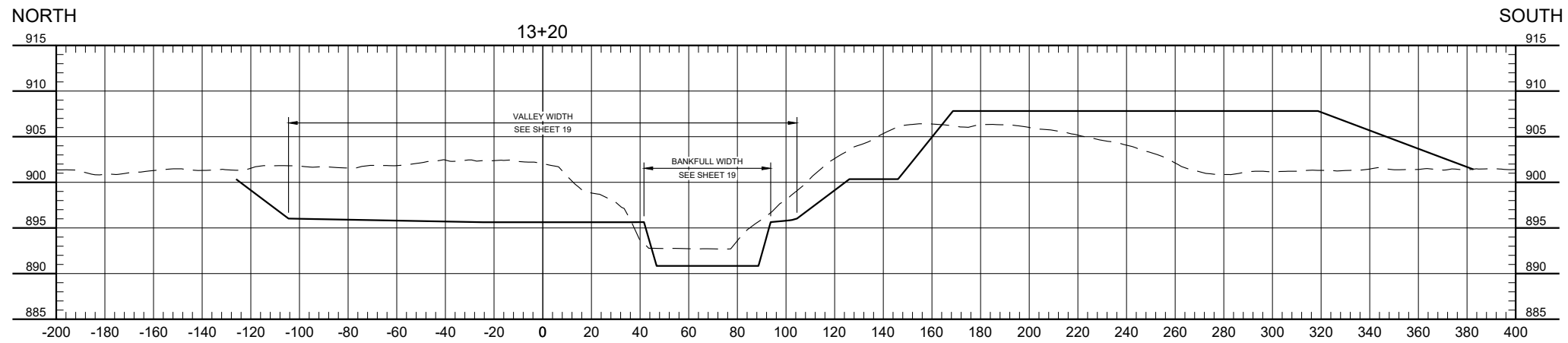
Location	Rock Arch Rapids No.	Length of Rapid (Crest to Toe)(ft)	Distance Between Boulder Weirs (ft)	Number of Weirs.	Weir Length (ft)
Channelized Reach		128	21	7	47
Beach Ridge	1	243	18	14	63
Beach Ridge	2	269	18	15	63
Beach Ridge	3	333	18	18	63
Beach Ridge	4	286	18	16	62
Beach Ridge	5	185	18	11	62
Beach Ridge	6	257	18	15	62
Upper Ridge	1	318	18	18	59
Upper Ridge	2	259	18	15	70
Upper Ridge	3	226	18	13	70
Upper Ridge	4	139	19	8	64
Upper Ridge	5	198	19	11	59
Upper Ridge	6	192	18	11	58
Upper Ridge	7	280	18	16	58
Upper Ridge	8	240	18	14	56

No.	Revision	Date	By

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P: 701.237.5065 F: 701.237.5101	Checked by GLB/HRR	Scale AS SHOWN			35 of 73

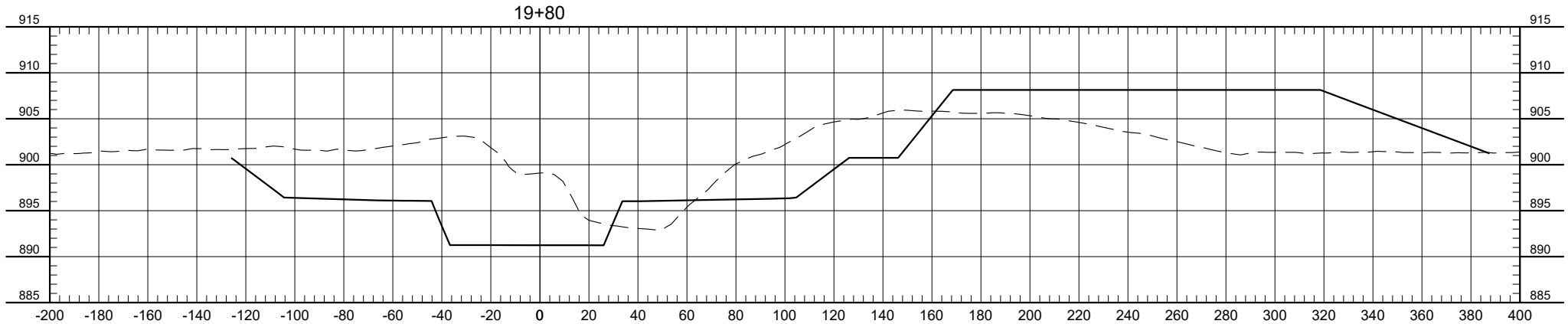
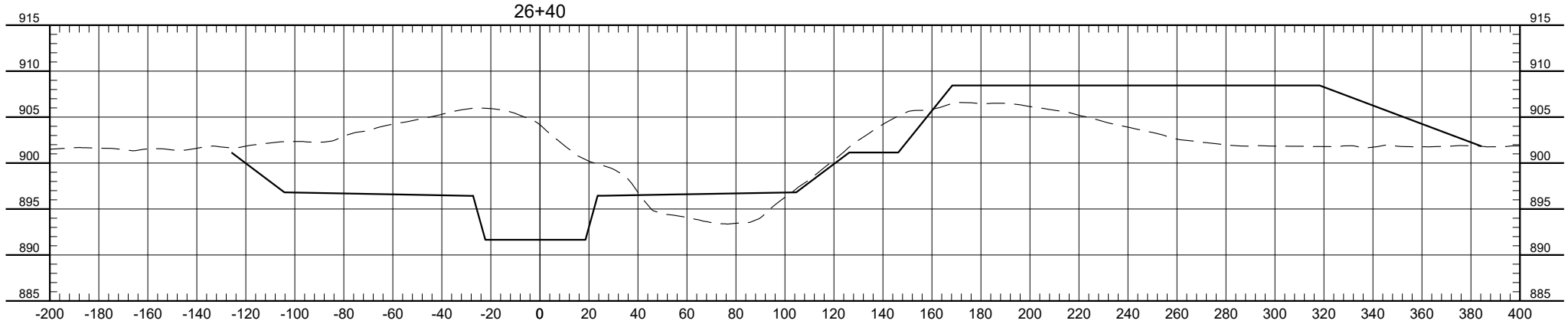
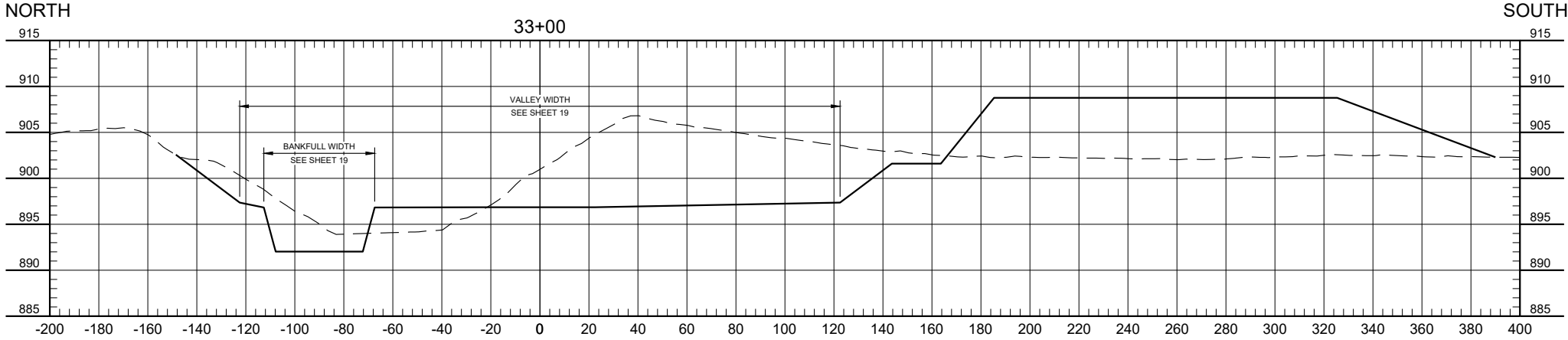


- NOTES:
1. FINAL DESIGN WILL INCLUDE PARABOLIC/ELLIPTICAL CHANNEL SHAPE.
 2. BANKFULL WIDTHS AND SLOPES MAY APPEAR SKEWED DUE TO DIRECTION OF CROSS SECTION. SEE TYPICAL CHANNEL SECTIONS ON SHEET 19 FOR ACCURATE BANKFULL WIDTHS AND SLOPES.

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				PRELIMINARY Not for Construction		Fargo	Drawn by AJK	Date 4-28-2020	SOUTH BRANCH WILD RICE RIVER RESTORATION & SEDIMENT REDUCTION PROJECT WILD RICE WATERSHED DISTRICT CLAY & NORMAN COUNTIES, MINNESOTA	LAKE PLAIN REACH CROSS SECTIONS PROJECT NO. 1432-0365	SHEET 36 of 73
						P: 701.237.5065 F: 701.237.5101	Checked by GLB/HRR	Scale AS SHOWN			
No.	Revision					Date	By				

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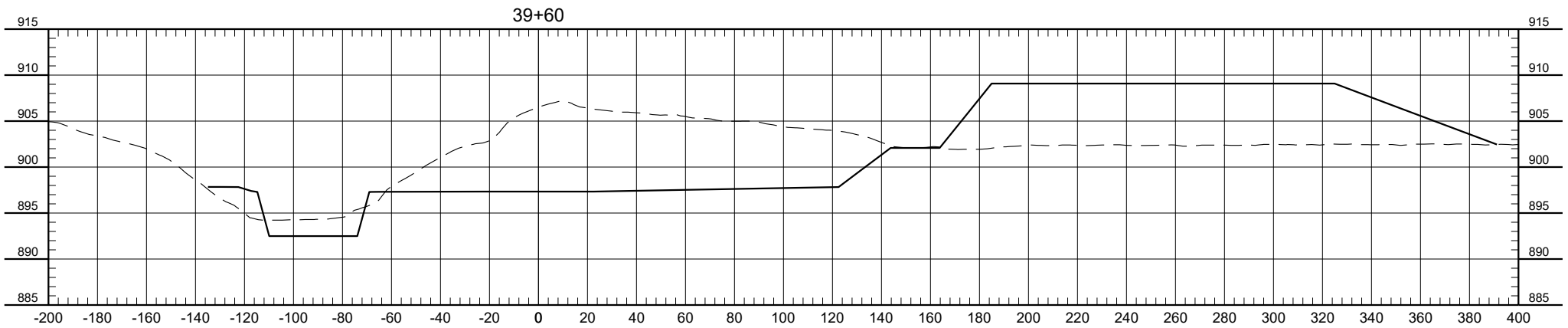
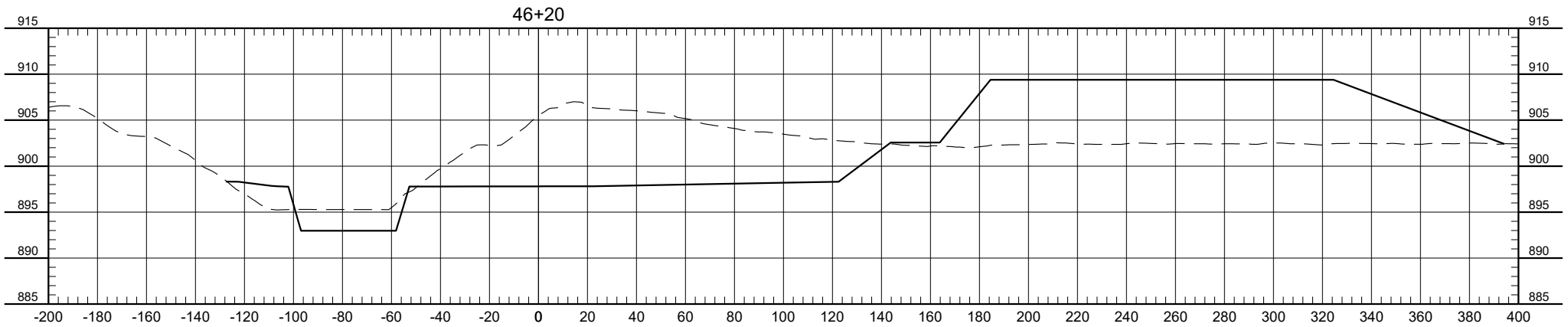
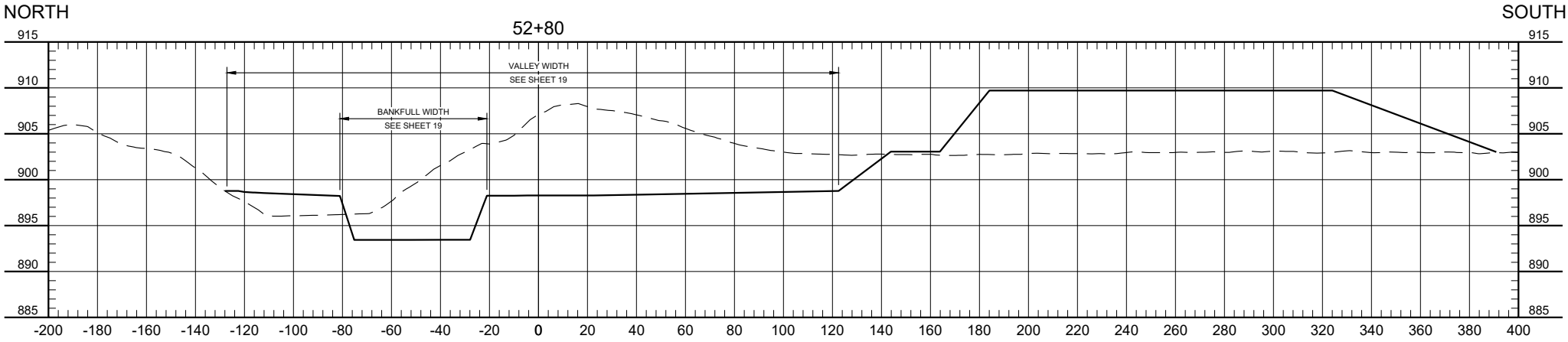
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

LAKE PLAIN REACH
CROSS SECTIONS
PROJECT NO. 1432-0365

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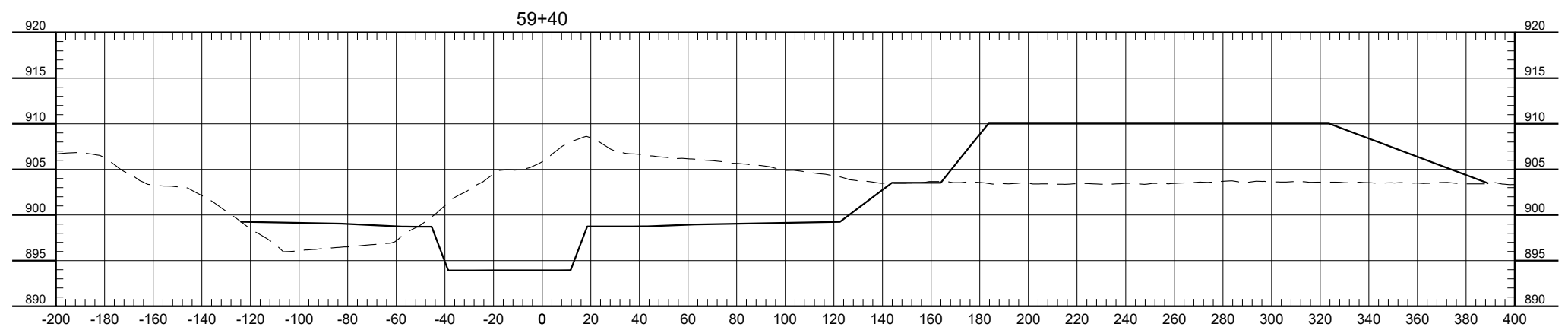
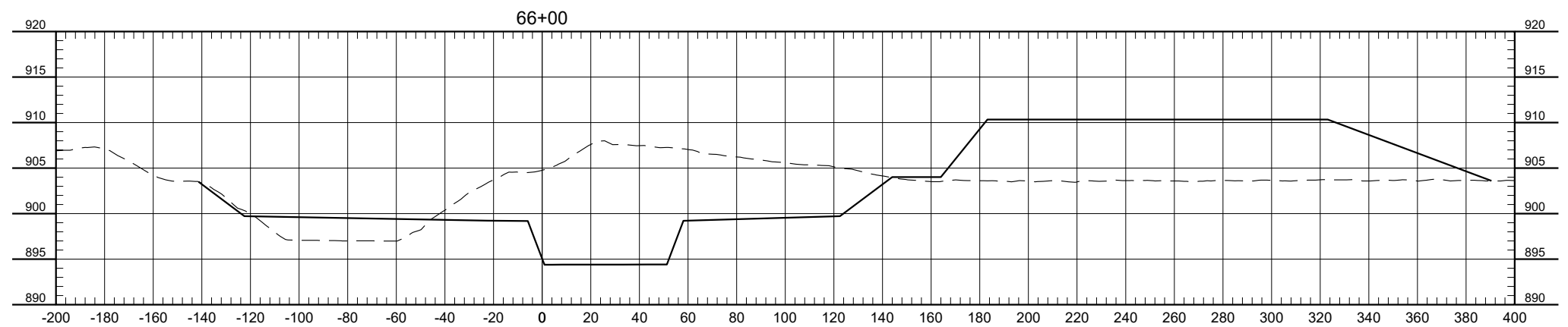
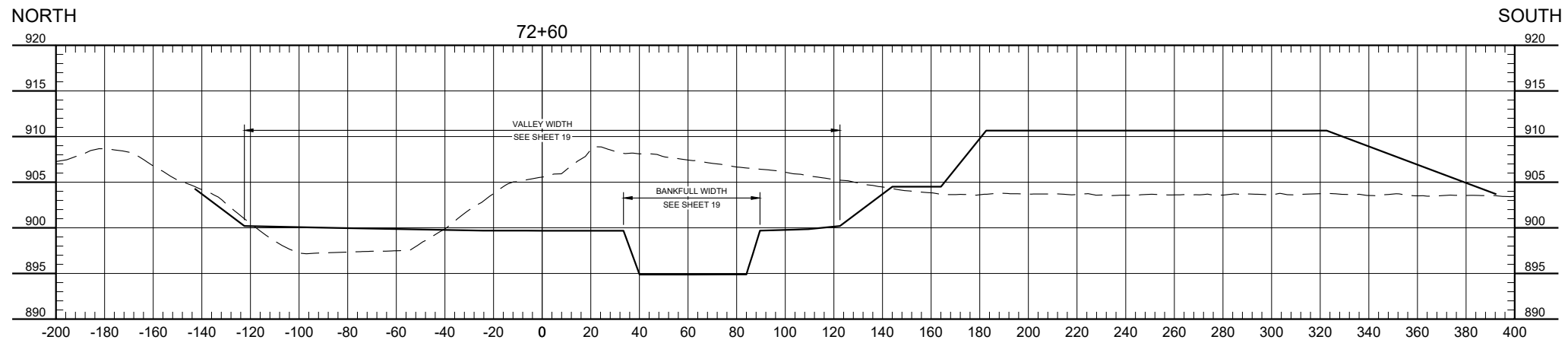


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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

LAKE PLAIN REACH
CROSS SECTIONS
PROJECT NO. 1432-0365

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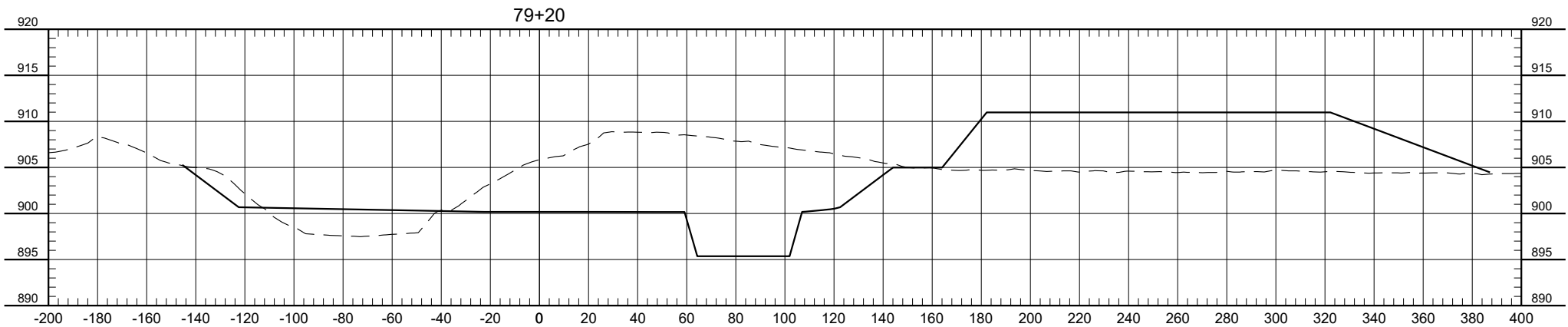
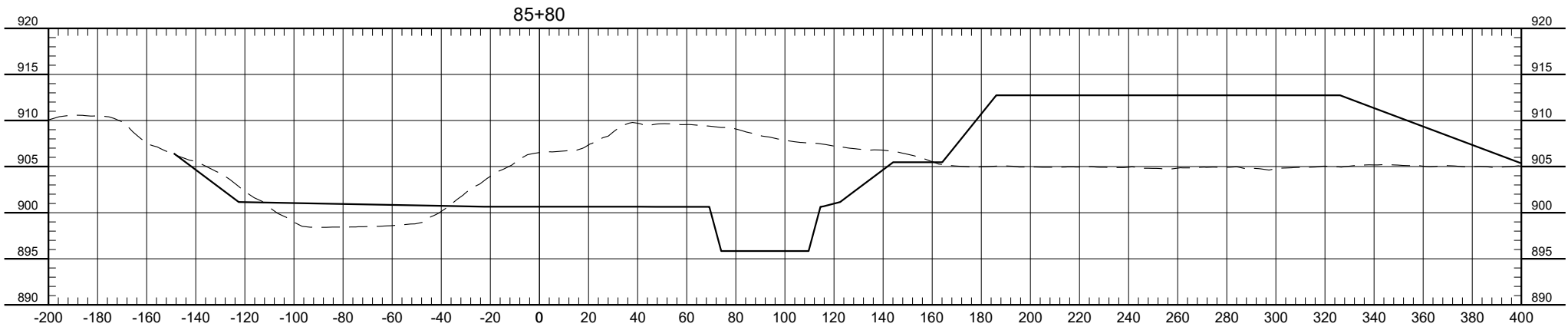
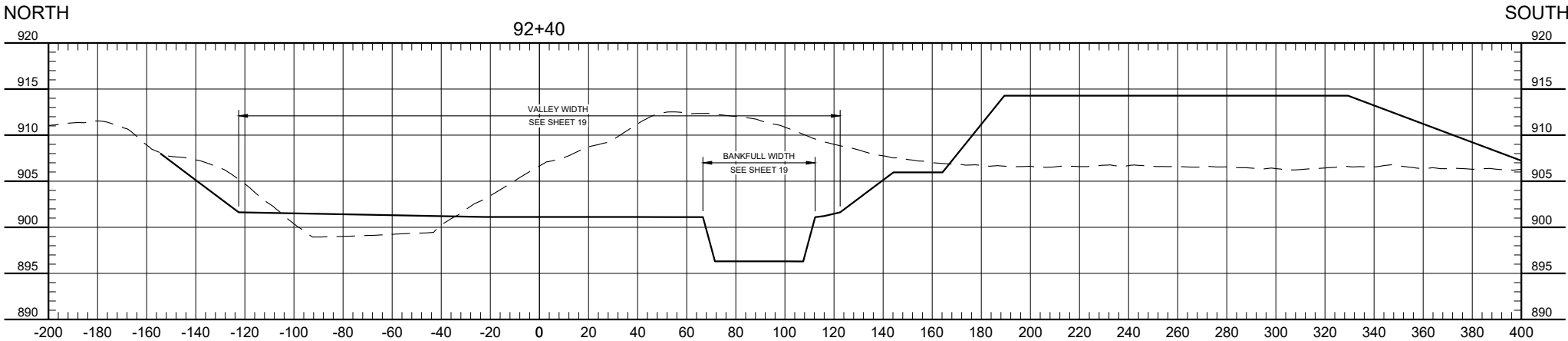


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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

LAKE PLAIN REACH
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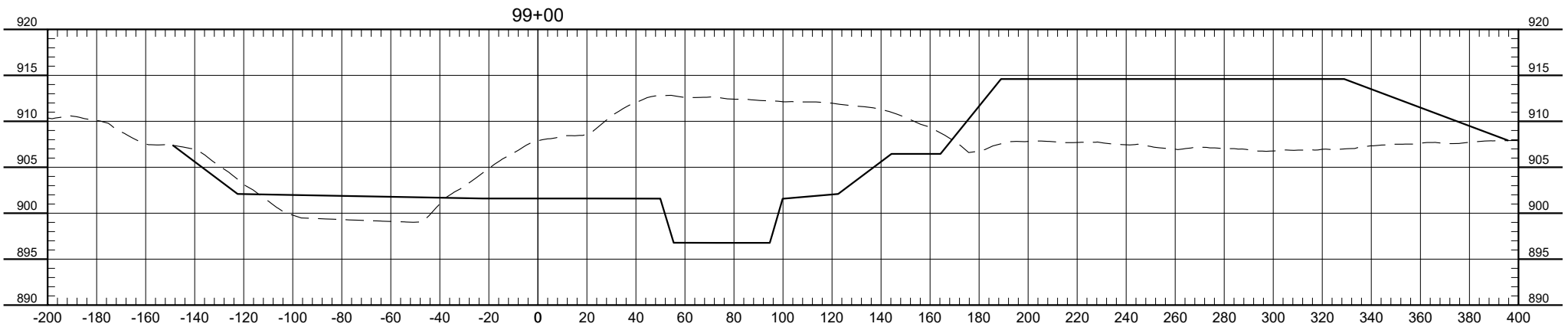
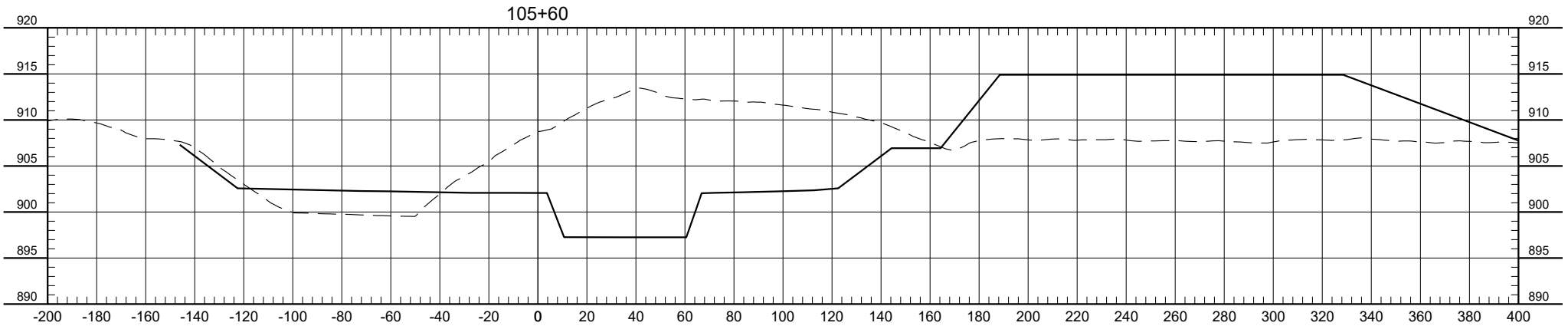
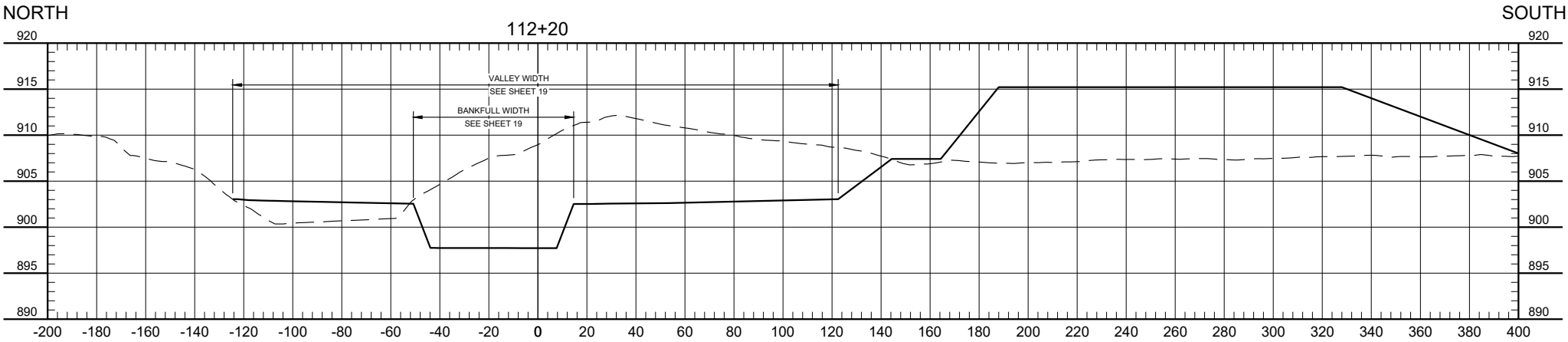
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WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

LAKE PLAIN REACH
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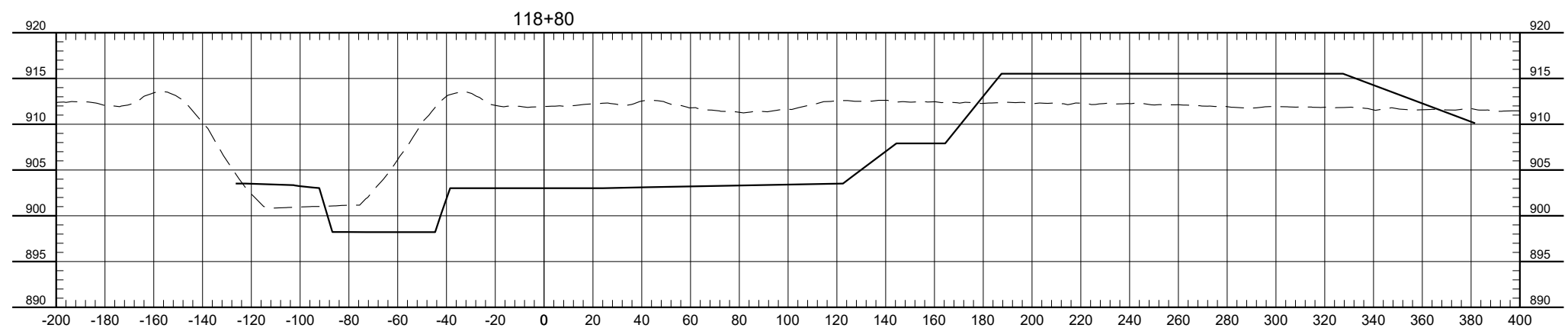
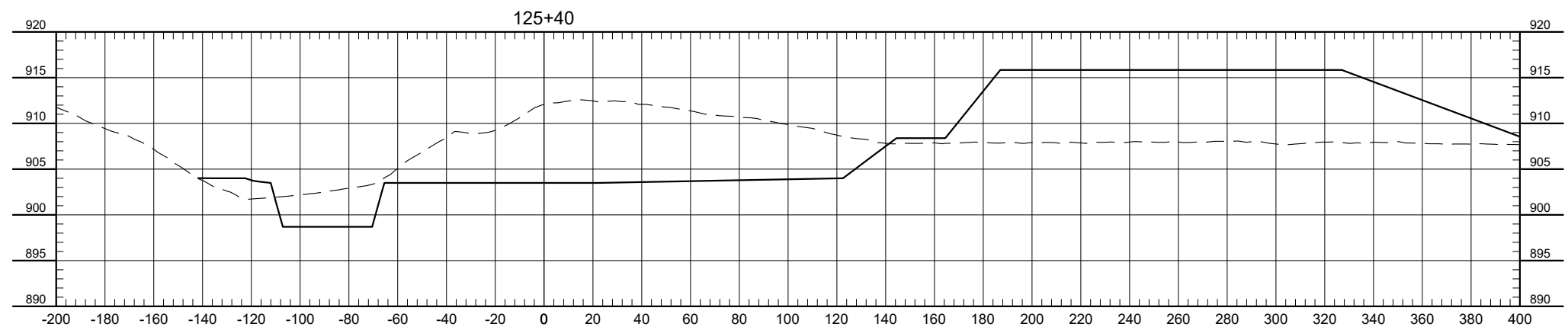
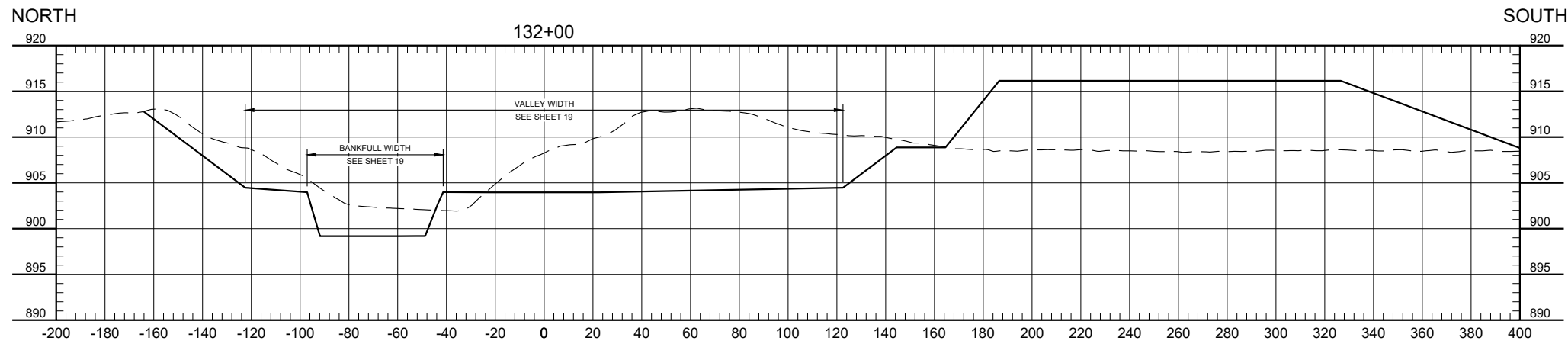
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RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

LAKE PLAIN REACH
CROSS SECTIONS
PROJECT NO. 1432-0365

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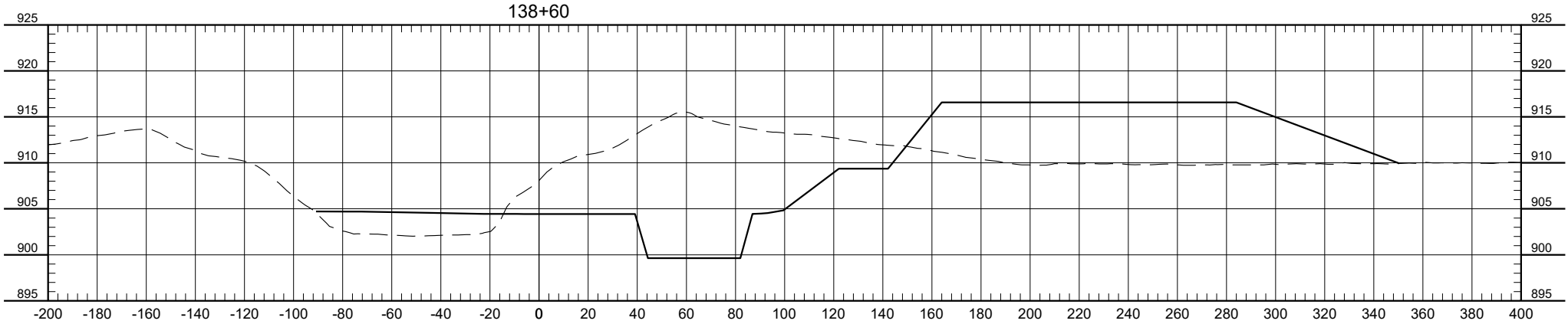
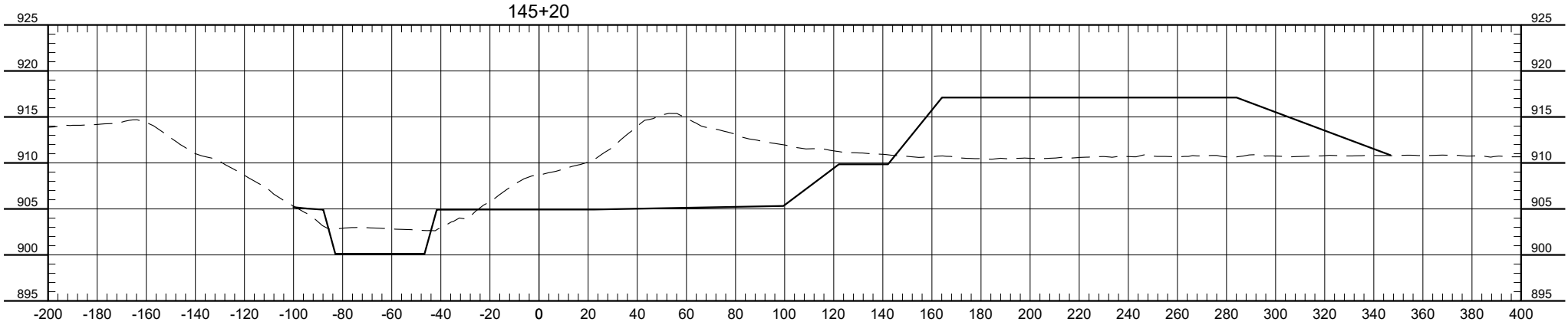
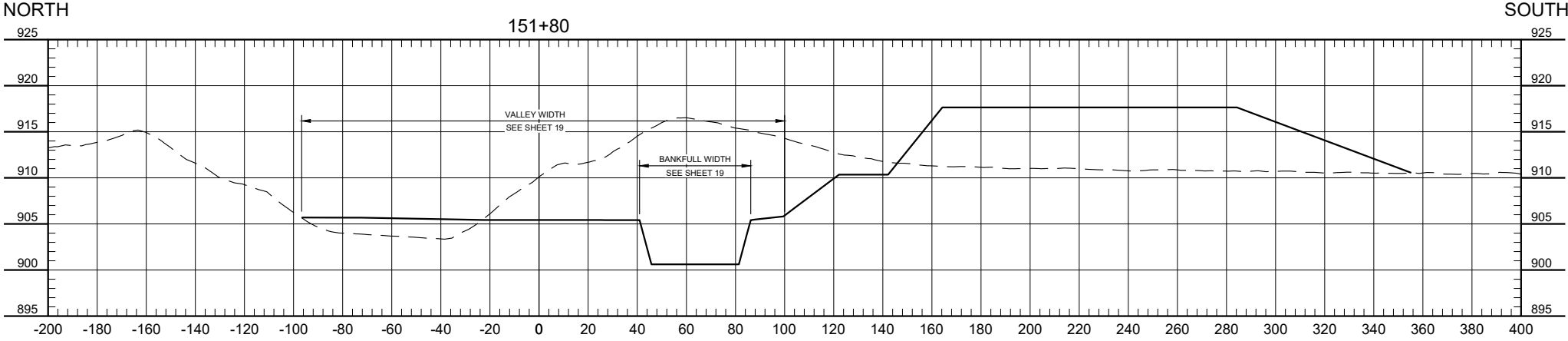
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No.	Revision	Date	By

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	Checked by GLB/HRR	Scale AS SHOWN			



- NOTES:
1. FINAL DESIGN WILL INCLUDE PARABOLIC/ELLIPTICAL CHANNEL SHAPE.
 2. BANKFULL WIDTHS AND SLOPES MAY APPEAR SKEWED DUE TO DIRECTION OF CROSS SECTION. SEE TYPICAL CHANNEL SECTIONS ON SHEET 19 FOR ACCURATE BANKFULL WIDTHS AND SLOPES.

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No.	Revision	Date	By

PRELIMINARY
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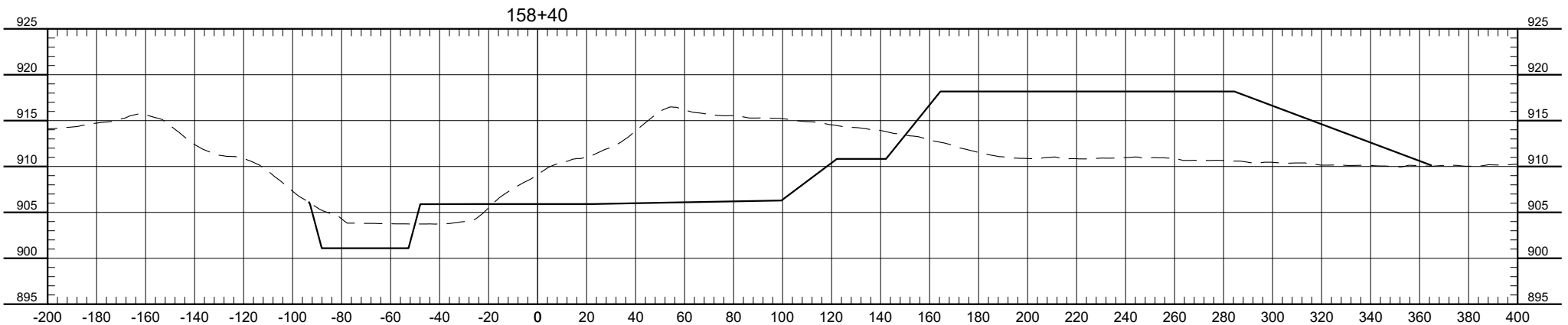
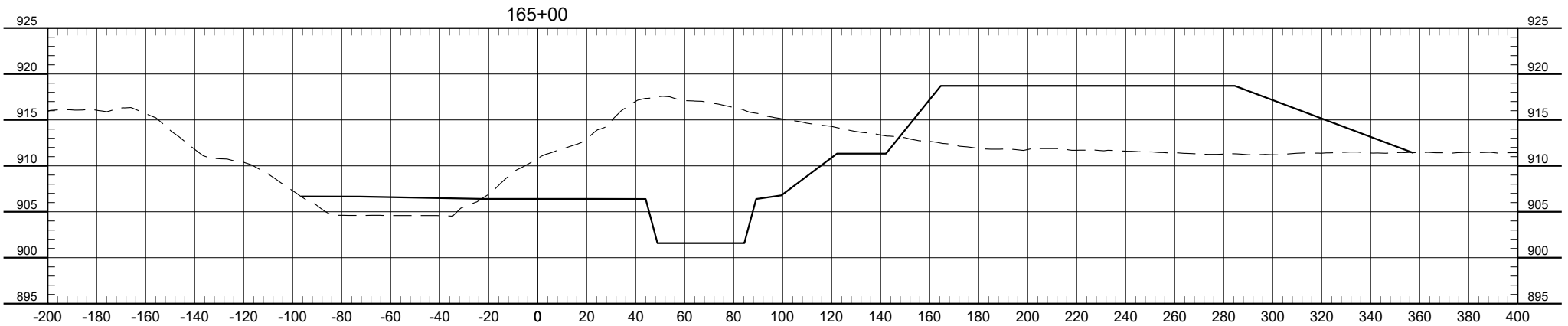
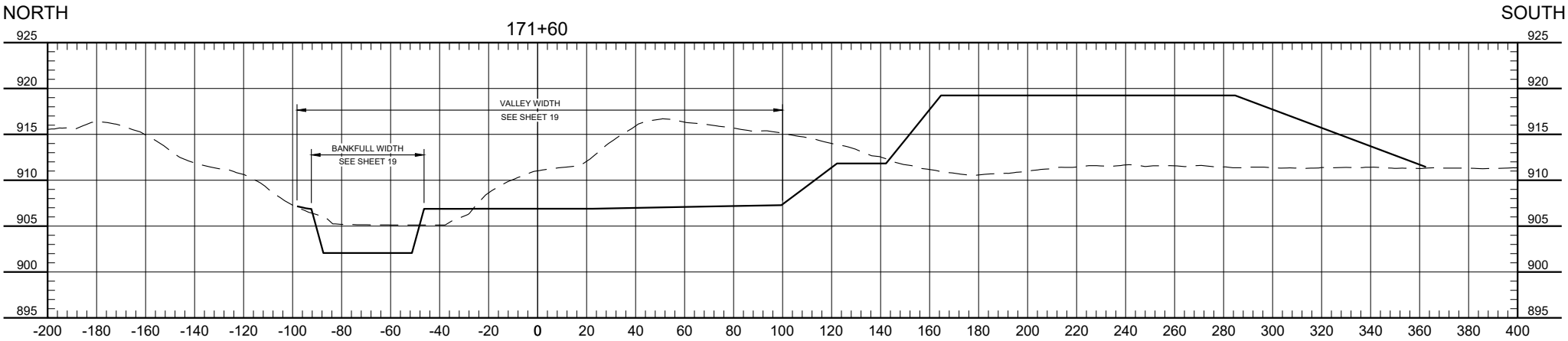


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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

LAKE PLAIN REACH
CROSS SECTIONS
PROJECT NO. 1432-0365

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- NOTES:
1. FINAL DESIGN WILL INCLUDE PARABOLIC/ELLIPTICAL CHANNEL SHAPE.
 2. BANKFULL WIDTHS AND SLOPES MAY APPEAR SKEWED DUE TO DIRECTION OF CROSS SECTION. SEE TYPICAL CHANNEL SECTIONS ON SHEET 19 FOR ACCURATE BANKFULL WIDTHS AND SLOPES.

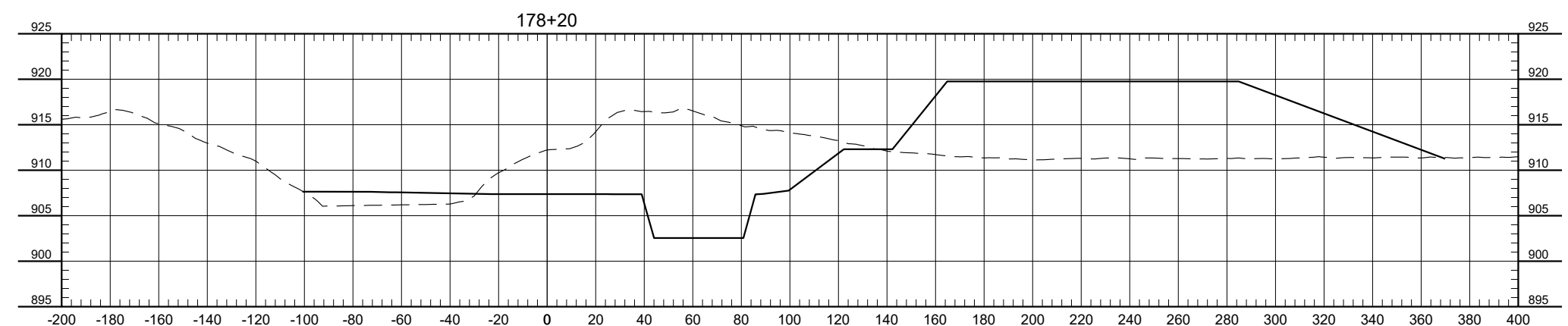
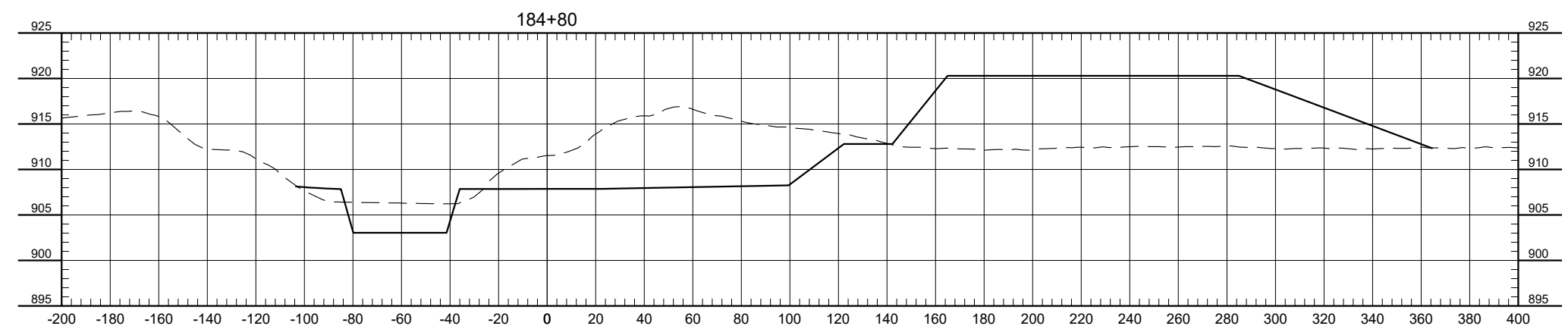
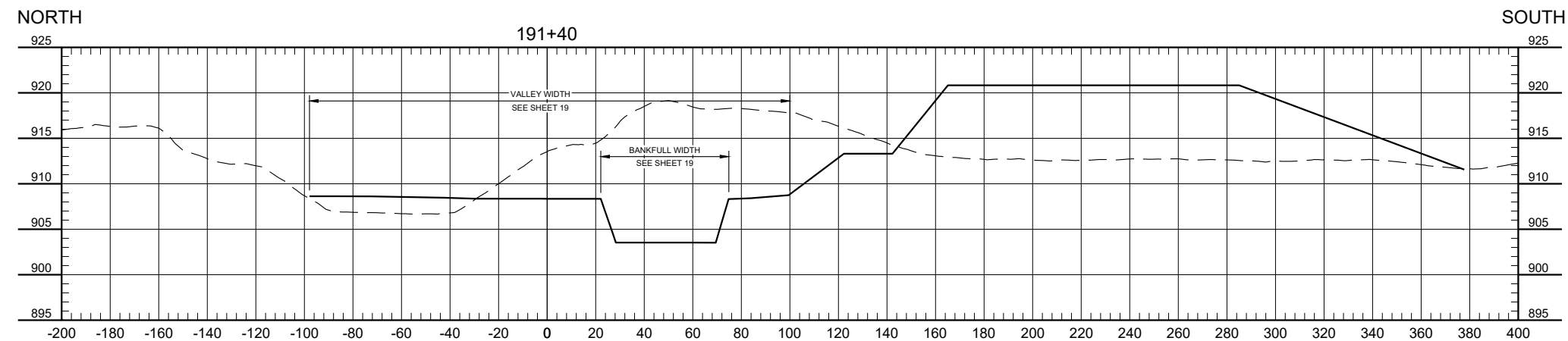
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No.	Revision	Date	By

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Not for Construction



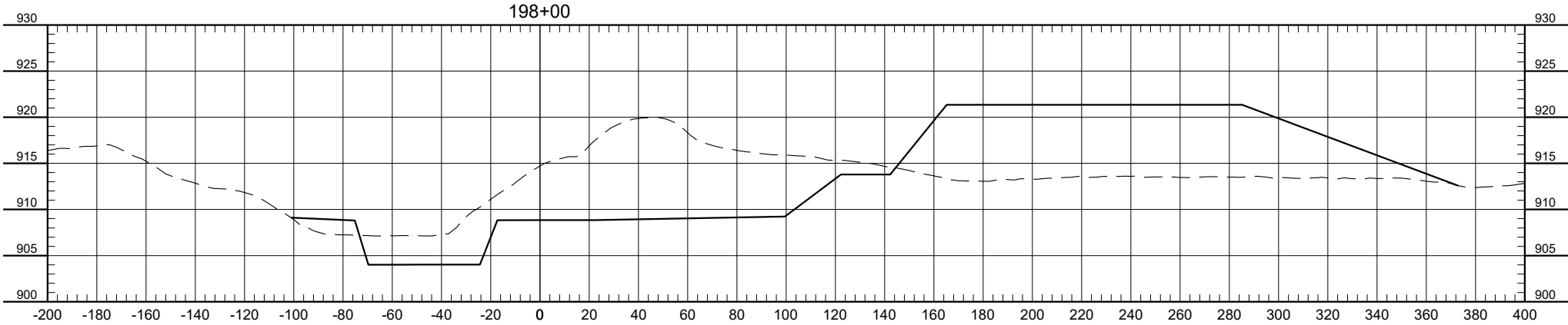
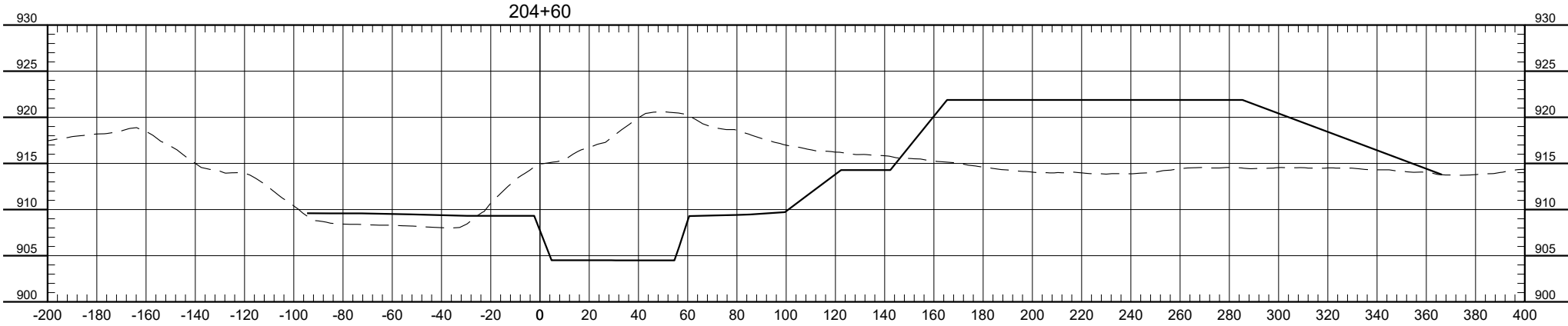
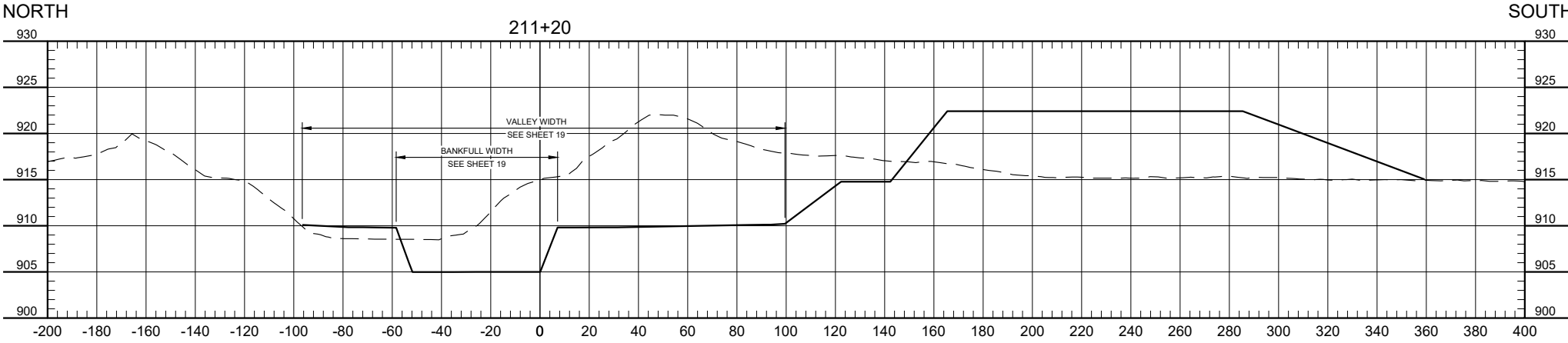
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P: 701.237.5065 F: 701.237.5101	Checked by GLB/HRR	Scale AS SHOWN			



- NOTES:
1. FINAL DESIGN WILL INCLUDE PARABOLIC/ELLIPTICAL CHANNEL SHAPE.
 2. BANKFULL WIDTHS AND SLOPES MAY APPEAR SKEWED DUE TO DIRECTION OF CROSS SECTION. SEE TYPICAL CHANNEL SECTIONS ON SHEET 19 FOR ACCURATE BANKFULL WIDTHS AND SLOPES.

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						P: 701.237.5065 F: 701.237.5101	Checked by GLB/HRR	Scale AS SHOWN			
No.	Revision	Date	By								



- NOTES:
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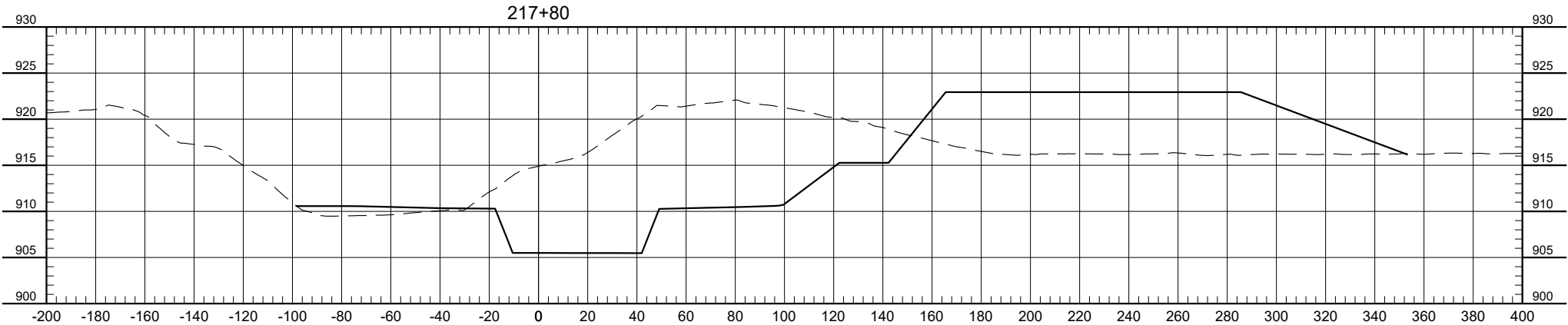
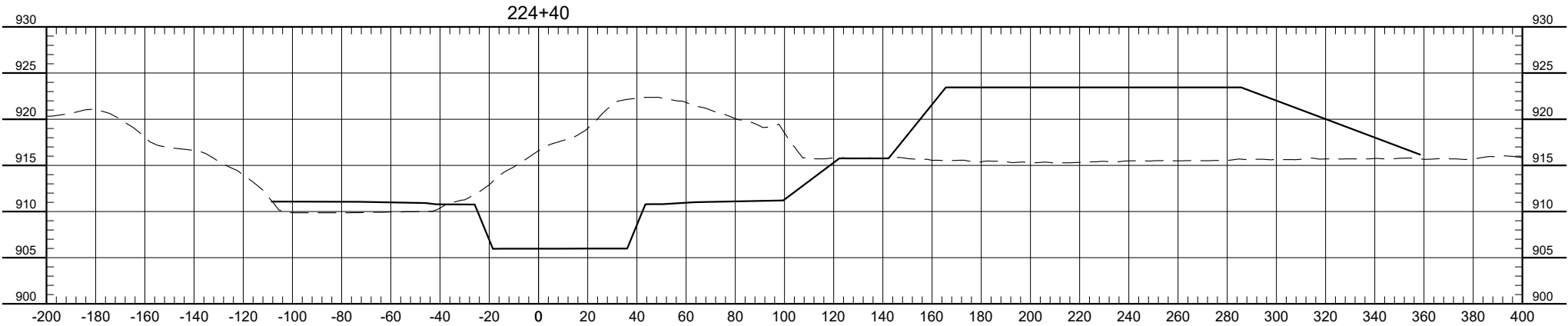
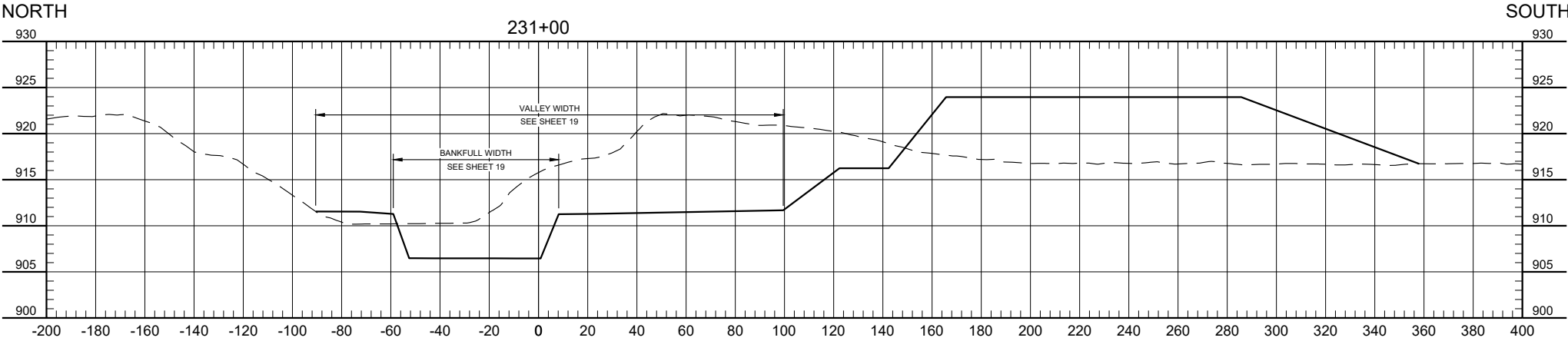
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	Checked by GLB/HRR	Scale AS SHOWN			

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- NOTES:
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No.	Revision	Date	By

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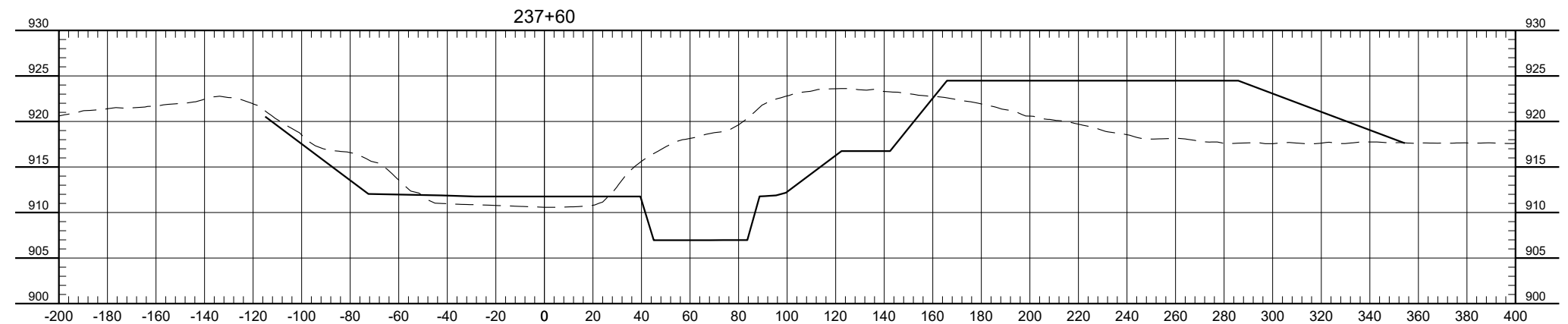
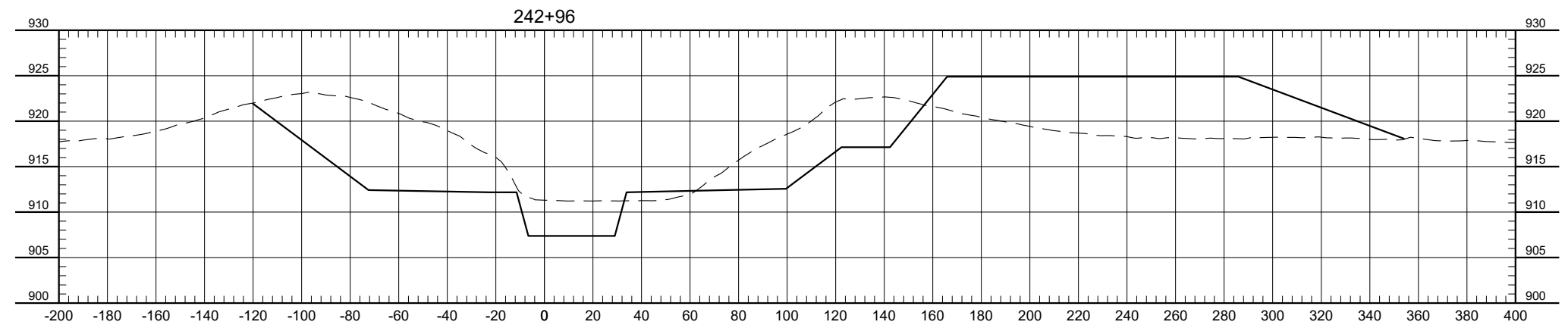
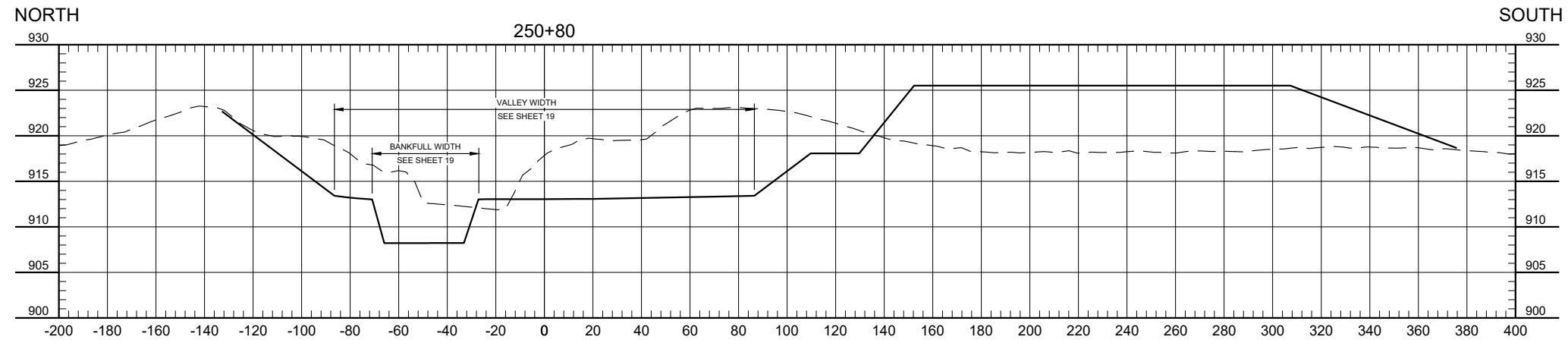


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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

LAKE PLAIN REACH
CROSS SECTIONS
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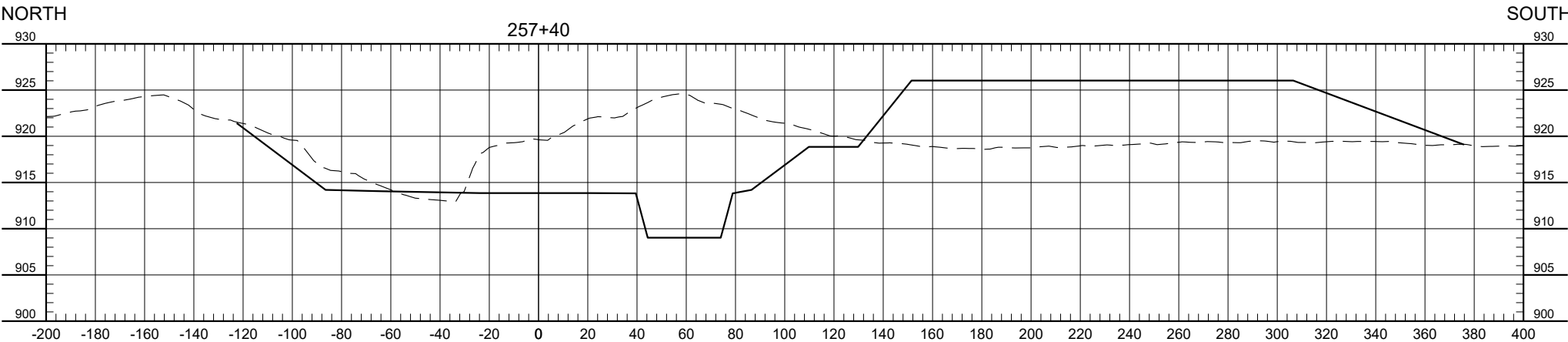
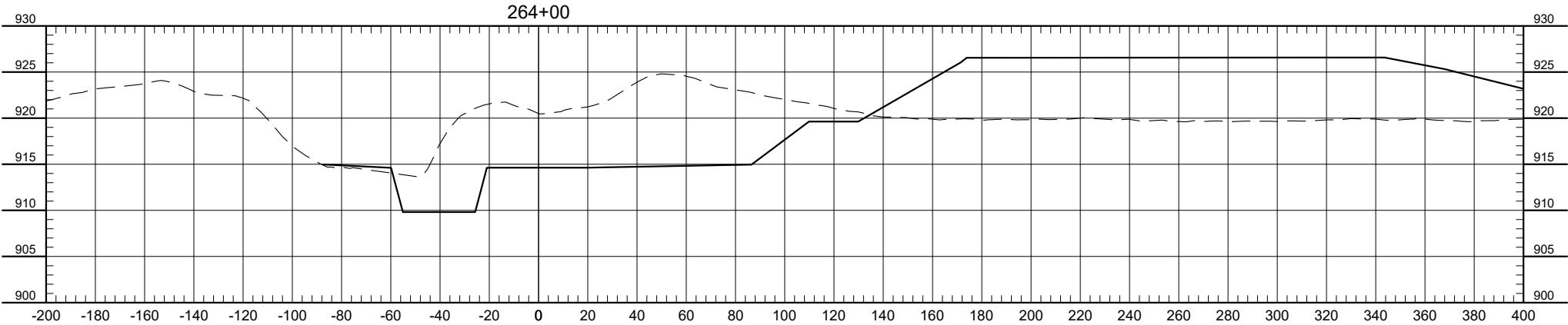
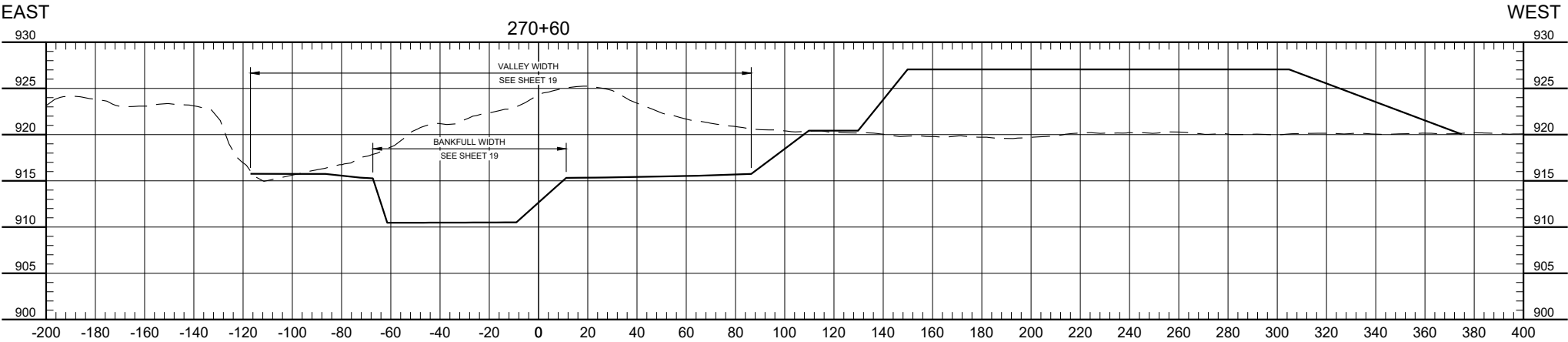


- NOTES:
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				PRELIMINARY Not for Construction		Fargo	Drawn by AJK	Date 4-28-2020	SOUTH BRANCH WILD RICE RIVER RESTORATION & SEDIMENT REDUCTION PROJECT WILD RICE WATERSHED DISTRICT CLAY & NORMAN COUNTIES, MINNESOTA	LAKE PLAIN REACH CROSS SECTIONS PROJECT NO. 1432-0365	SHEET 48 of 73
						P: 701.237.5065 F: 701.237.5101	Checked by GLB/HRR	Scale AS SHOWN			
No.	Revision					Date	By				

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- NOTES:
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No.	Revision	Date	By

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Not for Construction



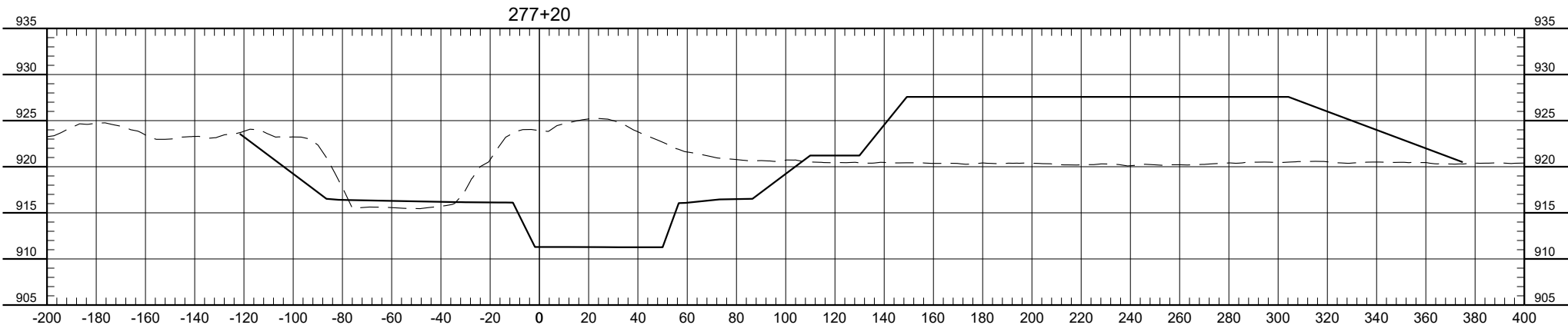
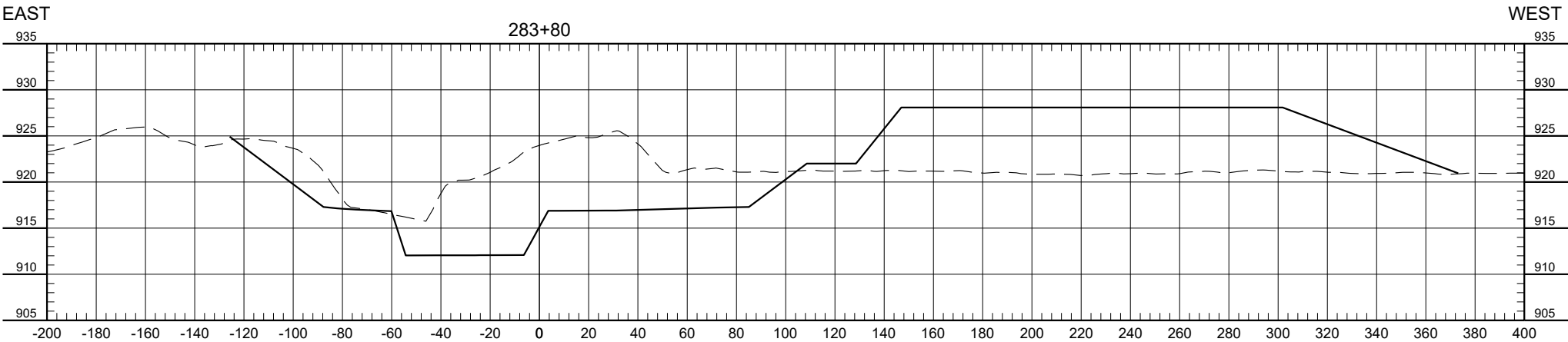
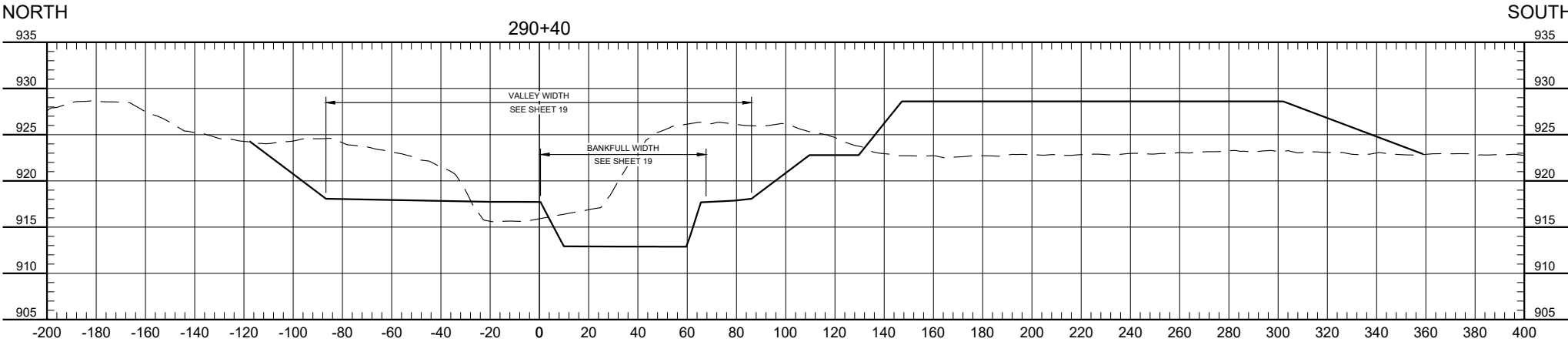
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

LAKE PLAIN REACH
CROSS SECTIONS
PROJECT NO. 1432-0365

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- NOTES:
1. FINAL DESIGN WILL INCLUDE PARABOLIC/ELLIPTICAL CHANNEL SHAPE.
 2. BANKFULL WIDTHS AND SLOPES MAY APPEAR SKEWED DUE TO DIRECTION OF CROSS SECTION. SEE TYPICAL CHANNEL SECTIONS ON SHEET 19 FOR ACCURATE BANKFULL WIDTHS AND SLOPES.

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No.	Revision	Date	By

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Not for Construction

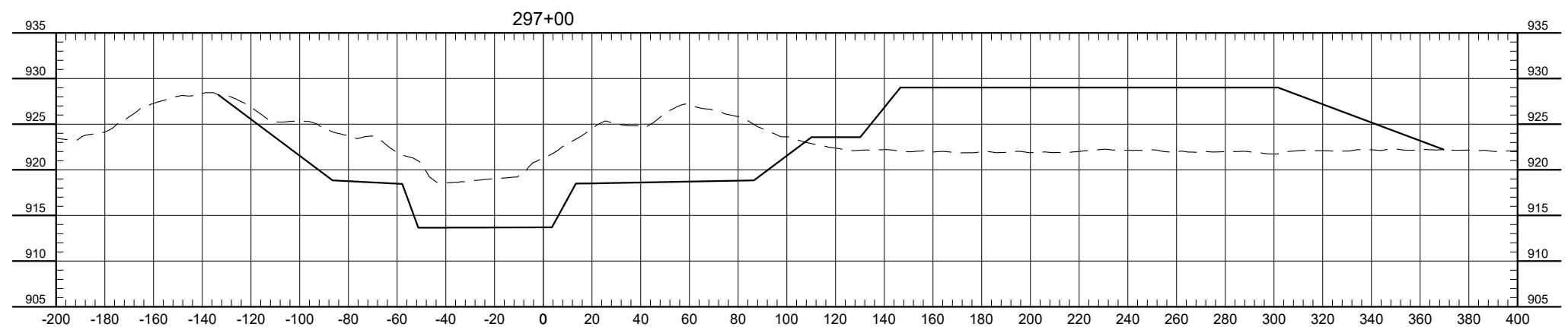
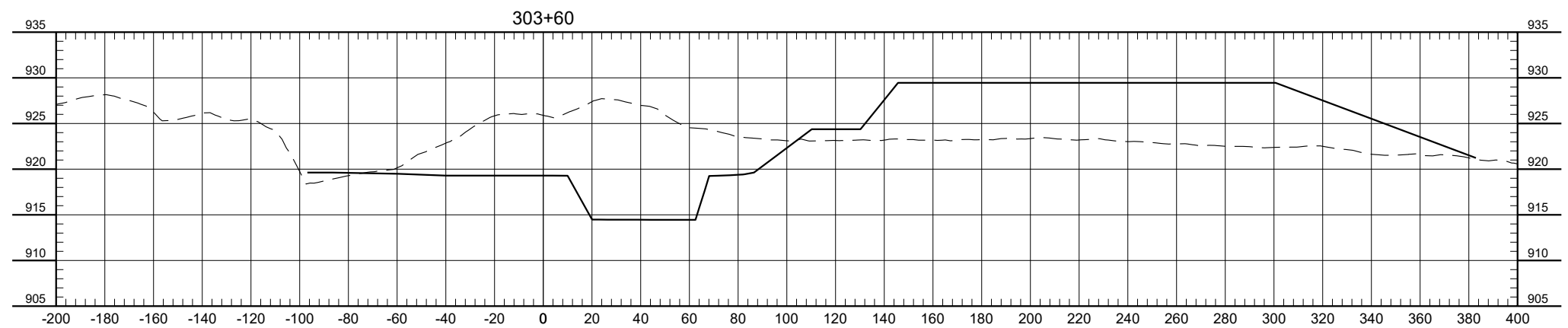
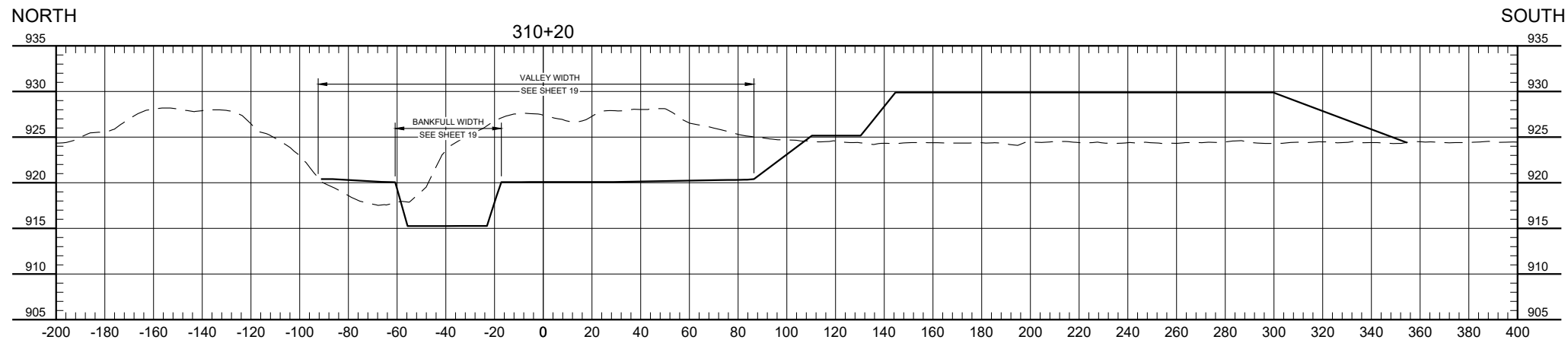


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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

LAKE PLAIN REACH
CROSS SECTIONS
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- NOTES:
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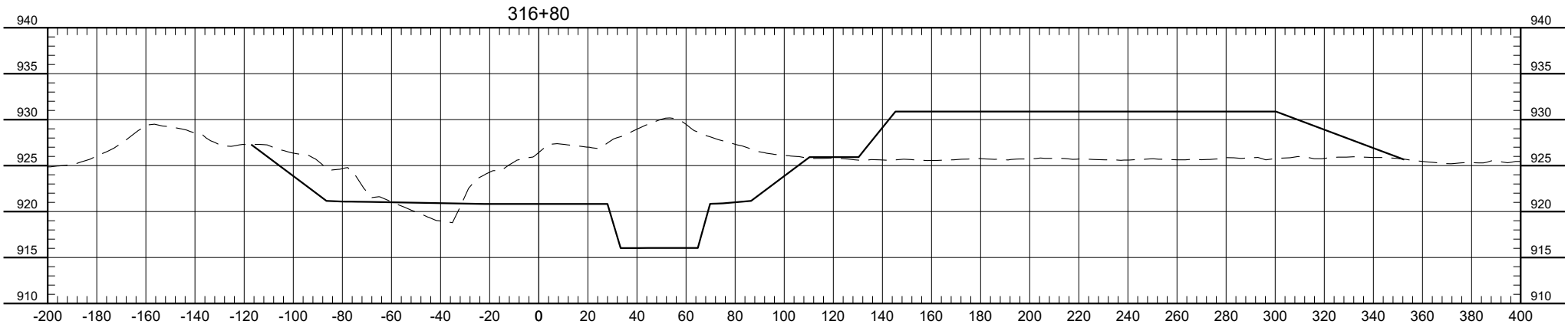
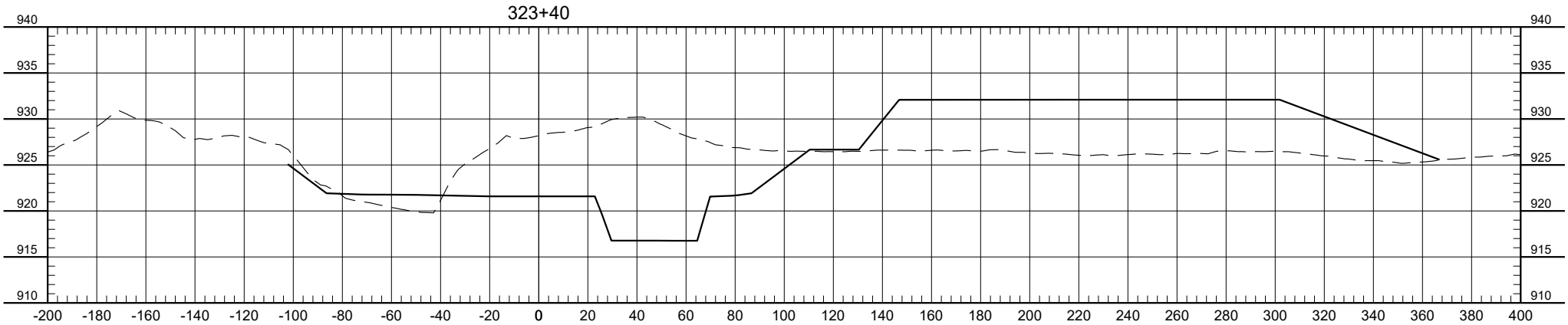
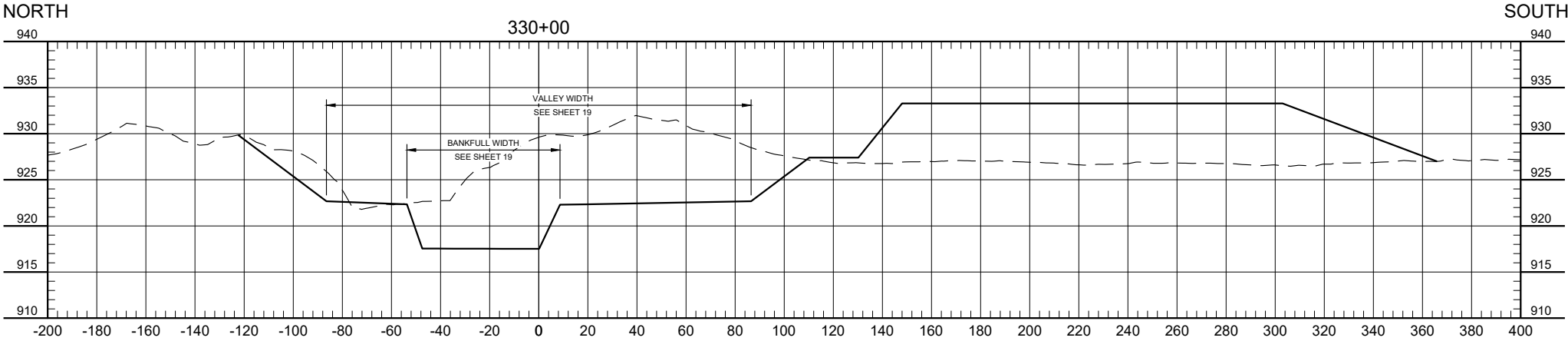
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

LAKE PLAIN REACH
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- NOTES:
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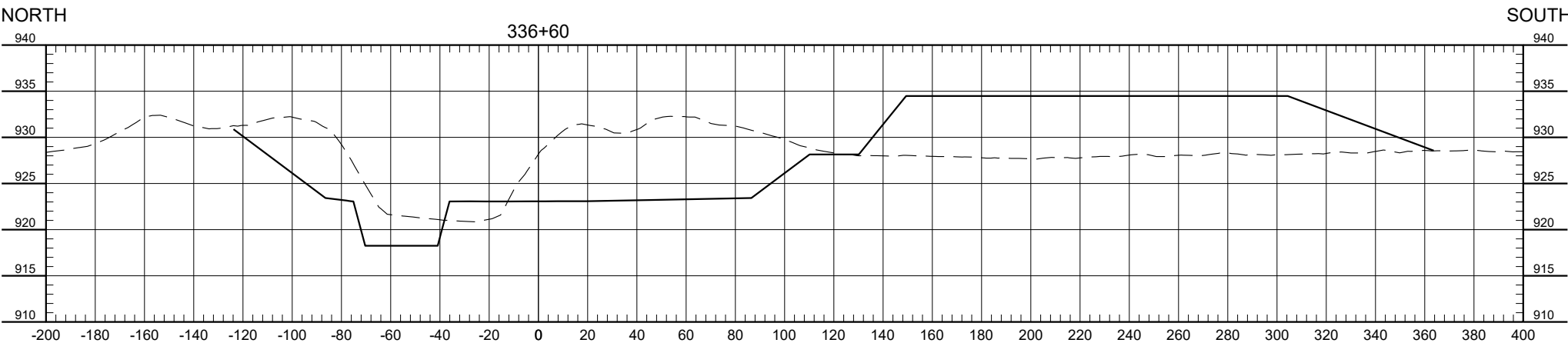
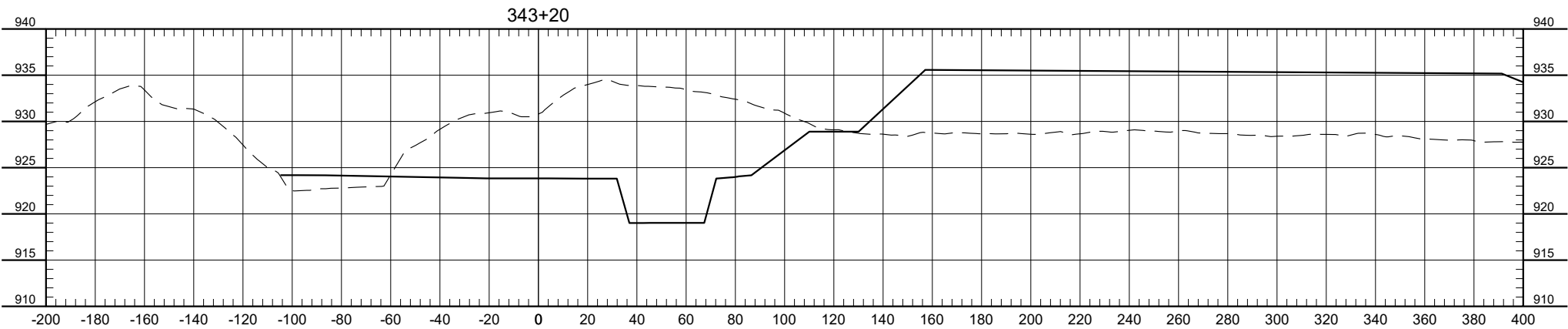
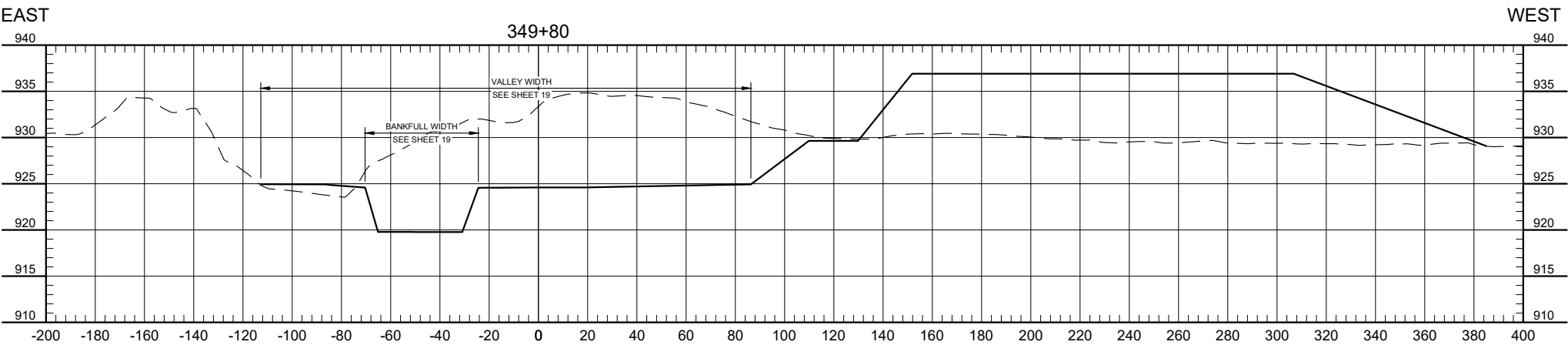
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GLB/HRR
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4-28-2020
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

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- NOTES:
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No.	Revision	Date	By

PRELIMINARY
Not for Construction



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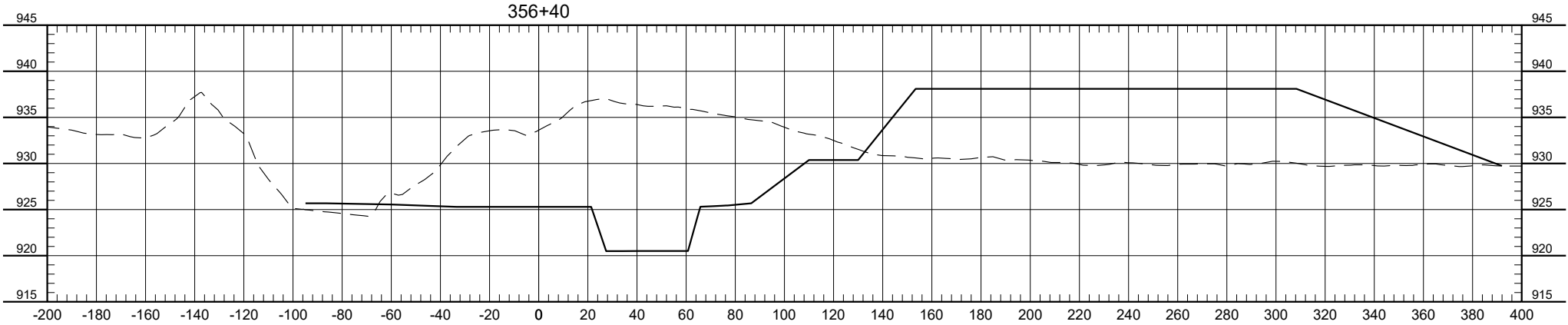
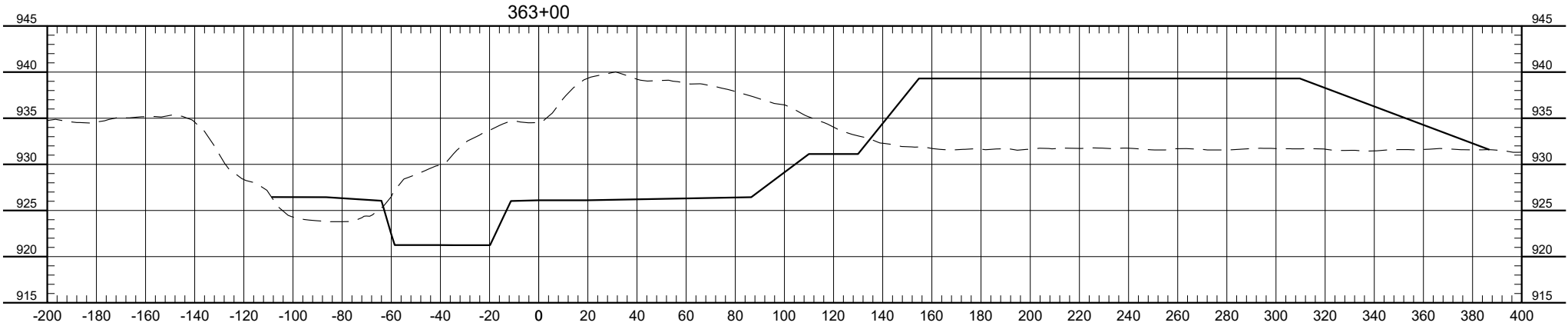
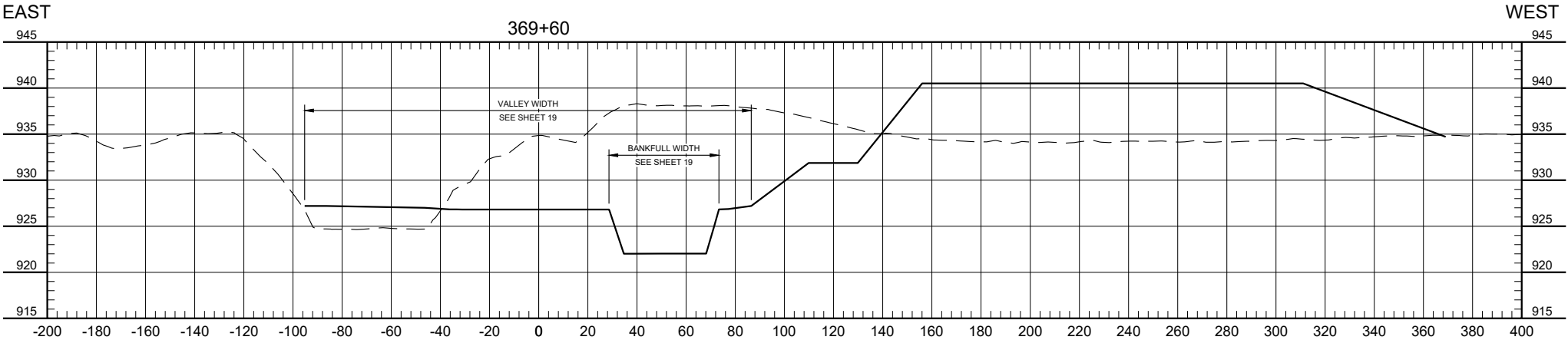
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

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- NOTES:
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No.	Revision	Date	By

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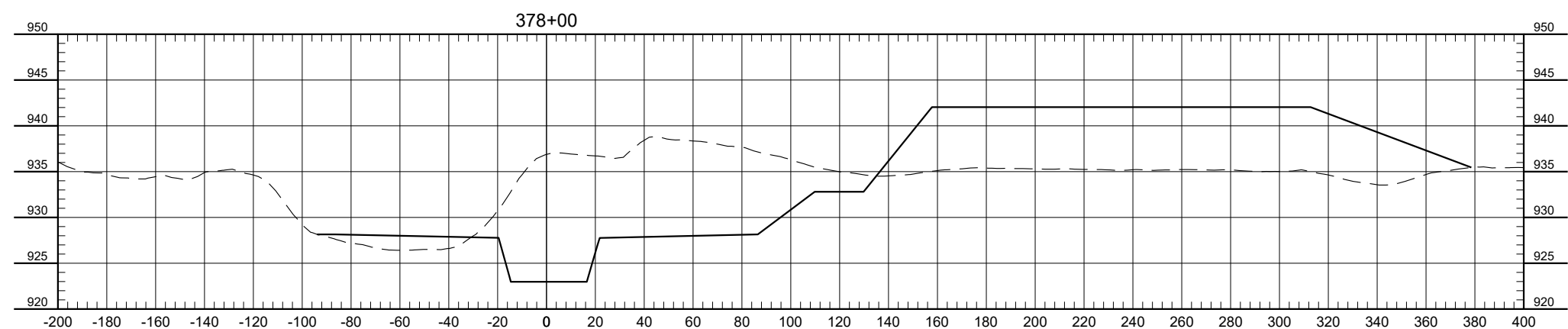
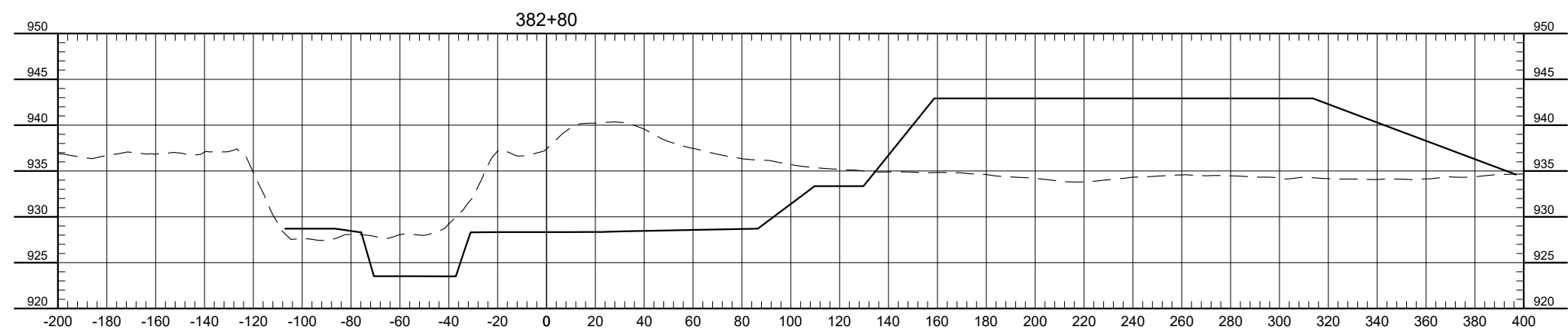
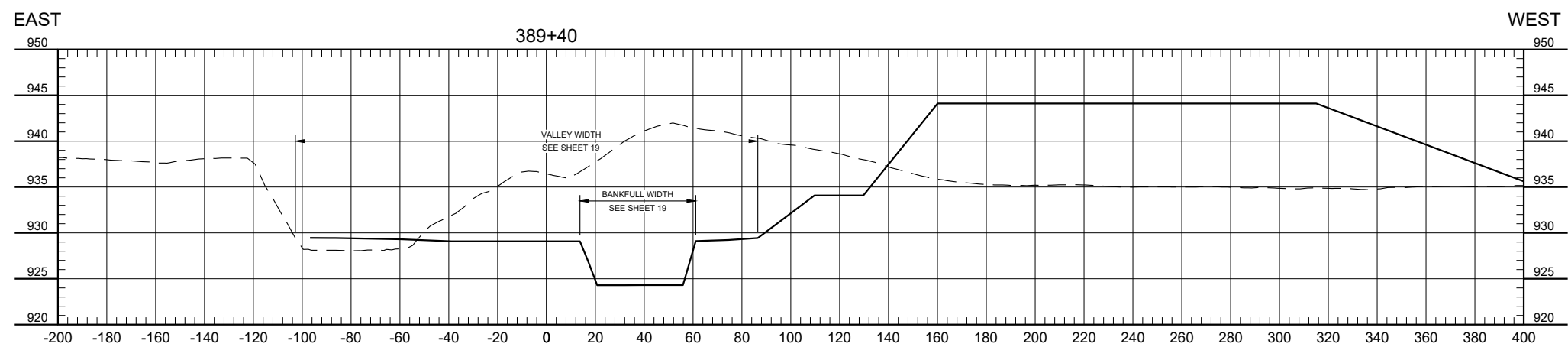


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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

LAKE PLAIN REACH
CROSS SECTIONS
PROJECT NO. 1432-0365

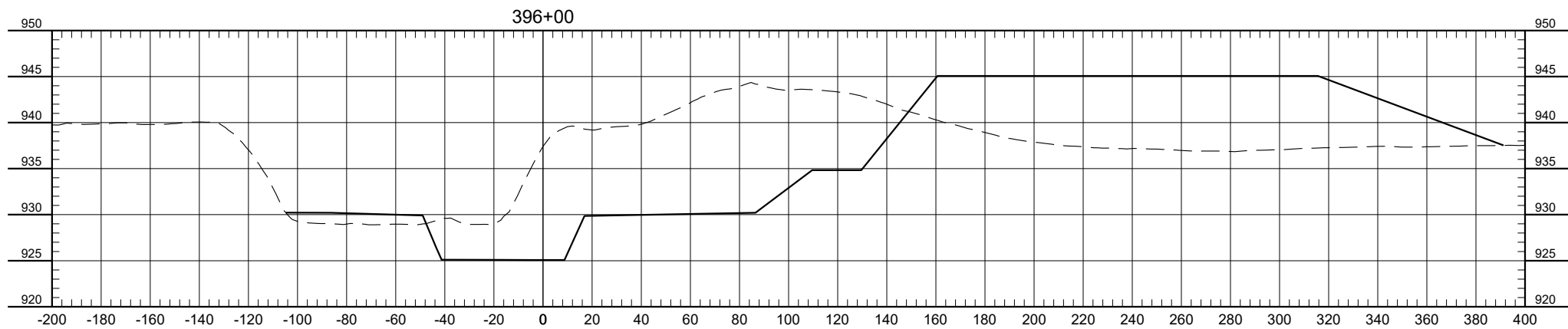
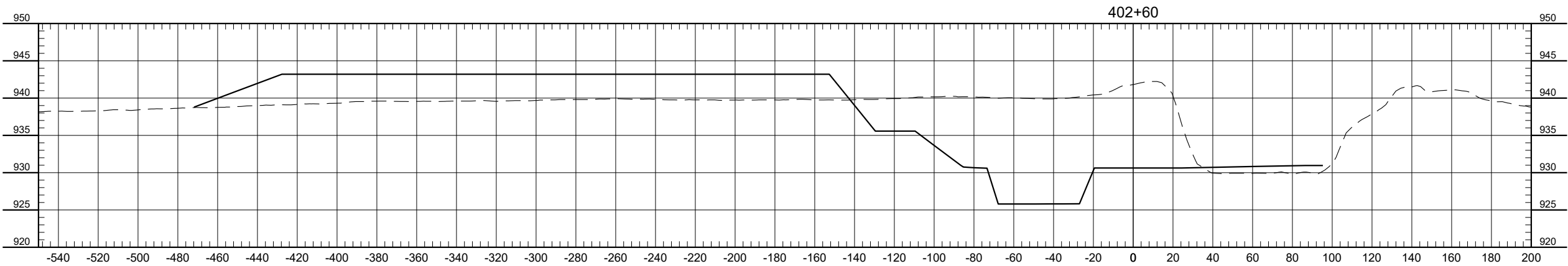
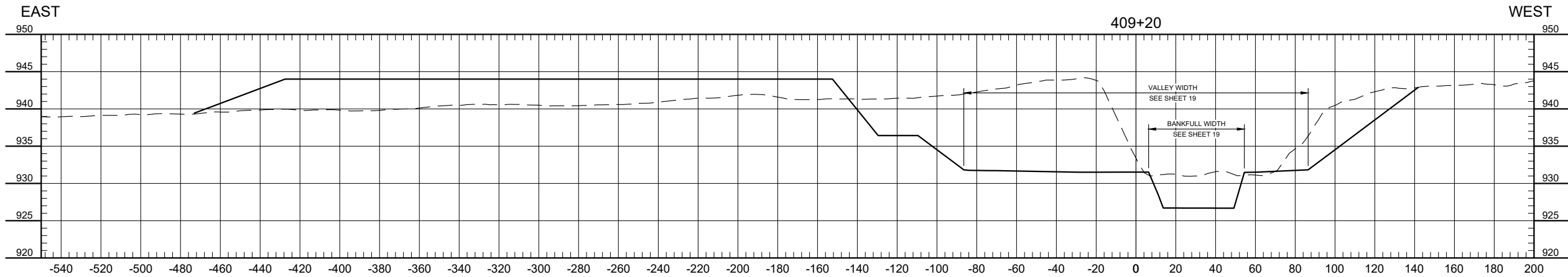
SHEET
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NOTES:

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- NOTES:
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PRELIMINARY
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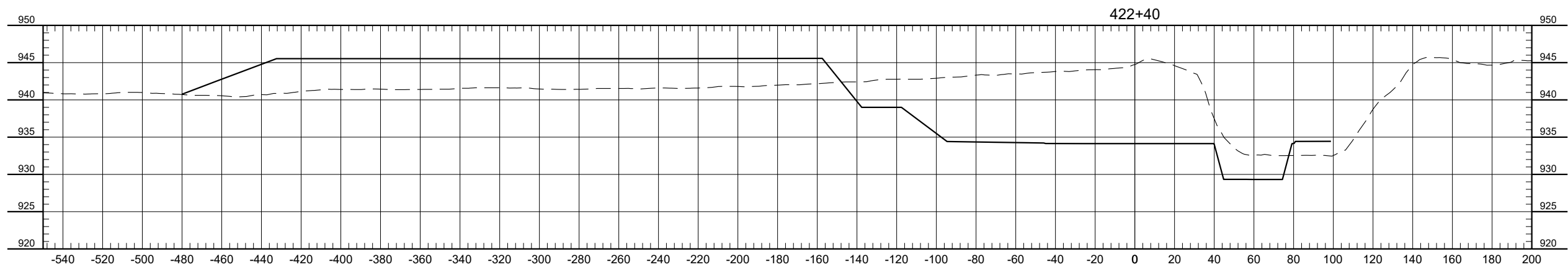
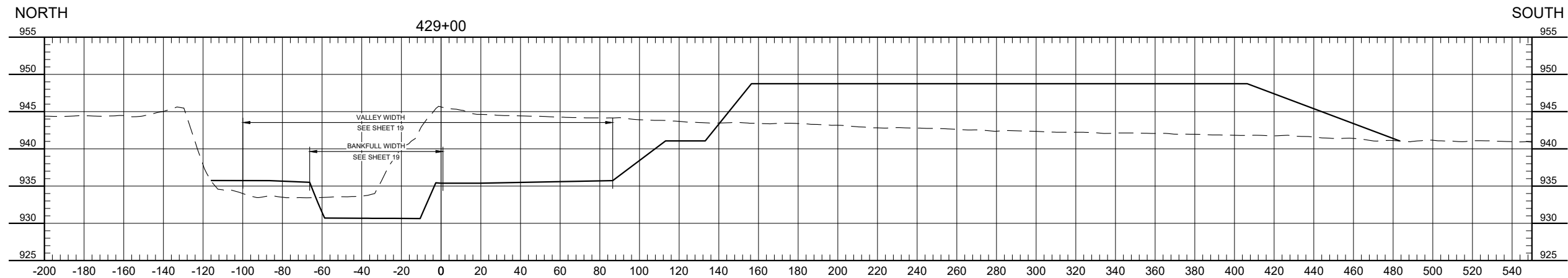
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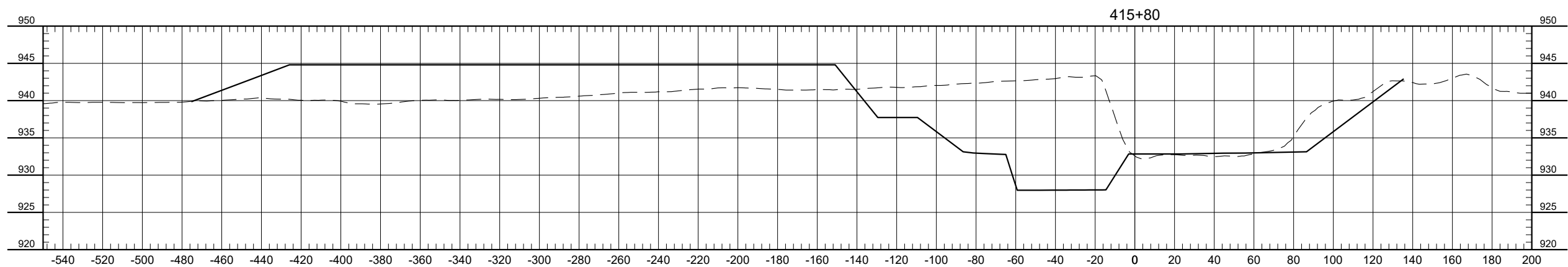
SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
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CLAY & NORMAN COUNTIES, MINNESOTA

LAKE PLAIN REACH
CROSS SECTIONS
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- NOTES:
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GLB/HRR

Date
4-28-2020

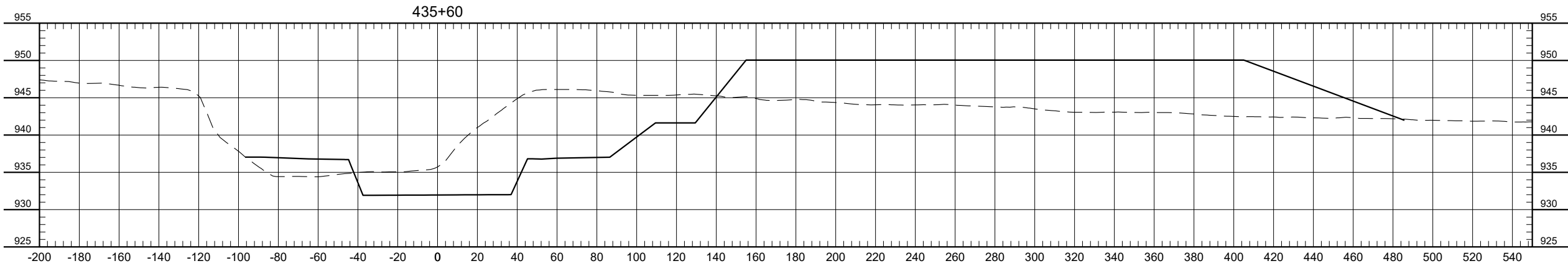
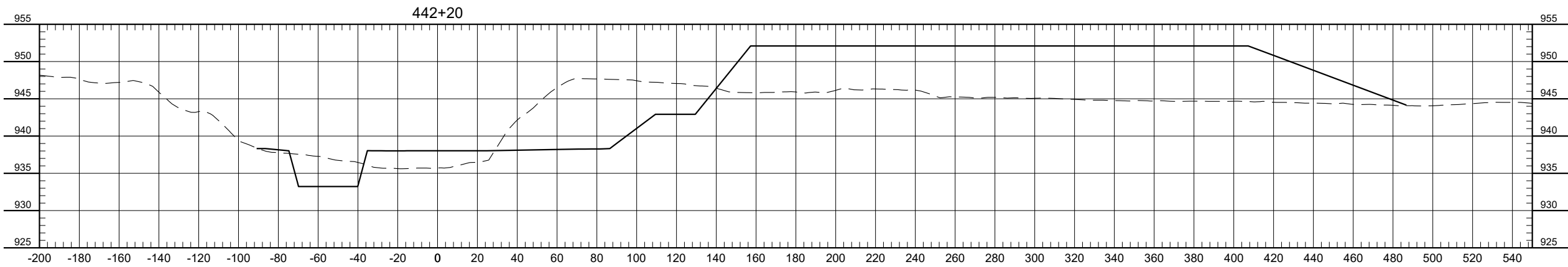
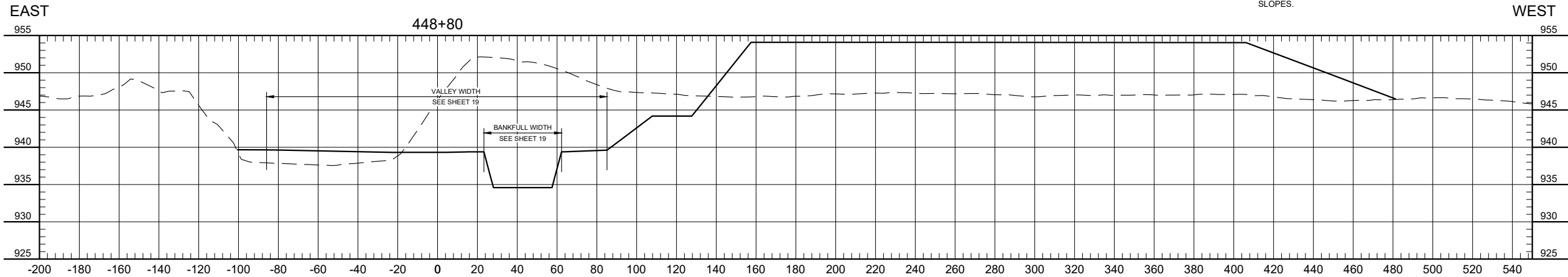
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

LAKE PLAIN REACH
CROSS SECTIONS
PROJECT NO. 1432-0365

SHEET
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- NOTES:
- 1. FINAL DESIGN WILL INCLUDE PARABOLIC/ELLIPTICAL CHANNEL SHAPE.
 - 2. BANKFULL WIDTHS AND SLOPES MAY APPEAR SKEWED DUE TO DIRECTION OF CROSS SECTION. SEE TYPICAL CHANNEL SECTIONS ON SHEET 19 FOR ACCURATE BANKFULL WIDTHS AND SLOPES.



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No.	Revision	Date	By

PRELIMINARY
Not for Construction



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F: 701.237.5101

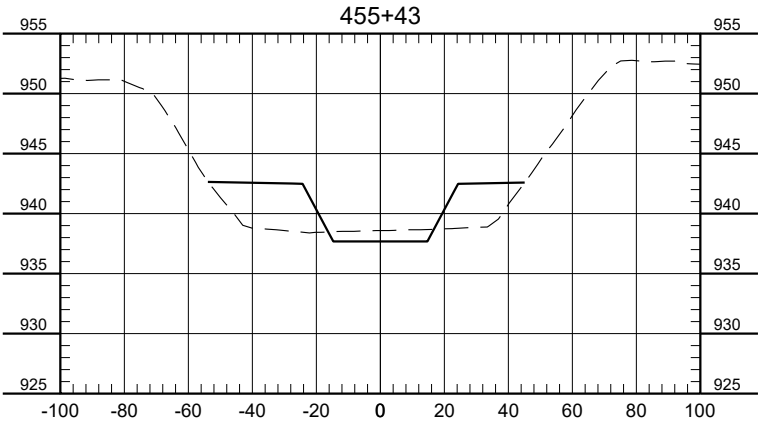
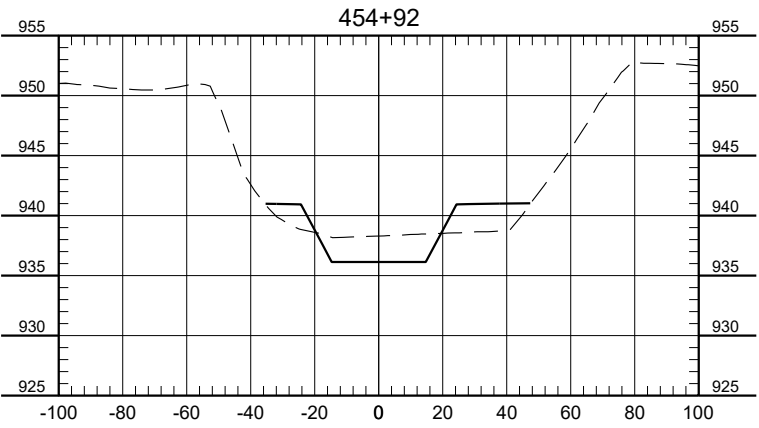
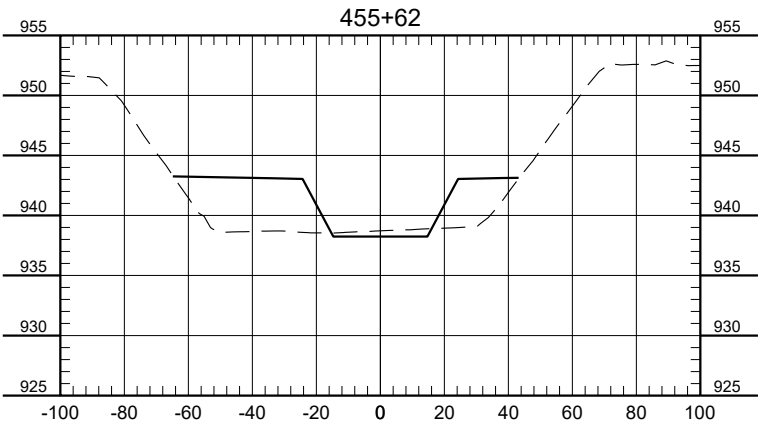
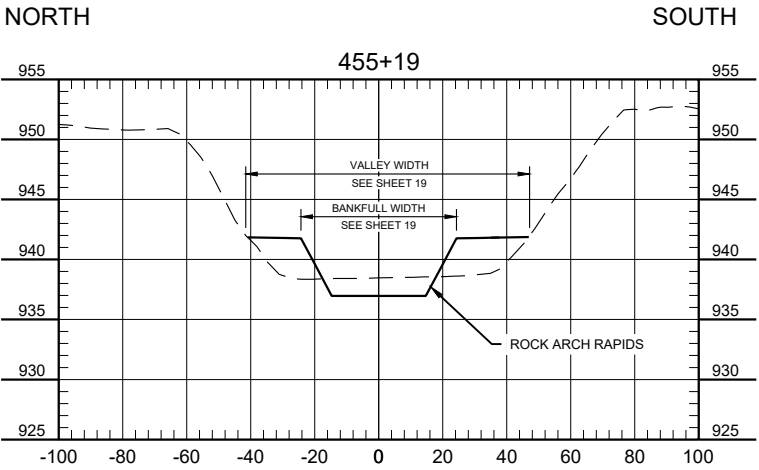
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Checked by GLB/HRR	Scale AS SHOWN

SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

LAKE PLAIN REACH
CROSS SECTIONS
PROJECT NO. 1432-0365

SHEET
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- NOTES:
1. FINAL DESIGN WILL INCLUDE PARABOLIC/ELLIPTICAL CHANNEL SHAPE.
 2. BANKFULL WIDTHS AND SLOPES MAY APPEAR SKEWED DUE TO DIRECTION OF CROSS SECTION. SEE TYPICAL CHANNEL SECTIONS ON SHEET 19 FOR ACCURATE BANKFULL WIDTHS AND SLOPES.

No.	Revision	Date	By

PRELIMINARY
Not for Construction



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AJK

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Date
4-28-2020

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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

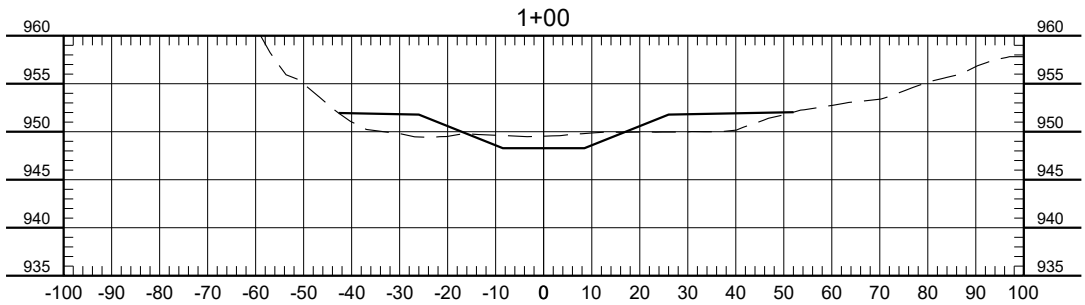
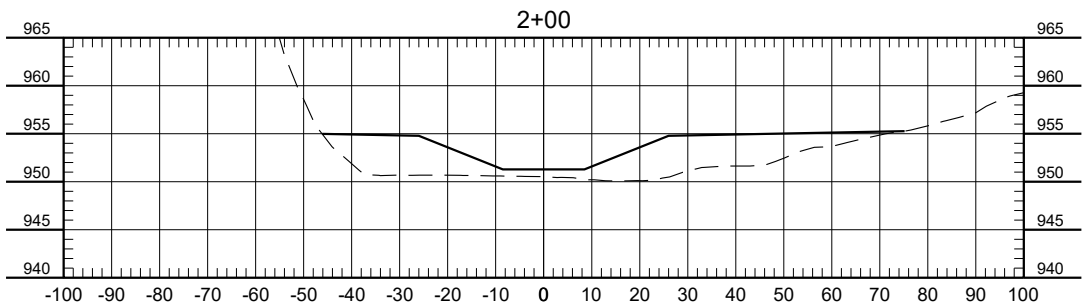
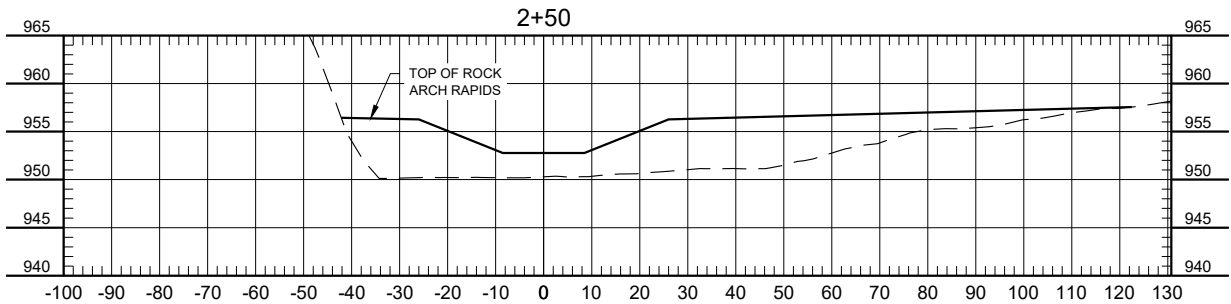
LAKE PLAIN REACH
CROSS SECTIONS

PROJECT NO. 1432-0365

SHEET

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- NOTES:
- EXISTING GROUND IS BASED ON LIDAR. LIDAR WAS EXTRAPOLATED TO ESTIMATE ROCK ARCH RAPID EXTENTS.

No.	Revision	Date	By

PRELIMINARY
Not for Construction



Fargo
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F: 701.237.5101

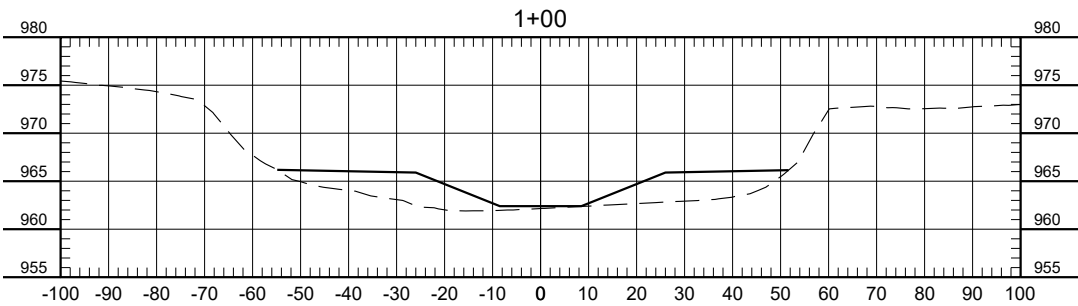
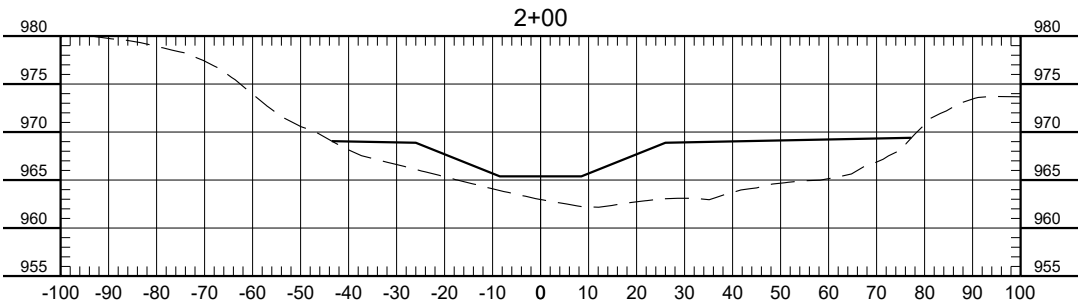
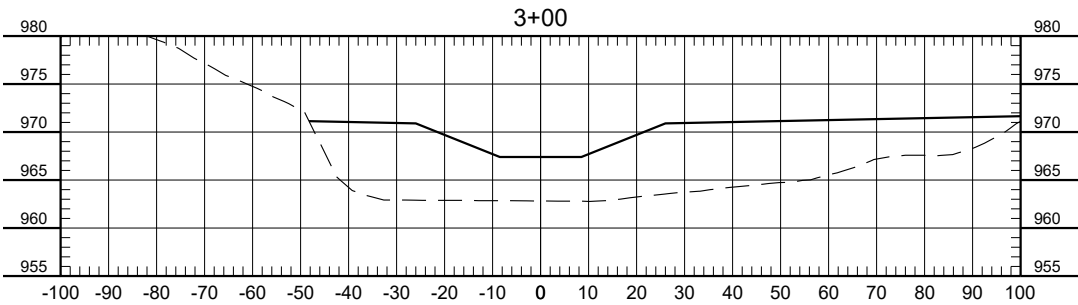
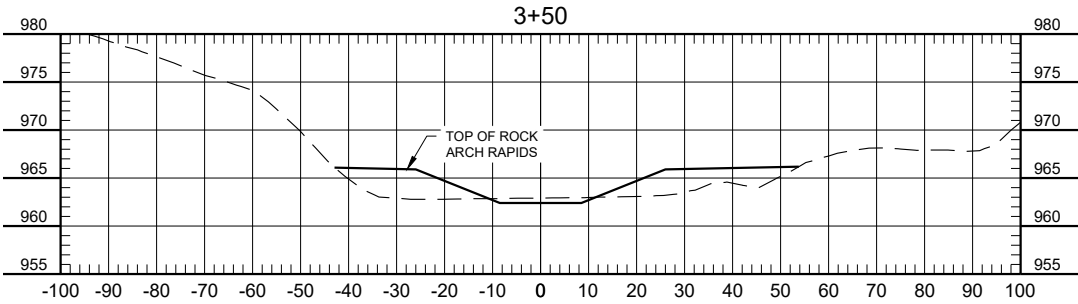
Drawn by AJK	Date 4-28-2020
Checked by GLB/HRR	Scale AS SHOWN

SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

BEACH RIDGE 1
ROCK ARCH RAPIDS
CROSS SECTIONS
PROJECT NO. 1432-0365

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- NOTES:
- EXISTING GROUND IS BASED ON LIDAR. LIDAR WAS EXTRAPOLATED TO ESTIMATE ROCK ARCH RAPID EXTENTS.

No.	Revision	Date	By

PRELIMINARY
Not for Construction



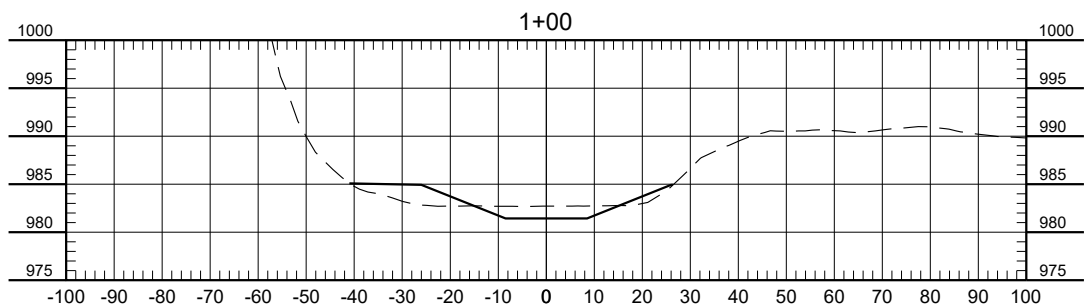
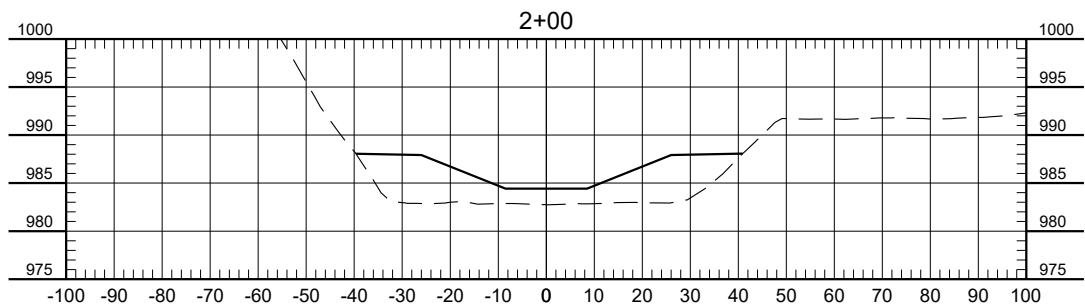
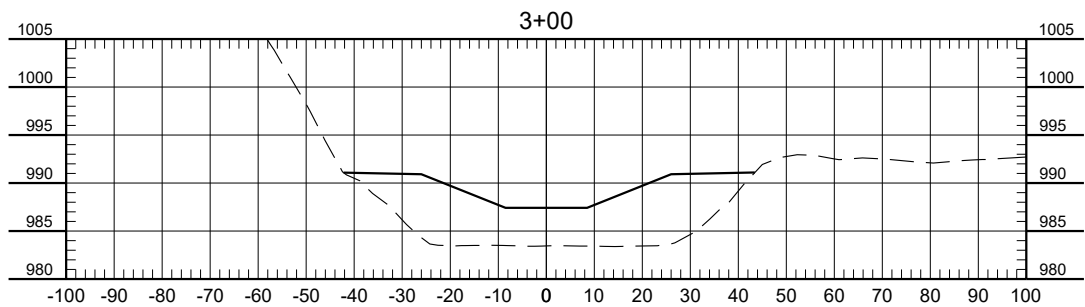
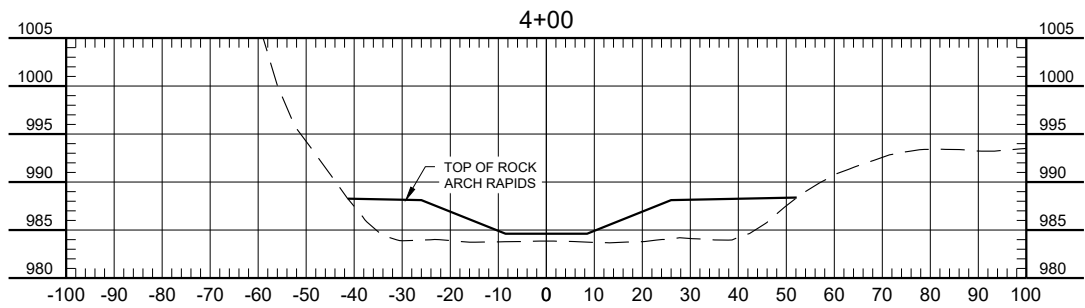
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

BEACH RIDGE 2
ROCK ARCH RAPIDS
CROSS SECTIONS
PROJECT NO. 1432-0365

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NOTES:
1. EXISTING GROUND IS BASED ON LIDAR.
LIDAR WAS EXTRAPOLATED TO ESTIMATE
ROCK ARCH RAPID EXTENTS.

No.	Revision	Date	By

PRELIMINARY
Not for Construction



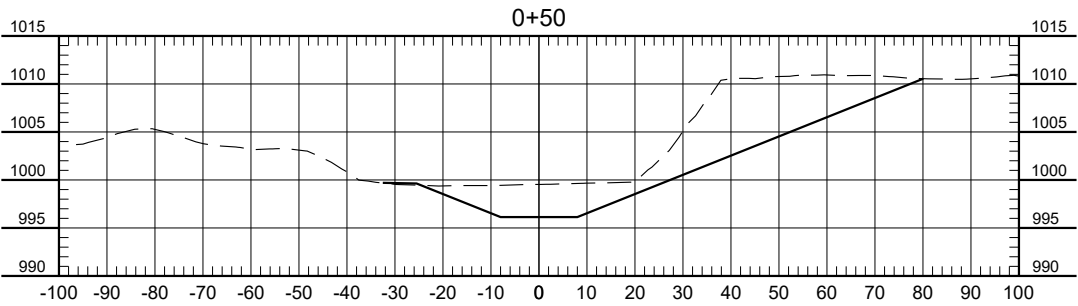
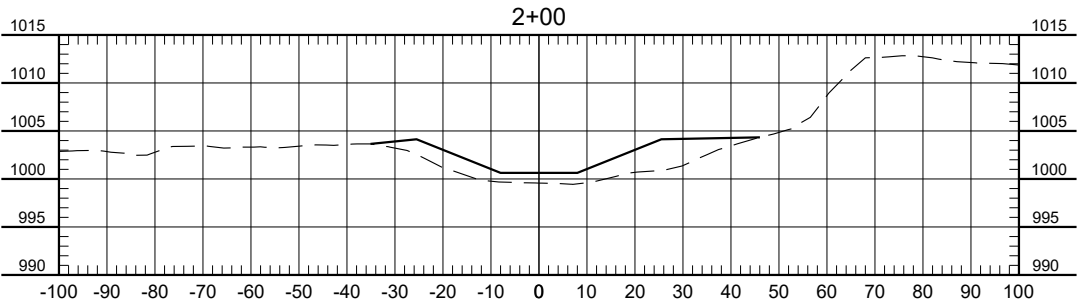
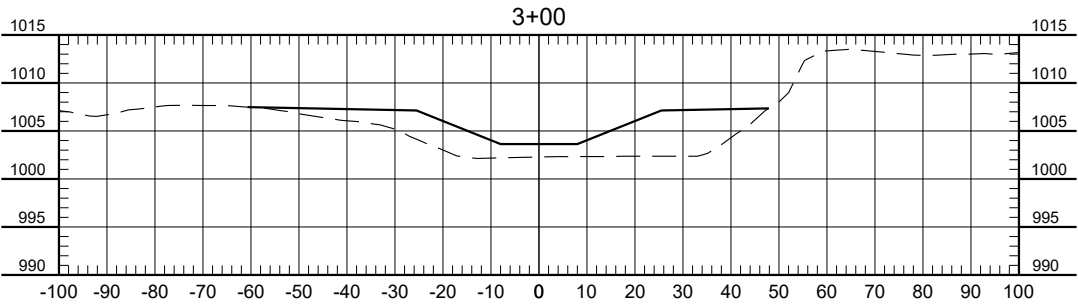
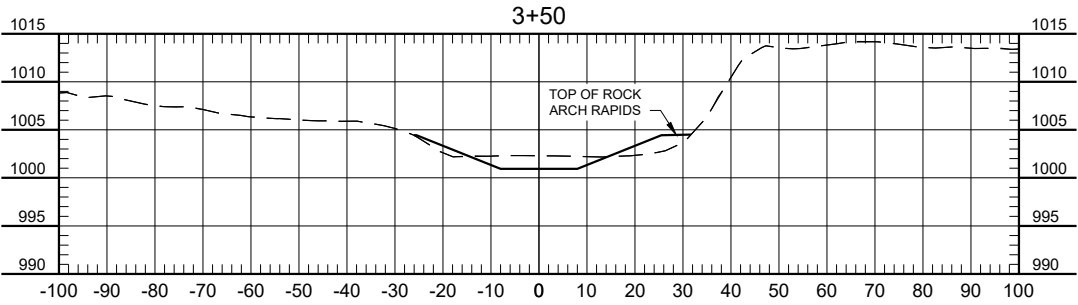
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

BEACH RIDGE 3
ROCK ARCH RAPIDS
CROSS SECTIONS
PROJECT NO. 1432-0365

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NOTES:
1. EXISTING GROUND IS BASED ON LIDAR.
LIDAR WAS EXTRAPOLATED TO ESTIMATE
ROCK ARCH RAPID EXTENTS.

No.	Revision	Date	By

PRELIMINARY
Not for Construction



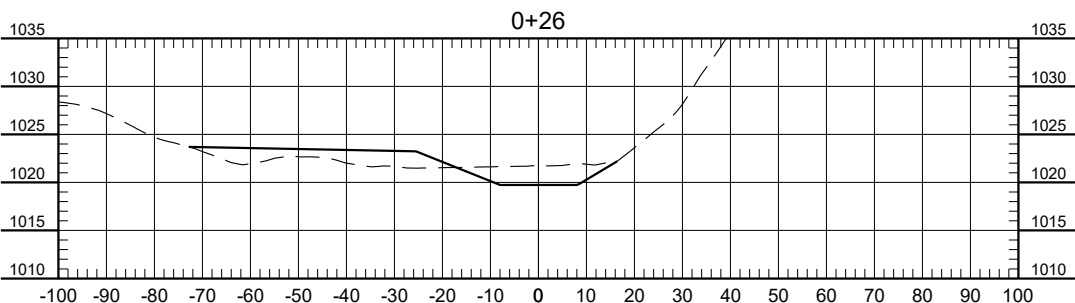
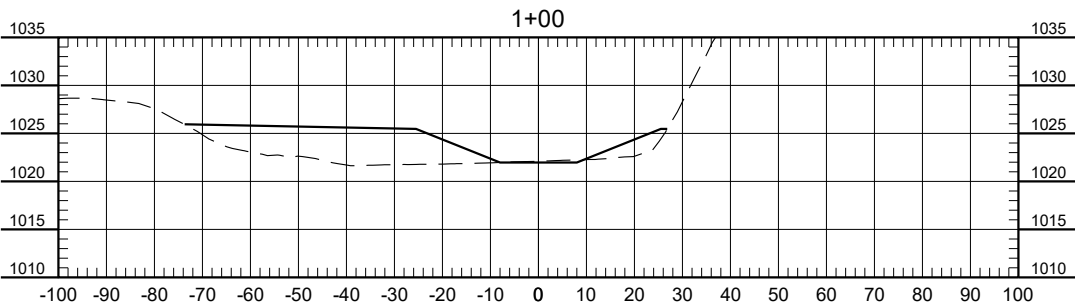
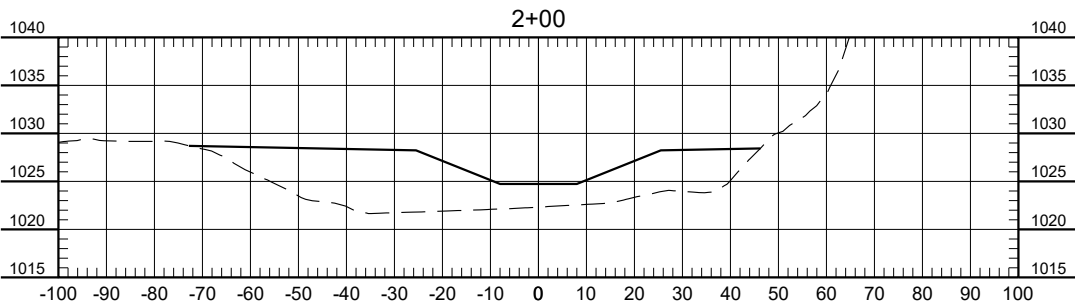
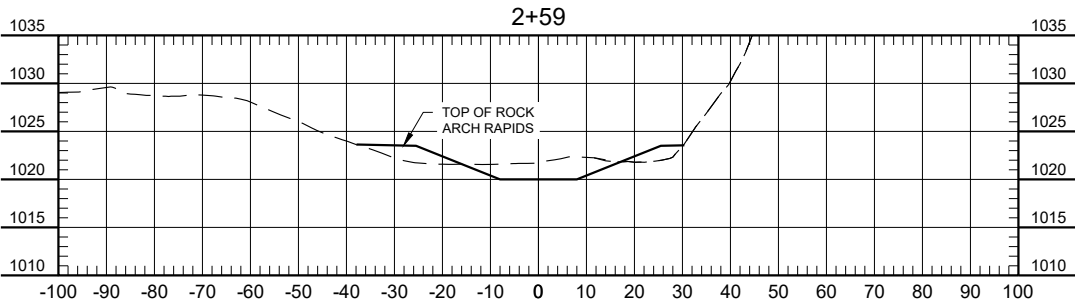
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

BEACH RIDGE 4
ROCK ARCH RAPIDS
CROSS SECTIONS
PROJECT NO. 1432-0365

SHEET
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NOTES:
1. EXISTING GROUND IS BASED ON LIDAR.
LIDAR WAS EXTRAPOLATED TO ESTIMATE
ROCK ARCH RAPID EXTENTS.

No.	Revision	Date	By

PRELIMINARY
Not for Construction



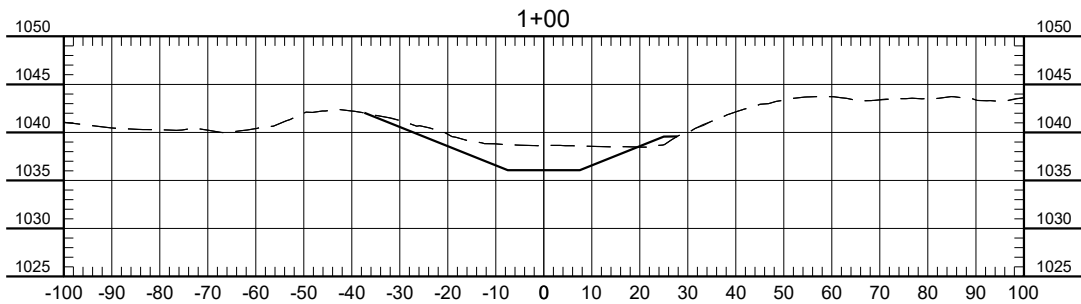
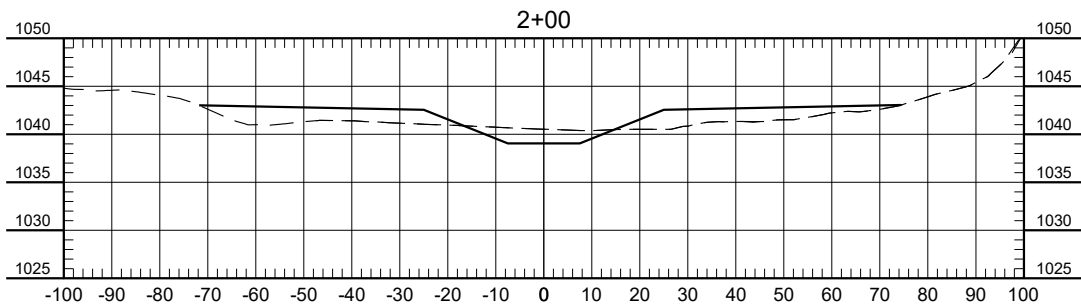
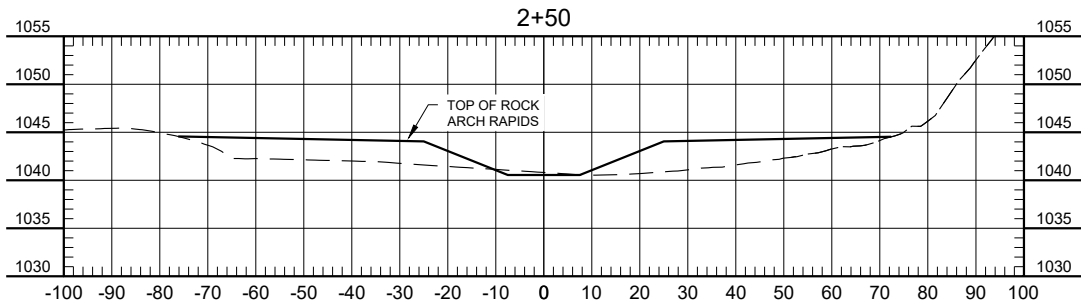
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

BEACH RIDGE 5
ROCK ARCH RAPIDS
CROSS SECTIONS
PROJECT NO. 1432-0365

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- NOTES:
- EXISTING GROUND IS BASED ON LIDAR. LIDAR WAS EXTRAPOLATED TO ESTIMATE ROCK ARCH RAPID EXTENTS.

No.	Revision	Date	By

PRELIMINARY
Not for Construction



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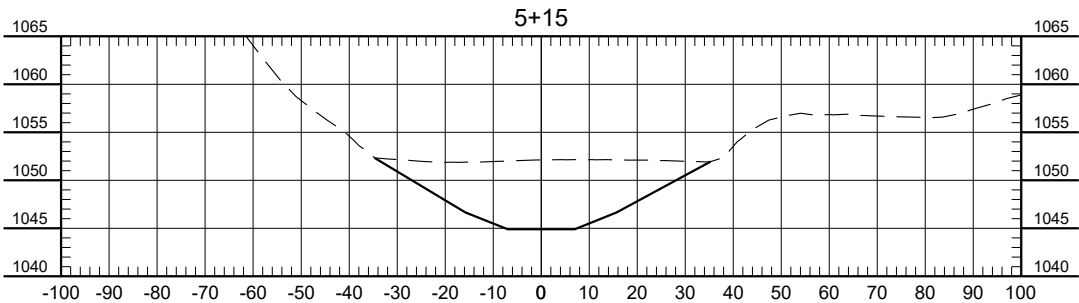
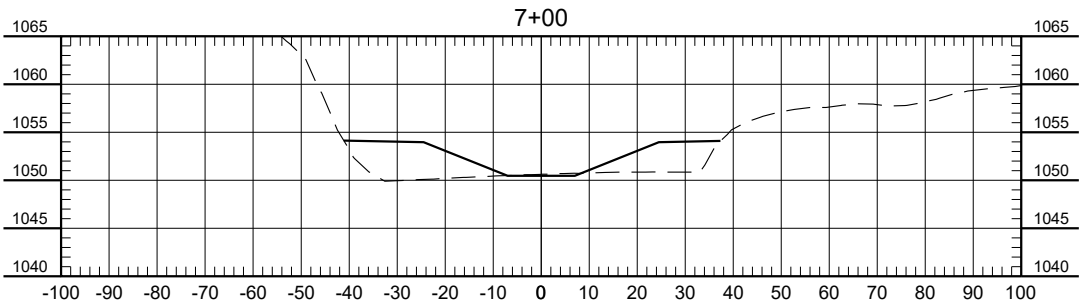
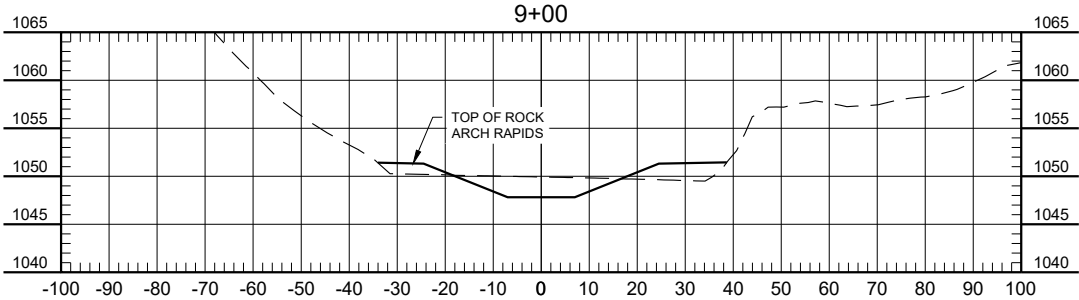
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4-28-2020
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

BEACH RIDGE 6
ROCK ARCH RAPIDS
CROSS SECTIONS
PROJECT NO. 1432-0365

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NOTES:
1. EXISTING GROUND IS BASED ON LIDAR.
LIDAR WAS EXTRAPOLATED TO ESTIMATE
ROCK ARCH RAPID EXTENTS.

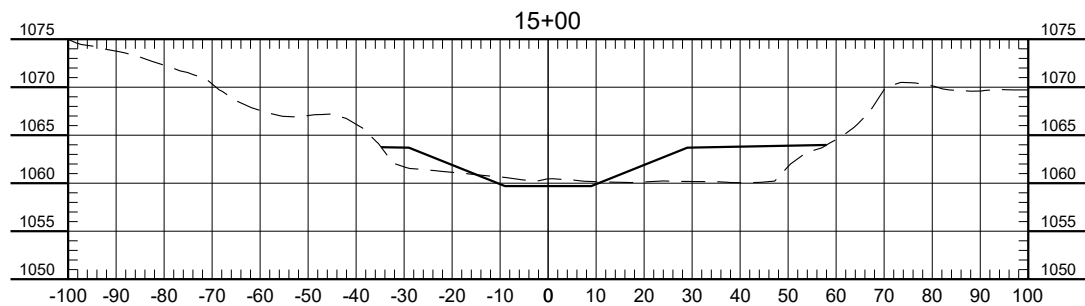
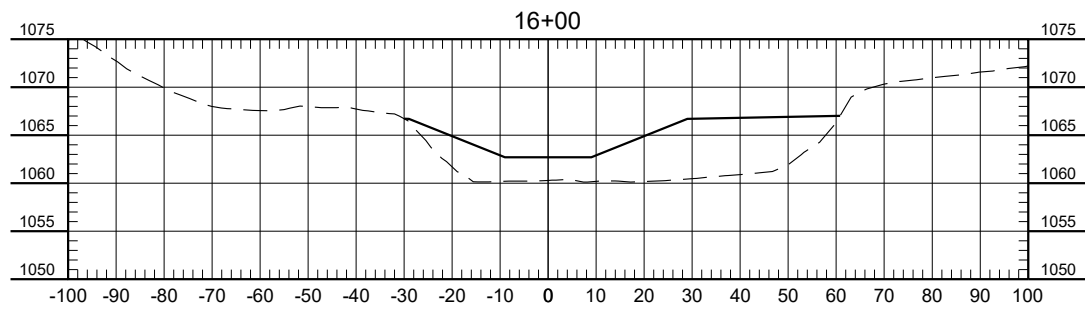
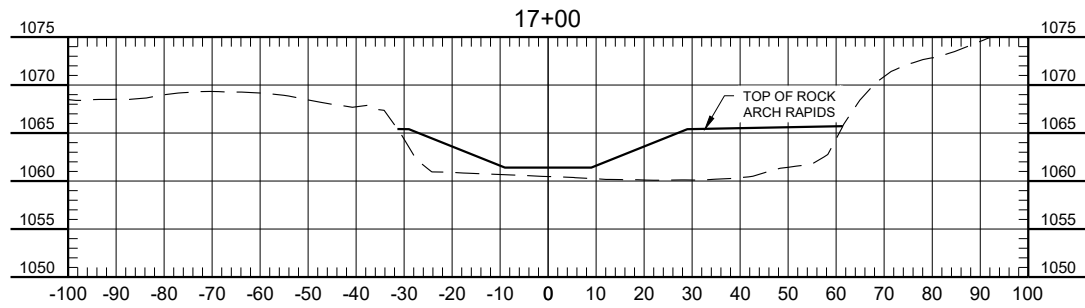
No.	Revision	Date	By

PRELIMINARY
Not for Construction



Fargo	Drawn by AJK	Date 4-28-2020	SOUTH BRANCH WILD RICE RIVER RESTORATION & SEDIMENT REDUCTION PROJECT WILD RICE WATERSHED DISTRICT CLAY & NORMAN COUNTIES, MINNESOTA	UPPER RIDGE 1 ROCK ARCH RAPIDS CROSS SECTIONS PROJECT NO. 1432-0365	SHEET 66 of 73
	Checked by GLB/HRR	Scale AS SHOWN			

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- NOTES:
1. EXISTING GROUND IS BASED ON LIDAR. LIDAR WAS EXTRAPOLATED TO ESTIMATE ROCK ARCH RAPID EXTENTS.

No.	Revision	Date	By

PRELIMINARY
Not for Construction



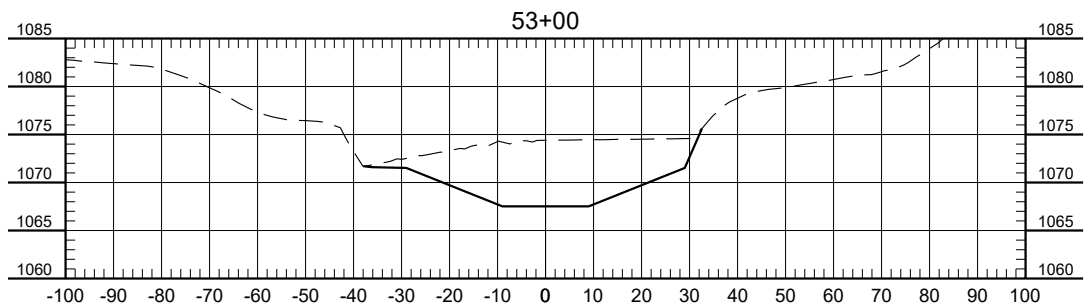
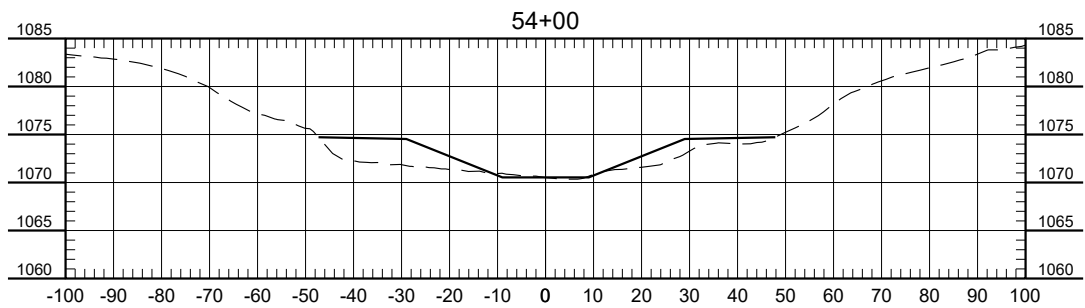
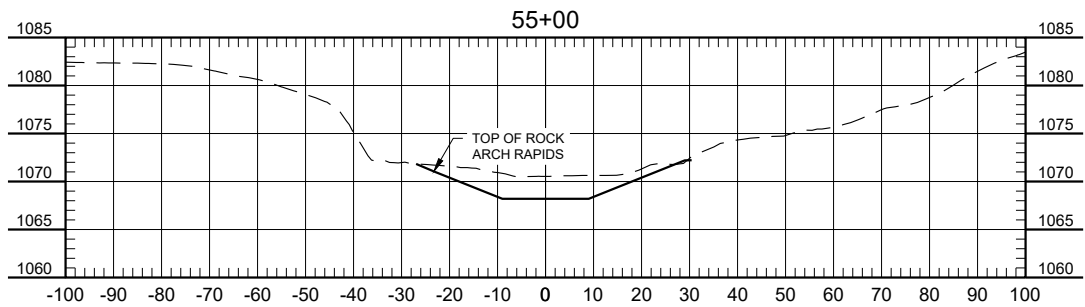
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

UPPER RIDGE 2
ROCK ARCH RAPIDS
CROSS SECTIONS
PROJECT NO. 1432-0365

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- NOTES:
1. EXISTING GROUND IS BASED ON LIDAR. LIDAR WAS EXTRAPOLATED TO ESTIMATE ROCK ARCH RAPID EXTENTS.

No.	Revision	Date	By

PRELIMINARY
Not for Construction



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AJK
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GLB/HRR

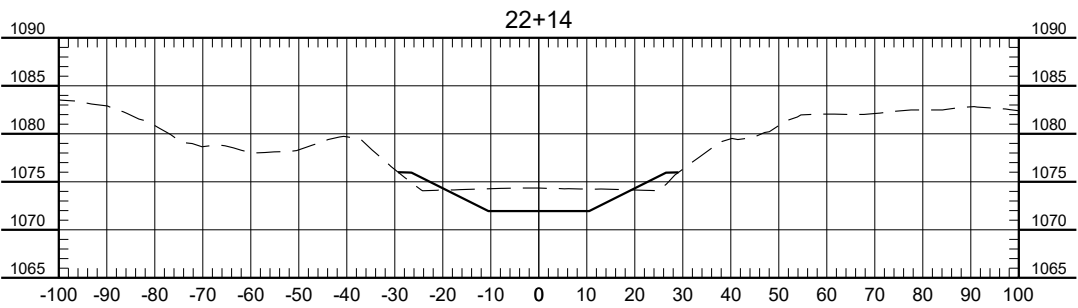
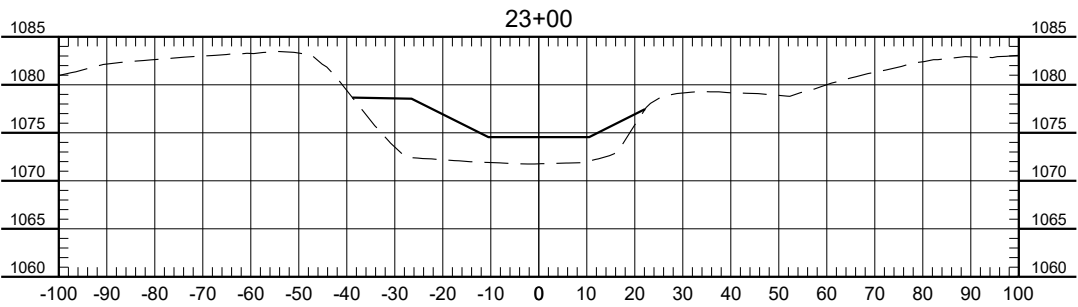
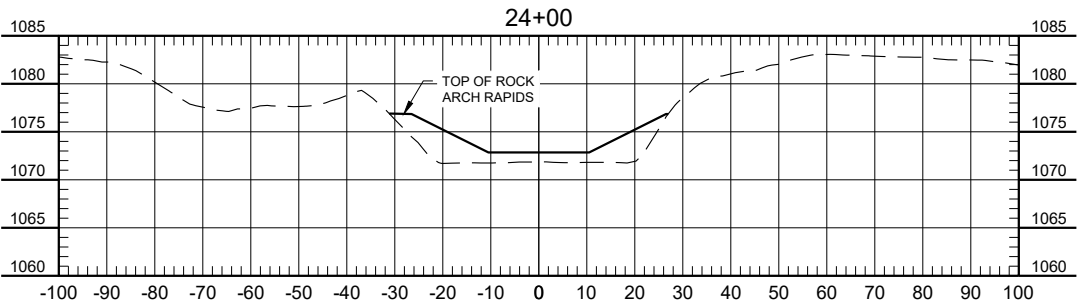
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

UPPER RIDGE 3
ROCK ARCH RAPIDS
CROSS SECTIONS
PROJECT NO. 1432-0365

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- NOTES:
1. EXISTING GROUND IS BASED ON LIDAR. LIDAR WAS EXTRAPOLATED TO ESTIMATE ROCK ARCH RAPID EXTENTS.

No.	Revision	Date	By

PRELIMINARY
Not for Construction



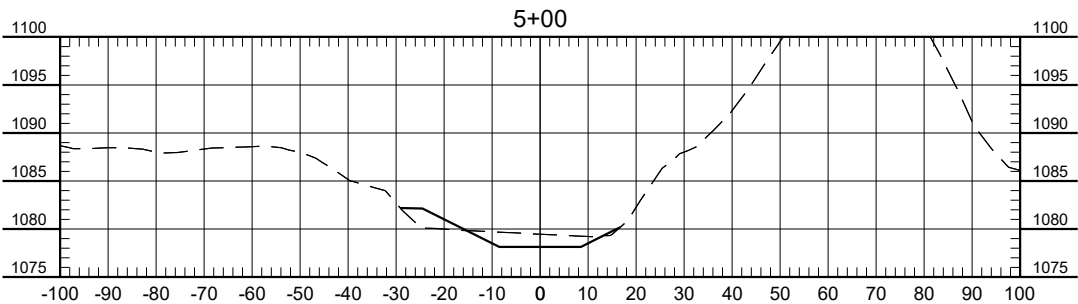
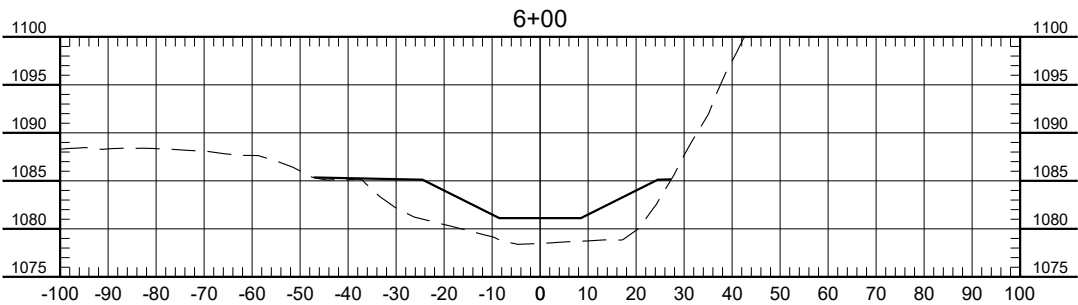
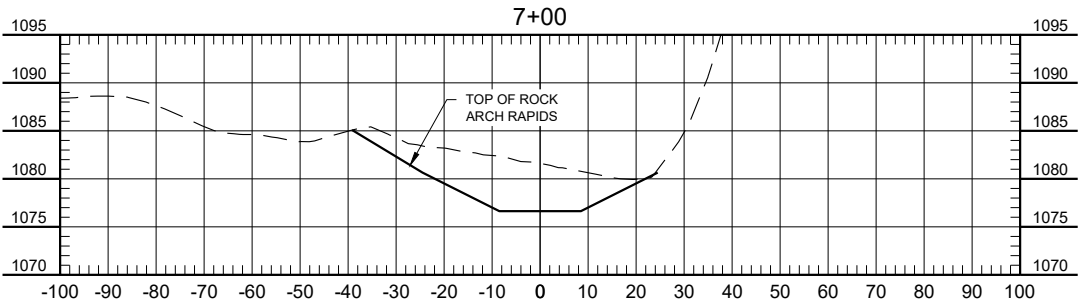
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

UPPER RIDGE 4
ROCK ARCH RAPIDS
CROSS SECTIONS
PROJECT NO. 1432-0365

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- NOTES:
1. EXISTING GROUND IS BASED ON LIDAR. LIDAR WAS EXTRAPOLATED TO ESTIMATE ROCK ARCH RAPID EXTENTS.

No.	Revision	Date	By

PRELIMINARY
Not for Construction



Fargo

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AJK

Checked by
GLB/HRR

Date
4-28-2020

Scale
AS SHOWN

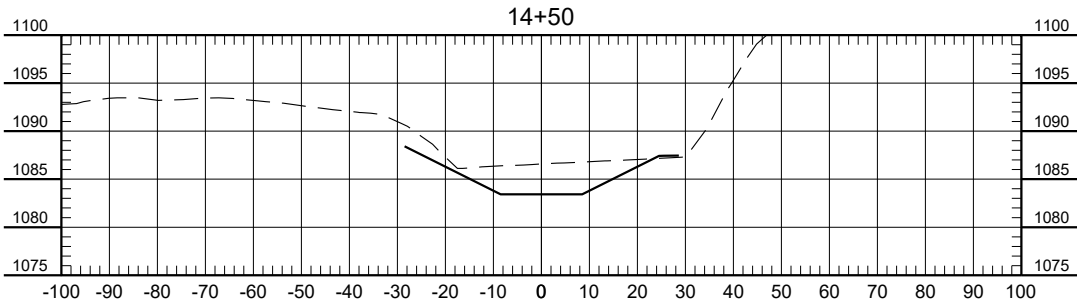
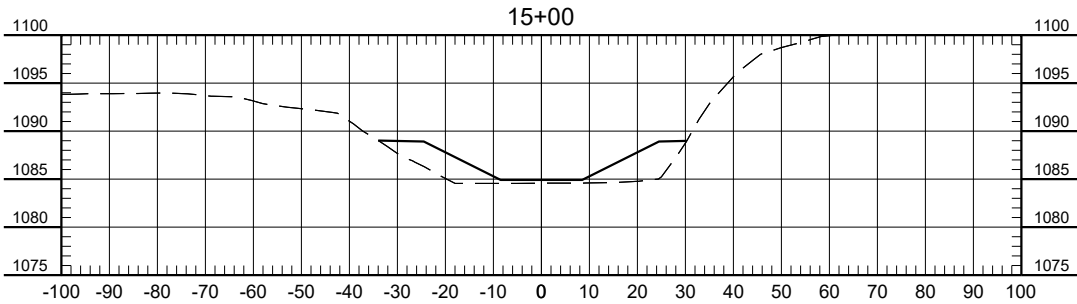
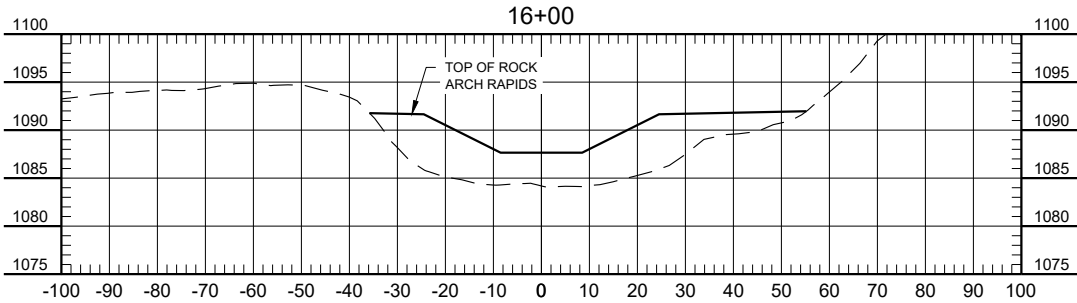
SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

UPPER RIDGE 5
ROCK ARCH RAPIDS
CROSS SECTIONS
PROJECT NO. 1432-0365

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- NOTES:
1. EXISTING GROUND IS BASED ON LIDAR. LIDAR WAS EXTRAPOLATED TO ESTIMATE ROCK ARCH RAPID EXTENTS.

No.	Revision	Date	By

PRELIMINARY
Not for Construction



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F: 701.237.5101

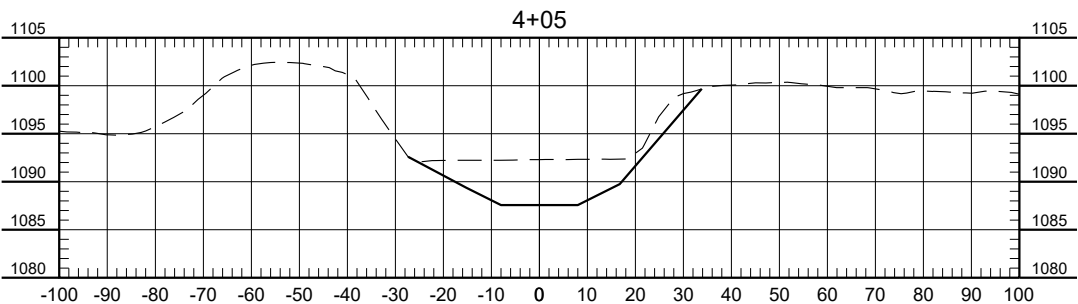
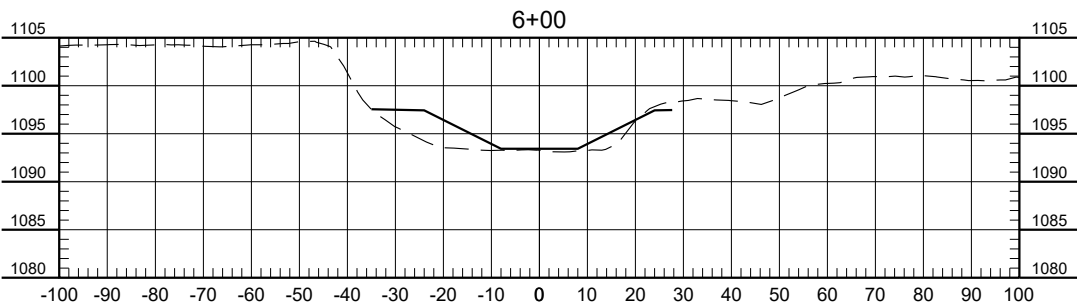
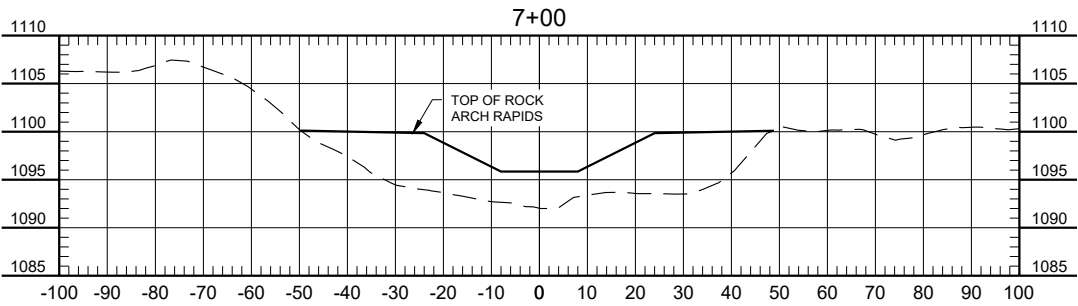
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

UPPER RIDGE 6
ROCK ARCH RAPIDS
CROSS SECTIONS
PROJECT NO. 1432-0365

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- NOTES:
- EXISTING GROUND IS BASED ON LIDAR. LIDAR WAS EXTRAPOLATED TO ESTIMATE ROCK ARCH RAPID EXTENTS.

No.	Revision	Date	By

PRELIMINARY
Not for Construction



Fargo

P: 701.237.5065
F: 701.237.5101

Drawn by
AJK

Checked by
GLB/HRR

Date
4-28-2020

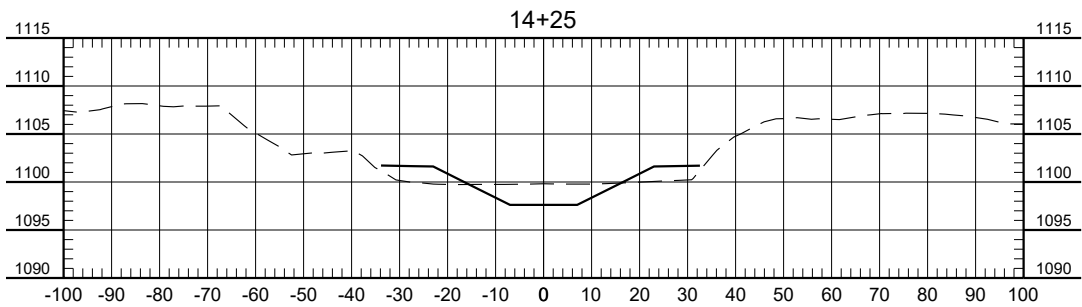
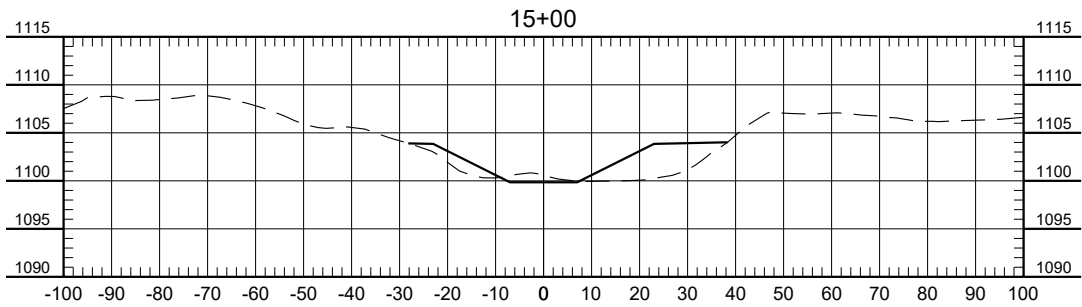
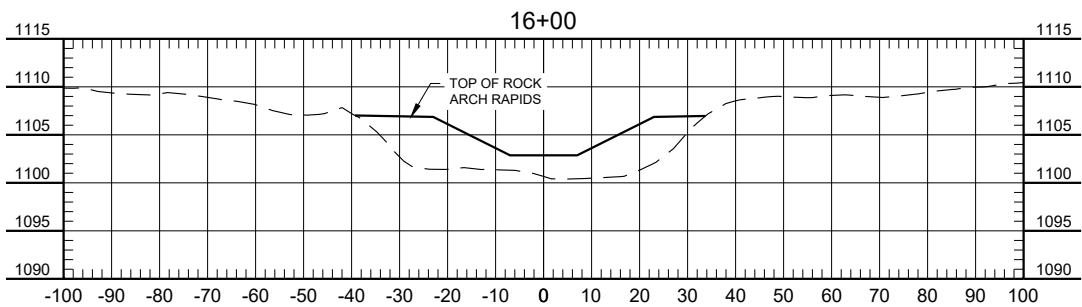
Scale
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SOUTH BRANCH WILD RICE RIVER
RESTORATION & SEDIMENT REDUCTION PROJECT
WILD RICE WATERSHED DISTRICT
CLAY & NORMAN COUNTIES, MINNESOTA

UPPER RIDGE 7
ROCK ARCH RAPIDS
CROSS SECTIONS
PROJECT NO. 1432-0365

SHEET
72 of 73

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SHEET
73 of 73



APPENDIX E

Technical Memorandum – Wild Rice River Watershed Altered Hydrology Analysis

Technical Memorandum

To: Wild Rice Planning Partnership
From: Jeremiah Jazdzewski, PE
Timothy Erickson, PE
Houston Engineering, Inc.
Subject: Wild Rice River Watershed Altered Hydrology Analysis
Date: November 27, 2019
Project: 1432-369

1. INTRODUCTION

One of the stressors commonly referenced as a reason for aquatic life impairments is “altered hydrology.” Altered hydrology is commonly thought to be characterized by increases (or decreases) in peak discharge and runoff volume for a range of precipitation events, as compared to some historic or benchmark condition. Numerous studies have suggested that this hydrologic alteration is a result of some combination of climatic variation, land use/land cover changes, or other landscape scale changes. Aquatic habitat loss, increased streambank erosion and bank failure, and increased sediment levels are some of the suggested consequences of altered hydrology. Individually and collectively these are believed to lead to the impairment of aquatic life, exhibited by lower ecological diversity.

This technical memorandum (TM) describes a framework used to define and quantify altered hydrology using records from the USGS’s long-term, continuous flow gaging network. In addition, this TM describes methods to estimate storage goals based on changes of altered hydrology metrics that can be used to develop management plans to help mitigate the impacts of alteration.

1.1. A Need to Assess Altered Hydrology

Although a general sense of the characteristics of altered hydrology exists, a substantive challenge remains. When addressing altered hydrology there is the lack of a common definition, including agreement on a set of science-based metrics to establish the desired (i.e., benchmark) condition, and assess whether altered hydrology has indeed occurred. **Figure 1** provides an example of hydrologic data which could be used to illustrate altered hydrology. **Figure 1** shows a flow duration curve for a streamflow gage in the Sand Hill River Watershed, within northwestern Minnesota. Two 30-year time periods are shown on the graph; i.e., 1980 – 2010 (solid line) and 1945 – 1975 (dashed line). The graph represents the likelihood of exceeding a specific daily mean discharge in the Sand Hill River. For the same likelihood of exceedance, the daily mean discharge is greater for the more recent time period (solid line is above the dashed line) indicating an increase in the daily mean discharge through most of the flow range. This suggests “altered hydrology” meaning that flow conditions in the watershed differ between the two time periods. The example illustrates one possible visual metric which could be used to describe altered hydrology.

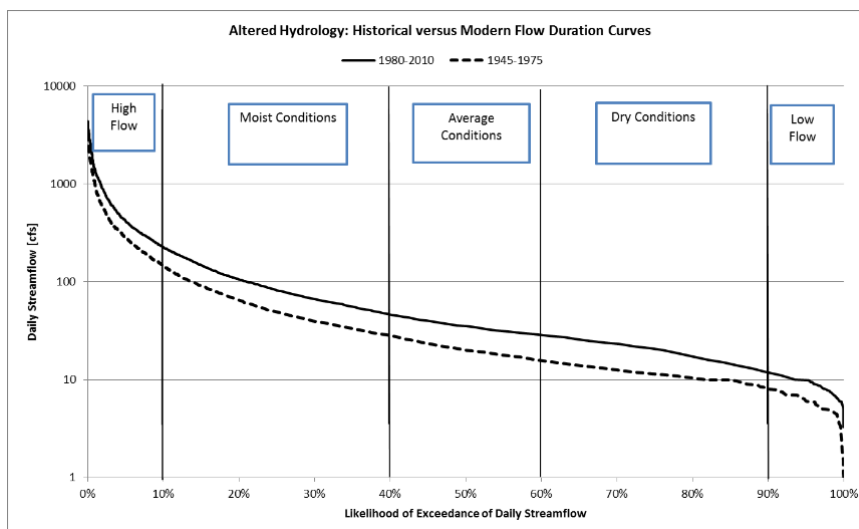


Figure 1. Flow duration curve for the Sand Hill River at Climax, Minnesota. The solid black line shows an increase in daily mean discharge for the 1980 – 2010 period, compared to the early 1945 – 1975 period.

Agreement on a set of science-based metrics to assess the extent of hydrologic alteration and the desired (i.e., benchmark) condition is needed in order to quantitatively assess changes in the hydrology of a watershed. A definition is needed to rigorously assess whether hydrology has indeed changed through time, establish goals for altered hydrology, and assess and evaluate various means, methods and projects to mitigate the adverse effects of altered hydrology.

Considerable research has been completed and technical information developed relative to describing altered hydrology. The recently released report titled “Technical Report: Protection Aquatic Life from Hydrologic Alternatives” (Novak et al., 2015) is one example. The report presents metrics which can be used to describe altered hydrology. However, causal information about how the change in hydrology results in the alteration or loss of ecological function is lacking within the report.

For the hydrology of a watershed to be altered there must be some deviation from a preferred or desired hydrologic condition; i.e., a “benchmark” condition. The benchmark for altered hydrology could be the “natural hydrologic regime” or some other condition. The natural hydrologic regime (Poff et al 1997; Arthington et al 2006; Bunn and Arthington 2002 ; Sparks 1995) is the characteristic pattern of water quantity, timing and variability in a natural water body. A river’s hydrologic or flow regime consists of environmental flow components

(Mathews and Richter, 2007), each of which can be described in terms of the magnitude, frequency, duration, timing and rate of change in discharge. The integrity of an aquatic system presumably depends on the natural dynamic character of these flow components to thereby driving ecological processes.

Defining altered hydrology and the benchmark condition, identifying the metrics to describe altered hydrology, and translating the information into goals to mitigate the adverse consequences is technically challenging. The approach used to evaluate whether a watershed exhibits altered hydrology is presented within this document, along with a thorough definition of altered hydrology. Specific quantitative metrics to assess the benchmark conditions and the extent of hydrologic change are also presented. No effort is made to describe the causal relationship between hydrology and the ecological, geomorphological, or water quality effects. Rather, the assumption is made that the desired condition is achieved by obtaining the benchmark condition. Actual indices of ecological diversity between the two time periods is needed. These results are intended to be a beginning point in addressing the topic of altered hydrology in a more rigorous manner, which no doubt will evolve through time.

2. A METHODOLOGY TO DEFINE ALTERED HYDROLOGY

2.1. *A Brief History of Changing Hydrology*

Streamflow in Minnesota (Novotny & Stefan, 2007) and across the contiguous United States (Lins and Slack 1999, McCabe and Wolock, 2002) have been changing during the past century, with flows in the period starting from the 1970s to the beginning of the 21st Century tending to be higher than during the early to mid-1900s (Ryberg et al. 2014). Numerous studies have been conducted to quantify the magnitude of impact and pinpoint the relative importance of potential causes of these changes, but scientific consensus has currently not been achieved. The science is not at a point where specific causes can be attributed to altered hydrology with any significant certainty, and public discussion about specific causes usually leads to barriers to implementation.

In general, the leading candidate causes of altered hydrology can be categorized into two primary groups: climatic changes and landscape changes. Examples of climatic changes include changes in annual precipitation volumes, surface air temperature, timing of the spring snowmelt, annual distribution of precipitation, and rainfall characteristics (timing, duration, and intensity). Examples of landscape changes include changes in land use/land cover, increased imperviousness (urbanization), subsurface (tile) and surface drainage, wetland removal/restoration, groundwater pumping, flow retention and regulation, and increased storage (both in-channel and upland storage).

Although it is important to water resource management to understand the mechanics behind the changes in hydrology, the focus of this analysis is developing a definition for altered hydrology, implementing a method for assessing whether it has occurred within a watershed, and establishing a goal for addressing altered hydrology. No assumption of causation is made or needed to use this framework.

2.2. *Altered Hydrology Defined*

Altered hydrology is defined as a discernable change in streamflow between two time periods, as measured by a set of stream discharge metrics. The discernable change must occur through an entire annual hydrologic cycle and must exceed the discharge measurement error (i.e., 10%), compared to a benchmark condition. For this framework, *discernable* has been used as a proxy for statistical comparisons. The metrics are typically

some type of hydrologic statistic derived from the annual discharge record across a long period of time, usually a minimum of 20-years (Gan et al. 1991). The amount of baseflow, the hydrograph shape, peak discharge, and runoff volume for a range of precipitation event magnitudes, intensities, and durations are specific components of or derived from the annual hydrograph.

2.3. Establishing a Benchmark Condition

A reference or benchmark condition is needed to complete an assessment of whether hydrology is altered. A minimum of a 20-year time-periods reasonably ensures stable estimates of streamflow predictably (Gan et al. 1991; Olden & Poff 2003), sufficient duration to capture climate variability and the interdecadal oscillation typically found in climate (McCabe et al. 2004, Novotny and Stefan 2007), and is the minimum timespan necessary to establish “normal” climate statistics in the United States. To the extent data allows it, the analysis is performed for two 35-year time periods; i.e., a benchmark period called “historic” and an “altered” state or called “modern”). The benchmark period used to establish benchmark conditions represents the period before shifts in hydrology are commonly thought to have begun within Minnesota as a result of land use/land cover changes, or increases in the depth, intensity, and duration of precipitation.

To illustrate an example of a change in streamflow and the validity in the breakpoint period, cumulative streamflow (using annual depth values) is plotted across time (**Figure 2**) for the USGS gage at the Wild Rice River at Hendrum, MN (USGS Station 05064000). Cumulative streamflow was used instead of straight annual streamflow because (1) it linearizes streamflow relationship where the slope of a trendline would be the average annual streamflow, (2) no assumptions about multi-year dependencies (e.g. changes in storage) or autocorrelation is necessary, and (3) changes in slope can be visualized, showing an altered state of hydrology.

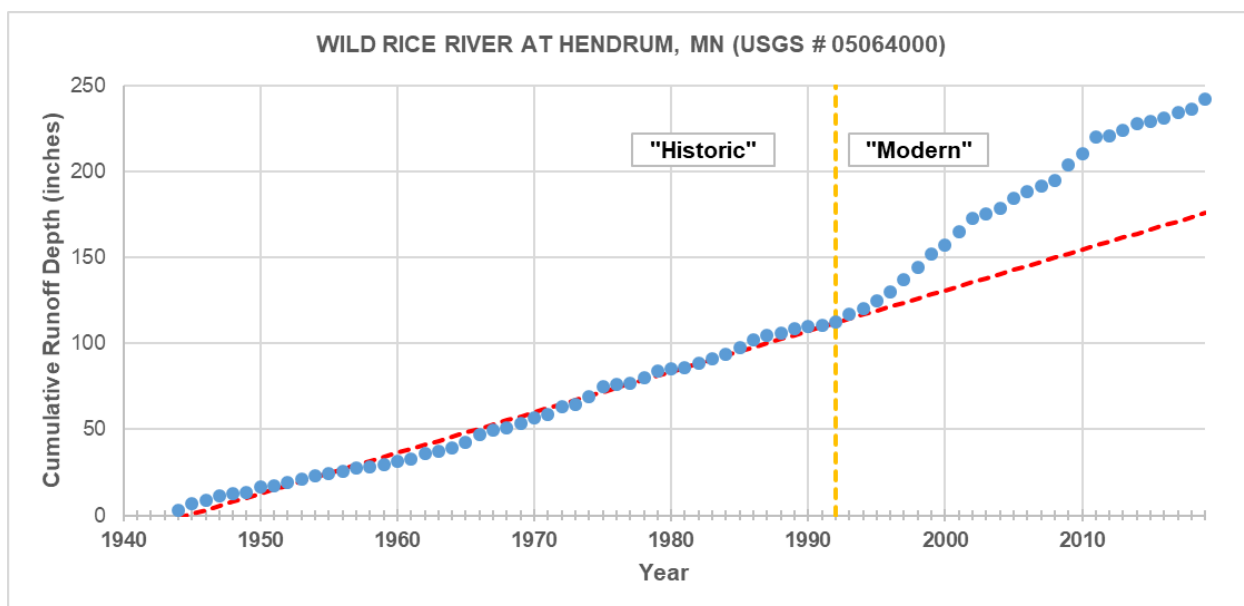


Figure 2. Cumulative streamflow for the Wild Rice River at Hendrum, MN (USGS Station 05064000).

Results from these analyses were used to determine the breakpoint and define the benchmark and modern conditions.

2.4. Metrics Used to Assess Altered Hydrology

Many potential metrics can be used to describe a measurable change in the annual hydrograph. For example, the indicators of hydrologic alteration software developed by the Nature Conservancy (<https://www.conservationgateway.org/ConservationPractices/Freshwater/EnvironmentalFlows/MethodsandTools/IndicatorsofHydrologicAlteration/Pages/indicators-hydrologic-alt.aspx>) uses 67 different statistics derived from mean daily discharge to describe altered hydrology. Ideally, each indicator or metric could be causally linked to an ecological or geomorphological consequence, although this is technically challenging. Use of such a large number of indicators can be problematic as many metrics often lack ecological or geomorphological meaning. Many of the metrics may also be correlated and are therefore interdependent.

The structure and therefore function of ecological systems are often “driven” by “non-normal” events; e.g., low flows associated with drought or higher flows which inundate the floodplain. Metrics used to complete this analysis were preferentially selected to reflect the variability in specific characteristics of the annual hydrograph, and include peak discharges, runoff volumes and hydrograph shape. Each metric was specifically selected to represent a flow condition believed to be of ecological or geomorphological importance, in the absence of causal information. **Table 1** shows the specific metrics used to complete the analysis. The use of these metrics is intended to identify: 1) whether the hydrology within a watershed is indeed altered; and 2) which resources may be at risk because of the alteration.

Table 1. Metrics used to define and assess whether hydrology is “altered” for a specific watershed.

Relevance	Hydrograph Feature	Frequency of Occurrence	Duration	Metric	Ecological or Geomorphic Endpoint
Condition of Aquatic Habitat	Baseflow	10-year Annual	7 day and 30 day	The minimum change between time periods is the accuracy of measuring streamflow discharge and estimating daily mean discharge. A discharge measurement accurate within 10% of the true value is considered excellent by the United States Geological Survey (USGS). Some additional error is induced through the conversion of these data to discharge. Therefore, a minimum change of 15% is needed between “historic” and “modern” period for this metric to classified as “altered.”	Discharge needed to maintain winter flow for fish and aquatic life.
			30-day median (November)		
Aquatic Organism Life Cycle	Shape (volume of flow)	Mean	Monthly average of daily means	Use the “historic” period of record to define “normal variability.” Develop a histograms of daily mean discharges for each month within the period of record for the “historic” and “modern” time periods. Compare the histograms of the monthly average of daily means using an appropriate statistical test. Assume the histograms are from the same statistical population and text for significance at an appropriate significance level.	Shape of the annual hydrograph and timing of discharges associated with ecological cues.
	Distribution of Flow				
	Timing	Julian day of minimum	1-day		
		Julian day of maximum			
Riparian Floodplain (Lateral) Connectivity	Peak discharge	10-year	24-hour and 10-day	The minimum change between time periods is the accuracy of measuring streamflow discharge and estimating daily mean discharge. A discharge measurement accurate within 10% of the true value is considered excellent by the United States Geological Survey (USGS). Some additional error is induced through the conversion of these data to discharge. Therefore, a minimum change of 15% is needed between “historic” period and “modern” period for this metric to classified as “altered.”	Represents the frequency and duration of flooding of the riparian area and the lateral connectivity between the stream and the riparian area. Functions include energy flow, deposition of sediment, channel formation and surface water – groundwater interactions.
		50-year			
		100-year			
	Volume	10-year	Days with a daily mean discharge exceeding the 10, 50, or 100-year, 24-hour discharge		
		50-year			
		100-year			
Geomorphic Stability and Capacity to Transport Sediment	Peak Discharge	1.5 year and 2 year	24-hour	The minimum change between time periods is the accuracy of measuring streamflow discharge and estimating daily mean discharge. A discharge measurement accurate within 10% of the true value is considered excellent by the United States Geological Survey (USGS). Some additional error is induced through the conversion of these data to discharge. Therefore, a minimum change of 15% is needed between “historic” period and “modern” period for this metric to classified as “altered.”	Channel forming discharge. An increase is interpreted as an increased risk of stream channel susceptibility to erosion.
	Volume	1.5 year and 2 year	Days exceeding channel forming discharge		
		Average daily	30-year flow duration curve		

2.5. *Determination of Altered Hydrology*

A simple weight of evidence approach is used to decide whether the hydrology of a watershed is “altered” between the two separate time periods. A “+” is assigned to a metric if it shows a discernable increase in hydrologic response between the historic and modern time periods, as defined by the metric. A “-” is assigned to a metric if it shows a discernable decrease in hydrologic response between the historic and modern time periods, as defined by the metric. An “o” is assigned to a metric if it lacks a discernable increase or decrease between the historic and modern time periods, as defined by the metric.

Metrics were then placed into one of four groups based on the primary effects that altered hydrology can have on the ecological and geomorphological aspects of a river. Each metric was placed into one of the groups based on the effect that the metric measures, as a response to altered hydrology. For instance, the group relating to the condition of the aquatic habitat includes metrics that primarily reflect the flow characteristics of the annual hydrograph and represent conditions needed to maintain adequate habitat for fish and aquatic life. Each group was composed of multiple metrics. If the number of “+” values in a group of metrics exceeds the number of “-” values, an increase in the watershed response to precipitation is implied and the hydrology is considered altered between the two time periods. On the other hand, if the number of “-” values exceeds the number of “+” values, a decrease in the watershed response to precipitation is implied and the hydrology is considered altered between the two time periods.

2.6. *Establishing Altered Hydrology Goals*

There are two types of goals; i.e., a qualitative and a quantitative goal. The qualitative goal is to return the hydrology to the benchmark condition. The qualitative goal is evaluated using a weight of evidence approach. The goal is simply to achieve the conditions for the historic period as defined by the metrics in **Table 1**. It is presumed the historic period is “better” from an ecological and geomorphological perspective.

The second type of goal is a quantitative volume reduction goal. Several of the metrics within **Table 1** can be used to establish a volume reduction goal. The reduction volume is represented by the amount of storage required on the landscape to return to hydrologic response to historic conditions. Water storage on the landscape may be accomplished by a variety of structural or management projects. Projects include not only traditional storage projects, but also management strategies that increase the organic matter content (and thus water holding capacity) of soils.

2.7. *Methods for Evaluating Altered Hydrology Mitigation Strategies*

Several methods can be used to develop strategies to mitigate the effects of altered hydrology. These methods include the use of continuous simulation hydrology models, like the Hydrologic Simulation Program Fortran (HSPF) and the event-based hydrology approaches like those within the Prioritize, Target and Measure Application (PTMApp).

3. ALTERED HYDOLOGY IN THE WILD RICE AND MARSH RIVERS

There are four long term USGS gaging stations within the Wild Rice River and Marsh River drainage areas (see **Table 2**).

Table 2. Available long-term USGS gage sites covering the Wild Rice and Marsh Rivers.

Stream	USGS ID	Drainage Area (sq mi)	Start Date	End Date	Observation Count ¹
Wild Rice River at Twin Valley, MN	05062500	934	7/1/1909	Present	33,437
South Branch Wild Rice River at Co. Rd. 27 near Felton, MN	05063398	190	8/16/2004	Present	5,532
Wild Rice River at Hendrum, MN	05064000	1,560	4/1/1944	Present	27,377
Marsh River near Shelly, MN	05067500	236	3/1/1944	Present	23,788

¹ As of October 13, 2019

The gage at the South Branch Wild Rice River at Co. Rd. 27 near Felton, MN (USGS #05063398) was installed in 2004 and does not have enough data to perform the altered hydrology analysis. Similarly, there are large gaps in the flow data record at the Marsh River near Shelby, MN (USGS #05067500). Therefore, results of the altered hydrology analysis can only be conducted on the remaining two sites.

The following are summaries of results from the altered hydrology analysis conducted on long-term gaging station with enough available data (USGS sites 05062500 and 05064000).

3.1. *Wild Rice River at Twin Valley, MN (USGS# 05062500)*

The USGS long-term continuous flow gaging station on the Wild Rice River at Twin Valley, MN (USGS# 05062500) monitors discharge from a drainage of approximately 934 square miles. The data record starts in 1909 and continues to operate at present day. The flow record used in this analysis was downloaded on October 10, 2019. The site includes both daily average streamflow records and peak flow measurements.

Figure 3 shows the cumulative streamflow (in inches per year) for the gaging site. Cumulative streamflow is used to determine a breakpoint between the benchmark condition and the altered condition (see **Section 2.3**).

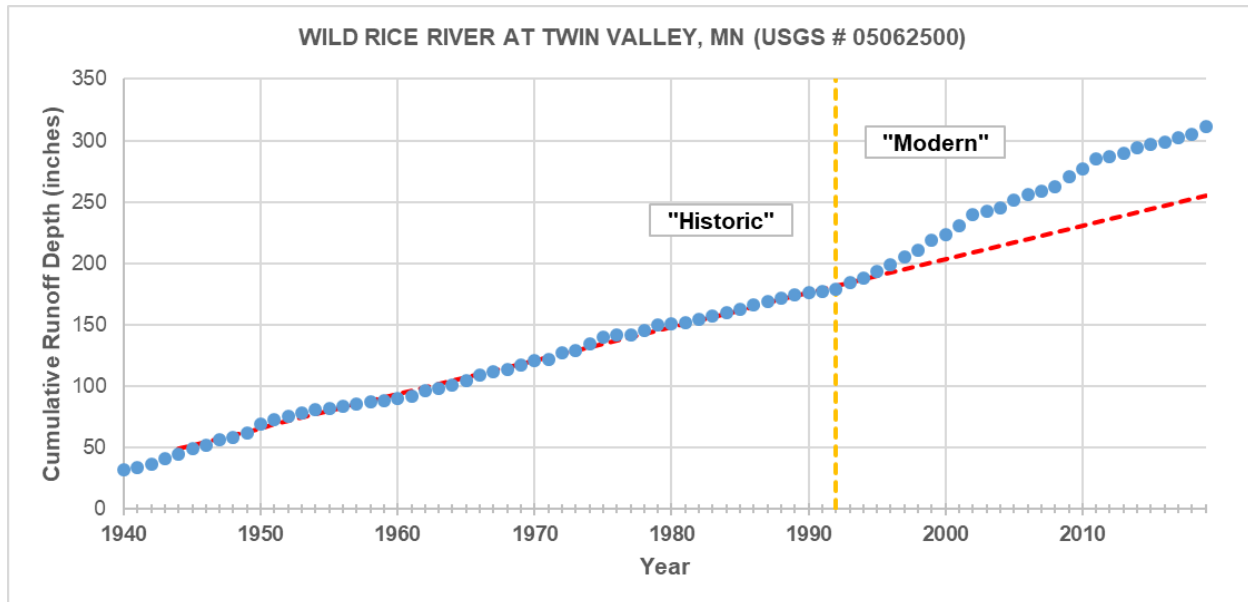


Figure 3. Cumulative streamflow for the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Additionally, the runoff (using non-cumulative annual depth values) is plotted in Figure 4.

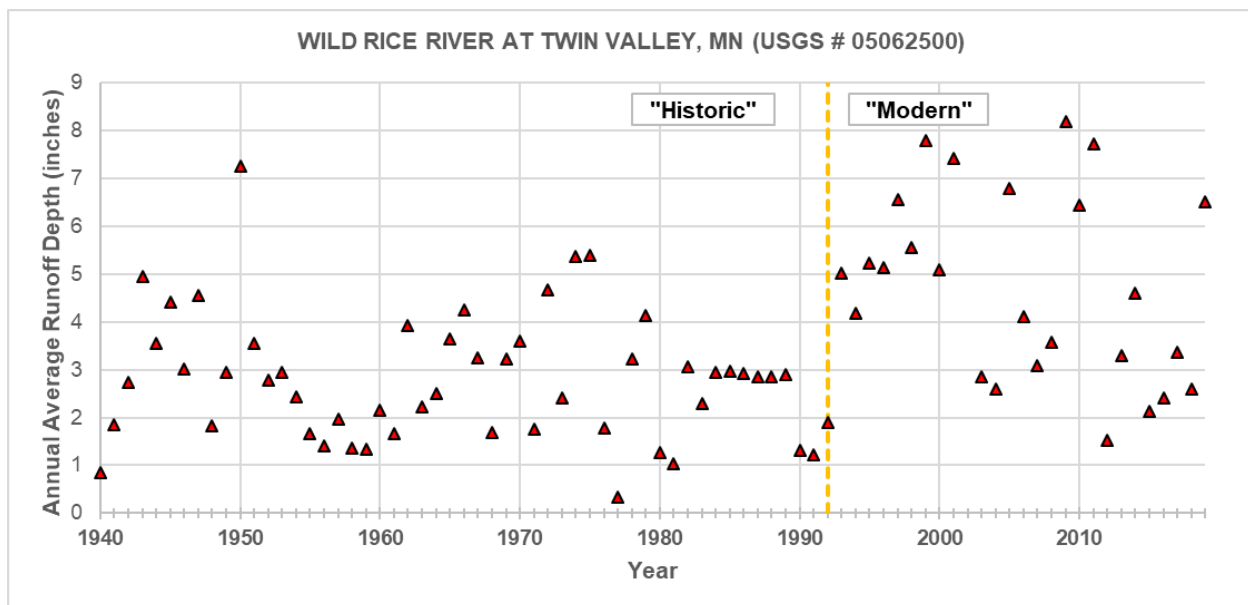


Figure 4. Average annual runoff depth for the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

According to the cumulative streamflow analysis, a breakpoint exists around 1992. Therefore, the benchmark “historic” conditions include data from 1967 through 1991 and the altered “modern” conditions include data from 1992 through 2018. This results in a comparison period of 26 years.

A summary of the results from the altered hydrology analysis is provided in **Table 3**. A more detailed description of the results is provided in **Appendix A**. A summary of the storage goals, based on the altered hydrology analysis, are provided in **Section 4**.

Table 3. Altered Hydrology Summary for the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Group	Metric	% Difference	Altered Hydrology Metric	Evidence of Altered Hydrology for Group
Aquatic Habitat	10-year, Annual Minimum 30-day Mean Daily Discharge	141.3%	+	Yes, Increasing
	10-year, Annual Minimum 7-day Mean Daily Discharge	159.2%	+	
	Median November (Winter Base) Flow	134.3%	+	
Aquatic Organism Life Cycle	Magnitude of Monthly Runoff Volumes	6.1% - 221.0%	o	No Trend
	Distribution of Monthly Runoff Volumes	-35.9% - 93.9%	o	
	Timing of Annual Peak Discharge	19.63%	+	
	Timing of Annual Minimum Discharge	2.44%	o	
Riparian Floodplain (Lateral) Connectivity	10-year Peak Discharge Rate	51.09%	+	Yes, Increasing
	50-year Peak Discharge Rate	42.21%	+	
	100-year Peak Discharge Rate	40.75%	+	
	Average Cumulative Volume above the Historic 10-year Peak Discharge	187.80%	+	
	Average Cumulative Volume above the Historic 50-year Peak Discharge	NA	NA	
	Average Cumulative Volume above the Historic 100-year Peak Discharge	NA	NA	
Geomorphic Stability and Capacity to Transport Sediment	1.5-year Peak Discharge Rate	107.71%	+	Yes, Increasing
	2-year Peak Discharge Rate	86.88%	+	
	Average Cumulative Volume above the Historic 1.5-year Peak Discharge	67.22%	+	
	Average Cumulative Volume above the Historic 2-year Peak Discharge	81.59%	+	
	Duration above the Historic 1.5-year Peak Discharge	24.62%	+	
	Duration above the Historic 2-year Peak Discharge	39.39%	+	
	Flow Duration Curve	40.0% - 303.0%	+	

+ symbol indicates metric exhibits altered hydrology and an increase for the modern Period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern Period compared to the historic Period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern Period compared to the historic period

3.2. Wild Rice River at Hendrum, MN (USGS# 05064000)

The USGS long-term continuous flow gaging station on the Wild Rice River at Hendrum, MN (USGS# 05064000) monitors discharge from a drainage of approximately 1,560 square miles. The data record starts in 1944 and continues to operate at present day. The flow record used in this analysis was downloaded on October 10, 2019. The site includes both daily average streamflow records and peak flow measurements.

Figure 5 shows the cumulative streamflow (in inches per year) for the gaging site. Cumulative streamflow is used to determine a breakpoint between the benchmark condition and the altered condition (see **Section 2.3**).

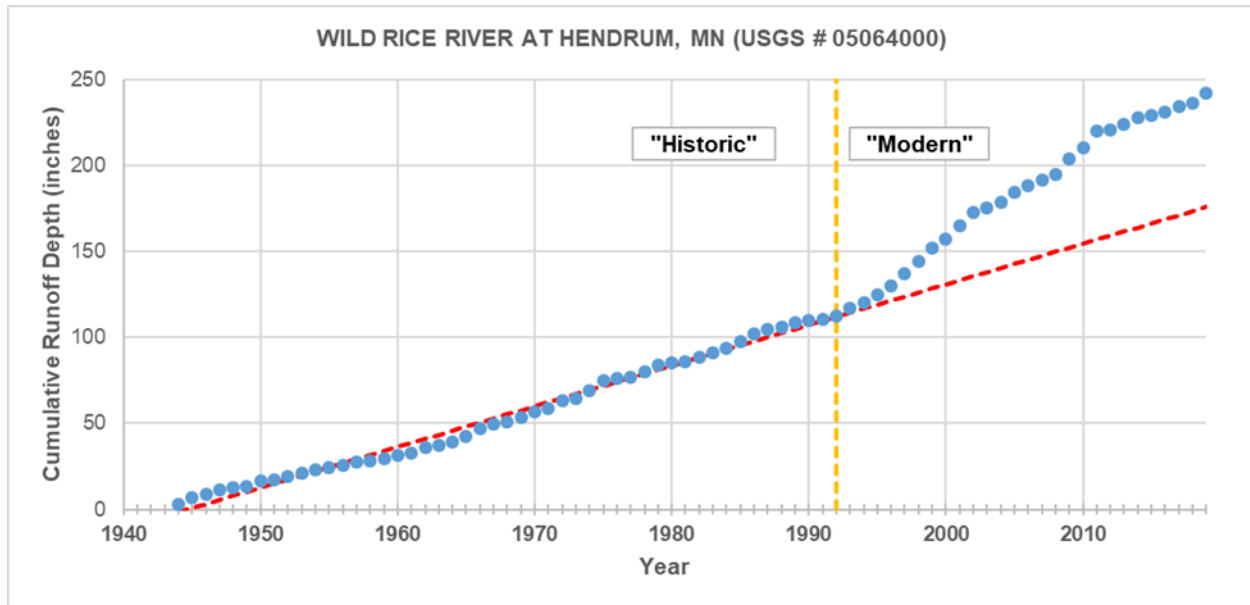


Figure 5. Cumulative streamflow for the Wild Rice River at Hendrum, MN (USGS# 05064000).

Additionally, the runoff (using non-cumulative annual depth values) is plotted in **Figure 4**.

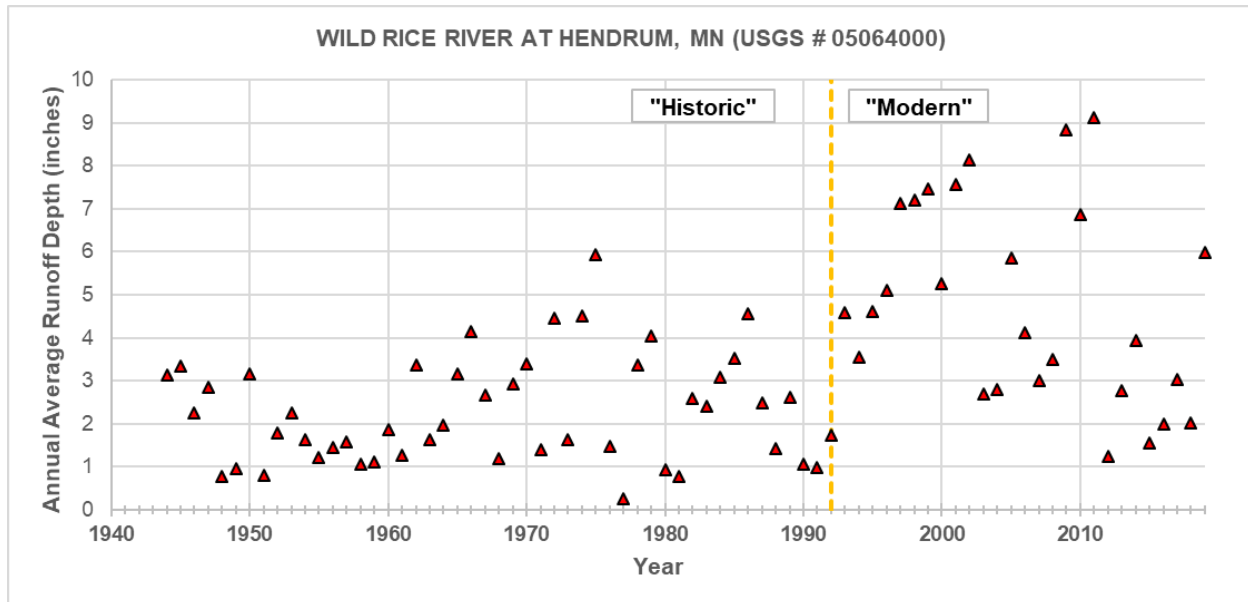


Figure 6. Average annual runoff depth for the Wild Rice River at Hendrum, MN (USGS Station 05064000).

According to the cumulative streamflow analysis, a breakpoint exists around 1992. Therefore, the benchmark “historic” conditions include data from 1967 through 1991 and the altered “modern” conditions include data from 1992 through 2018. This results in a comparison period of 26 years.

A summary of the results from the altered hydrology analysis is provided in **Table 4**. A more detailed description of the results is provided in **Appendix B**. A summary of the storage goals, based on the altered hydrology analysis, are provided in **Section 4**.

Table 4. Altered Hydrology Summary for the Wild Rice River at Hendrum, MN (USGS# 05064000).

Group	Metric	% Difference	Altered Hydrology Metric	Evidence of Altered Hydrology for Group
Aquatic Habitat	10-year, Annual Minimum 30-day Mean Daily Discharge	740.9%	+	Yes, Increasing
	10-year, Annual Minimum 7-day Mean Daily Discharge	1,317.9%	+	
	Median November (Winter Base) Flow	108.0%	+	
Aquatic Organism Life Cycle	Magnitude of Monthly Runoff Volumes	12.7% - 211.8%	+	Yes, Increasing
	Distribution of Monthly Runoff Volumes	-34.9% - 80.1%	o	
	Timing of Annual Peak Discharge	14.29%	+	
	Timing of Annual Minimum Discharge	9.57%	o	
Riparian Floodplain (Lateral) Connectivity	10-year Peak Discharge Rate	21.97%	+	Yes, Increasing
	50-year Peak Discharge Rate	16.54%	+	
	100-year Peak Discharge Rate	15.87%	+	
	Average Cumulative Volume above the Historic 10-year Peak Discharge	84.96%	+	
	Average Cumulative Volume above the Historic 50-year Peak Discharge	NA	NA	
	Average Cumulative Volume above the Historic 100-year Peak Discharge	NA	NA	
Geomorphic Stability and Capacity to Transport Sediment	1.5-year Peak Discharge Rate	62.26%	+	Yes, Increasing
	2-year Peak Discharge Rate	47.07%	+	
	Average Cumulative Volume above the Historic 1.5-year Peak Discharge	68.04%	+	
	Average Cumulative Volume above the Historic 2-year Peak Discharge	74.62%	+	
	Duration above the Historic 1.5-year Peak Discharge	40.47%	+	
	Duration above the Historic 2-year Peak Discharge	58.45%	+	
	Flow Duration Curve	17.5% - 10,562.5%	+	

+ symbol indicates metric exhibits altered hydrology and an increase for the modern Period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern Period compared to the historic Period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern Period compared to the historic period

4. STORAGE GOALS

Goals for addressing the change in hydrology were estimated using four methods. Each method is based on different assumptions and a different set of metrics for a specific “altered hydrology” group. The first method is focused on the aquatic habitat metric group and the geomorphic stability and capacity to transport sediment metric group. This method uses the change in the cumulative volume for mean daily discharges, exceeding the 1.5-year return period event. The cumulative total volume when the daily average discharge exceeds the 1.5-year peak discharge includes all flows above the 1.5-year peak, i.e. can include storms with much larger return periods. This method, and the associated storage goal, is based on the changes in the observed data, and since it includes all flows above the 1.5-year flow, relies on the two time periods to have a similar distribution of flows. The second method is based on the changes in hydrology across the entire annual hydrograph and integrates the differences in return period discharges (1.5-year, 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year return period events) between the modern and historic period, finding a probability-weighted representative change in flow rate for each return period event. A storage goal volume is found by assuming a flow period equal to the change in flow period for the 1.5-year flow (i.e. the change in the number of days above the 1.5-year flow). This method assumes a constant flow over a representative duration to estimate the storage goal. Since a hydrograph typically changes over time, this method may over-estimate the storage goal. The third method is also based on addressing the effects through the entire flow range and is a revision to Method two. Method three incorporates the observed change in the timing of the peak discharge for each return period event. This method uses the probability-weighted representative change in flow rate and multiplies the flow rates by the change in the number of days exceeding the return period flow for each return period. Method four estimates a storage goal based on changes in the flow duration curve (FDC) (see **Figures A-6 and B-6**). Method four integrates the changes in the FDC between the two periods and applies the probability of each flow to occur.

This analysis presents a preliminary framework for defining altered hydrology, applying a method to determine whether altered hydrology has occurred, and establishes a goal for relating to proposed projects. The storage goals are provided in **Table 5** for each of the four methods. For planning purposes, we recommend a preliminary goal equal to a representative goal, taken as the average of the 4 methods, across the watershed, realizing that the altered hydrology goals should ideally be established at the 12-digit HUC scale. The average storage goals are 0.43 inches for areas upstream of the Wild Rice River at Twin Valley, MN and 0.38 inches for areas upstream of the Wild Rice River at Hendrum, MN. The actual amount of mitigation needed may exceed the estimated range, as the methods used to achieve the goal are not expected to be 100% effective in removing volume from the peak of the hydrograph. The means to achieve the estimated mitigation goal may include the use of structural practices and management practices and should be specifically evaluated through completion of a hydrologic study or the use of appropriate tools and models.

Table 5. Storage goals for the Wild Rice watershed.

Stream	USGS ID	Storage Targets			
		Method 1	Method 2	Method 3	Method 4
Wild Rice River at Twin Valley, MN	05062500	0.39 in.	0.50 in.	0.33 in.	0.51 in.
Wild Rice River at Hendrum, MN	05064000	0.45 in.	0.36 in.	0.27 in.	0.43 in.

Details on calculations of the storage goals can be found in the Appendices.

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APPENDIX A: METRICS OF ALTERED HYDROLOGY FOR THE WILD RICE RIVER AT TWIN VALLEY, MN (USGS# 05062500)

The following provides the summary statistics used to determine the altered hydrology metrics and develop the volume reduction goals. A summary of these statistic is shown in **Table 3** in **Section 3.1**.

A.1 Condition of Aquatic Habitat

The condition of aquatic habitat includes a group of metrics that primarily reflect the flow characteristics of the annual hydrograph, needed to maintain adequate habitat for fish and aquatic life. The 30-day low flow, the 7-day low flow, and the median November mean daily discharge are metrics used to represent changes in the availability of flow for aquatic habitat.

A.1.1 Annual minimum 30-day mean daily discharge

The annual minimum 30-day mean daily discharge is the minimum of the 30-day moving mean daily discharge within a year (an annual minimum series). **Figure A-1** shows the annual minimum 30-day mean daily discharge for select return periods (1.01-year, 1.5-year, 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year). **Table A-1** summarizes the data shown in **Figure A-1**.

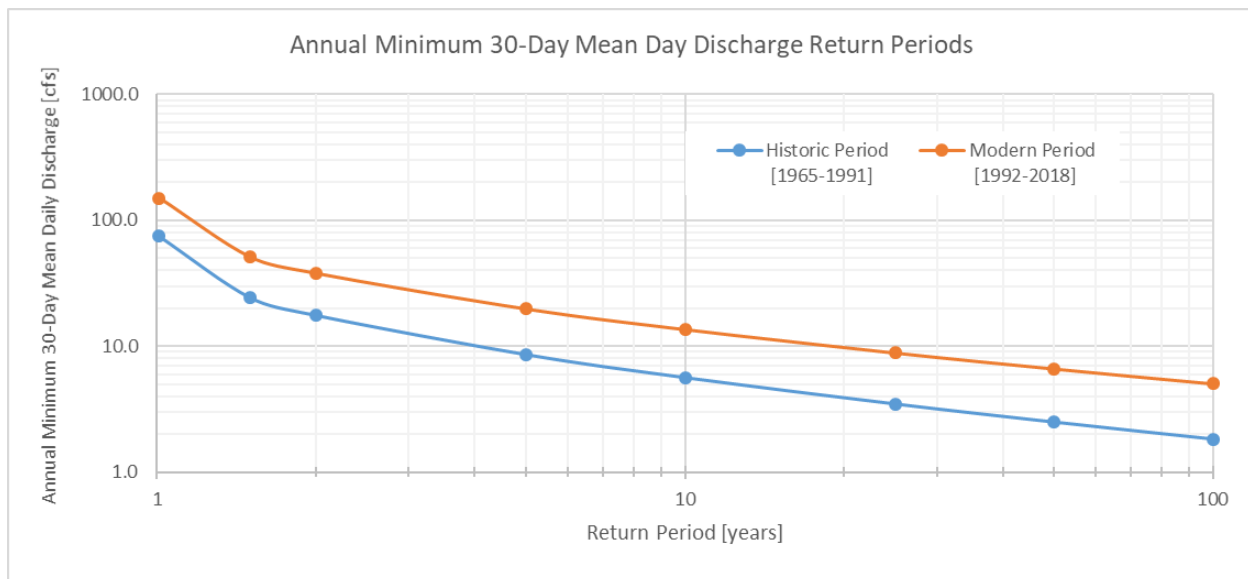


Figure A-1. Historical versus modern annual minimum 30-day mean daily discharge versus return period for the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Table A-1. Summary of annual minimum 30-day mean daily discharge by return periods for Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Return Period	Historic Period [1965-1991]	Modern Period [1992-2018]	% Diff	Altered Hydrology Criterion
1.01	74.4	149.7	101.1%	+
1.5	24.3	51.2	110.8%	+
2	17.5	37.9	116.1%	+
5	8.6	19.8	130.9%	+
10	5.6	13.6	141.3%	+
25	3.5	8.8	155.0%	+
50	2.5	6.6	165.4%	+
100	1.8	5.0	175.9%	+

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

A.1.2 Annual Minimum 7-Day Mean Daily Discharge

Like the annual minimum 30-day mean daily discharge, the annual minimum 7-day mean daily discharge is the minimum of the 7-day moving average flow in the year. **Figure A-2** shows the annual minimum 7-day mean daily discharges for select return periods (1.01-year, 1.5-year, 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year). **Table A-2** summarizes the data shown in **Figure A-2**.

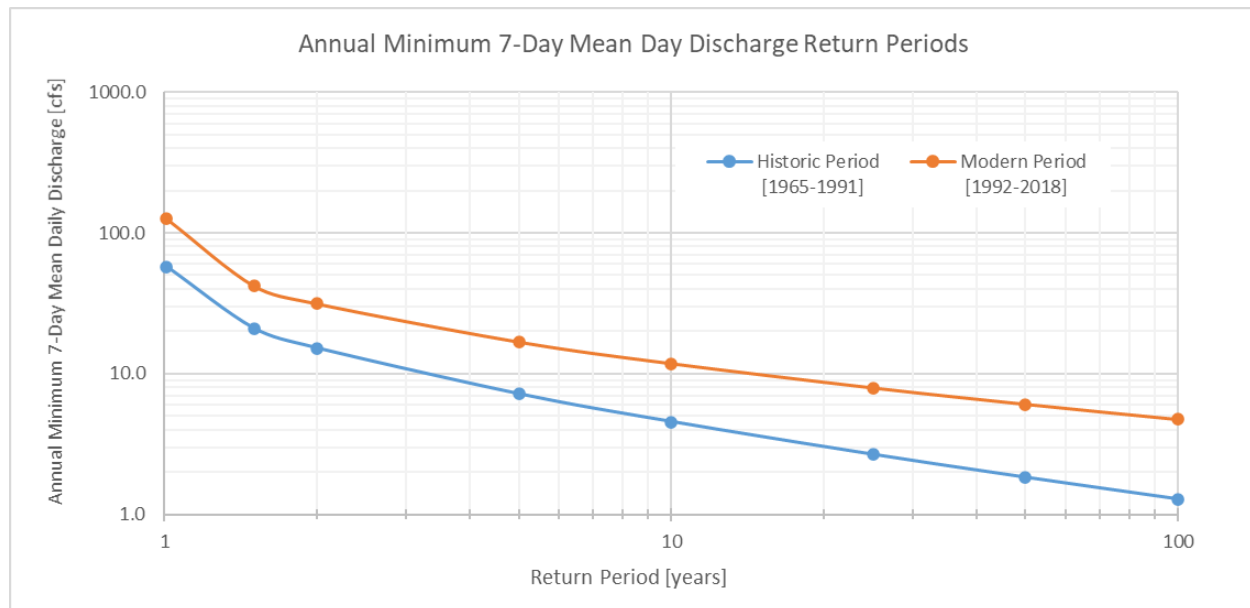


Figure A-2. Historical versus modern annual minimum 7-day mean daily discharge return periods for the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Table A-2. Summary of annual minimum 7-day mean daily discharge return periods for the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Return Period	Historic Period [1965-1991]	Modern Period [1992-2018]	% Diff	Altered Hydrology Criterion
1.0101	57.2	125.5	119.3%	+
1.5	21.0	42.0	100.3%	+
2	15.2	31.3	106.5%	+
5	7.2	16.8	134.0%	+
10	4.6	11.8	159.2%	+
25	2.7	7.9	197.7%	+
50	1.8	6.1	231.0%	+
100	1.3	4.7	268.5%	+

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

A.1.3 November Median Daily Discharge

The median daily mean discharge for November is another indicator of baseflow. This metric is intended to represent baseflow condition during the winter months. **Table A-3** provides the median November flow for each period.

Table A-3. Historical and modern median November flow for the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Return Period	Historic Period [1965-1991]	Modern Period [1992-2018]	% Diff.	Altered Hydrology Criterion
Period median November flow [cfs]	70.0	164.0	134.3%	+

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

A.2 Aquatic Organism Life Cycle

The shape of the annual hydrograph and timing of discharges are associated with ecological cues. Metrics related to the aquatic organism life cycle include the shape of the annual hydrographs, timing of the annual minimum flow, and timing of the annual peak flow.

A.2.1 Annual Distribution of Discharges

The annual distribution of runoff is shown two ways: as average monthly runoff volume in acre-feet per month (**Figure A-3**) and as a percentage of average annual runoff volume (**Figure A-4**). **Table A-4** summarized the data used to generate **Figures A-3** and **A-4**.

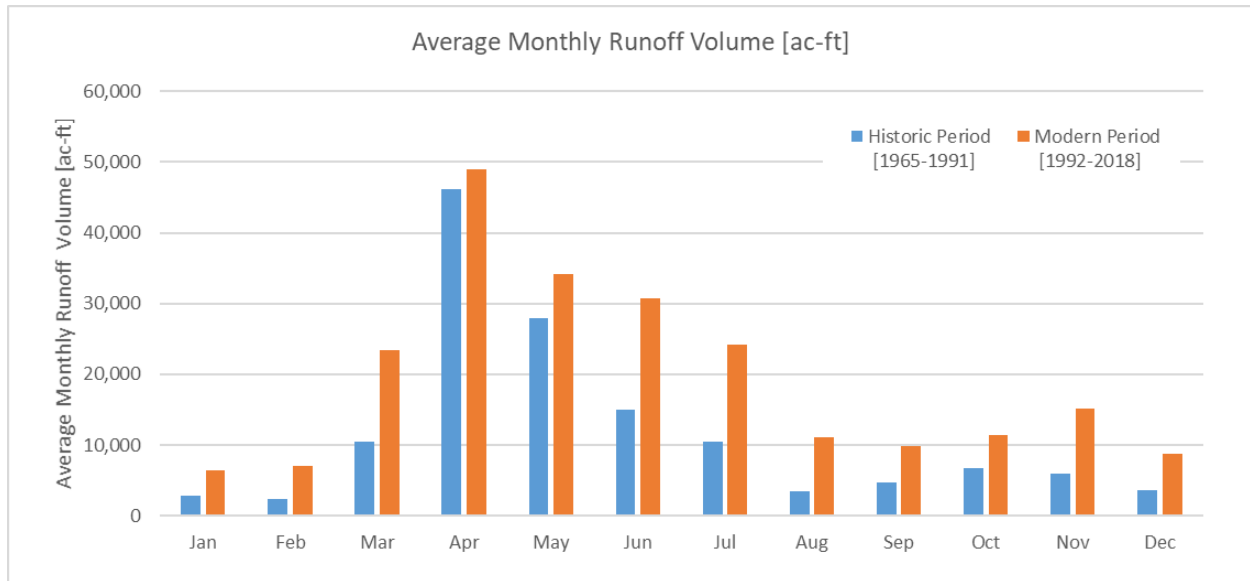


Figure A-3. Average monthly runoff volume [ac-ft] in the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

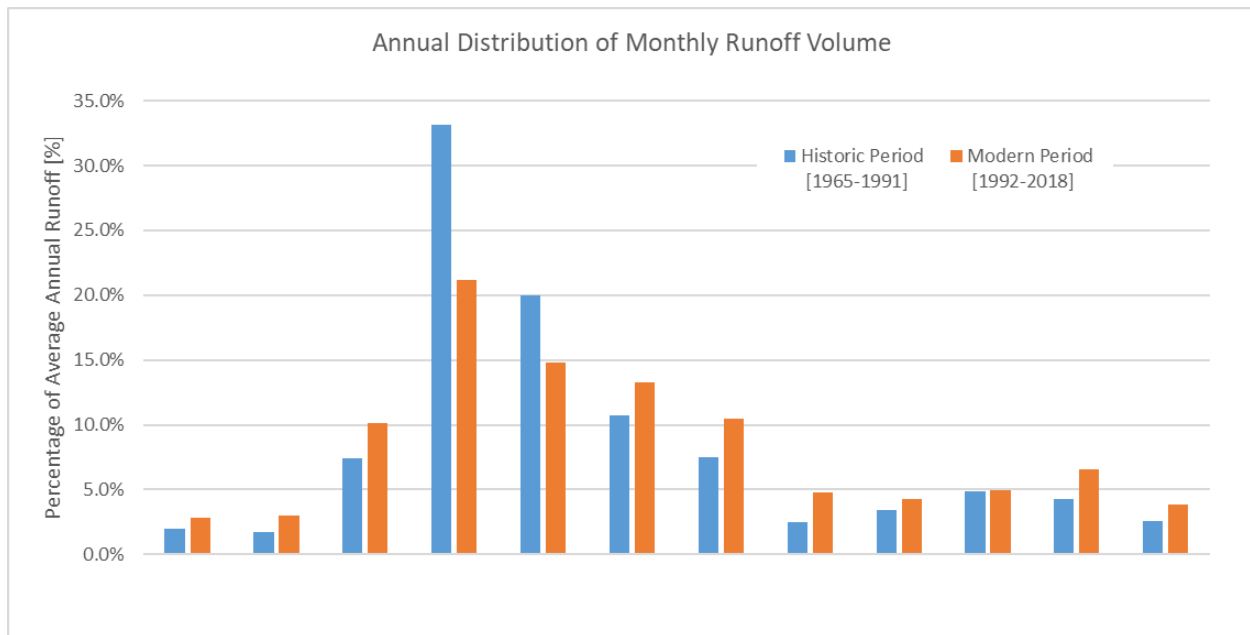


Figure A-4. Annual distribution of average monthly runoff volume as a percentage of annual total volume in the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Table A-4. Average monthly runoff volume and annual distribution of monthly runoff volumes in the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Month	Average Monthly Volumes [ac-ft]				Distribution of Annual Volume			
	Historic Period [1965-1991]	Modern Period [1992-2018]	% diff.	AH	Historic Period [1965-1991]	Modern Period [1992-2018]	% diff.	AH
Jan	2,765	6,455	133.5%	+	2.0%	2.8%	41.0%	+
Feb	2,387	7,012	193.8%	+	1.7%	3.0%	77.4%	+
Mar	10,387	23,332	124.6%	+	7.4%	10.1%	35.6%	+
Apr	46,227	49,048	6.1%	o	33.1%	21.2%	-35.9%	-
May	27,949	34,194	22.3%	+	20.0%	14.8%	-26.1%	-
Jun	14,952	30,695	105.3%	+	10.7%	13.3%	24.0%	+
Jul	10,459	24,161	131.0%	+	7.5%	10.4%	39.5%	+
Aug	3,474	11,152	221.0%	+	2.5%	4.8%	93.9%	+
Sep	4,762	9,839	106.6%	+	3.4%	4.3%	24.8%	+
Oct	6,739	11,414	69.4%	+	4.8%	4.9%	2.3%	o
Nov	5,995	15,164	153.0%	+	4.3%	6.6%	52.7%	+
Dec	3,561	8,819	147.6%	+	2.5%	3.8%	49.5%	+

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

AH means altered hydrology criterion

A.2.2 Timing of Annual Maximum and Minimum Flows

The timing of the annual maximum daily discharge and annual minimum daily discharge are important metrics of the annual distribution of flows. The timing of the annual maximum typically occurs during the spring flood and the timing of the annual minimum usually occurs during the winter months. **Table A-5** provides statistics on the Julian day of the annual maximum flow and **Table A-6** provides the Julian day for the annual minimum flow. The statistics include the average (mean), the median, and the standard deviation of the Julian days when the maximum or minimum flow occur.

Table A-5. Julian Day of annual maximum in the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Statistic	Historic Period [1965-1991]	Modern Period [1992-2018]	% diff.	AH
Average	27-Apr	20-May	19.63%	+
Median	12-Apr	14-May	31.37%	+
Standard Deviation	48 days	64 days	32.09%	+

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

Based on 365-day year

Table A-6. Julian Day of annual minimum flow in the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Statistic	Historic Period [1965-1991]	Modern Period [1992-2018]	% diff.	AH
Average	4-Sep	10-Sep	2.44%	o
Median	15-Sep	29-Sep	5.43%	o
Standard Deviation	55 days	60 days	8.26%	o

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

Based on 365-day year

A.3 Riparian Floodplain (Lateral) Connectivity (Peak Flows)

The riparian floodplain connectivity metrics represent the frequency and duration of flooding of the riparian area and the lateral connectivity between the stream and the riparian area. Functions include energy flow, deposition of sediment, channel formation and surface water – groundwater interactions. The riparian floodplain connectivity metrics include the discharge rates for the 10-year, the 25-year, the 50-year, and the 100-year peak discharges. The annual peak discharge rates for select return periods (1.01-year, 1.5-year, 2-year, 5-year, 10-year, 25-year, 50-year, 100-year, and 200-year) are shown in **Figure A-5**.

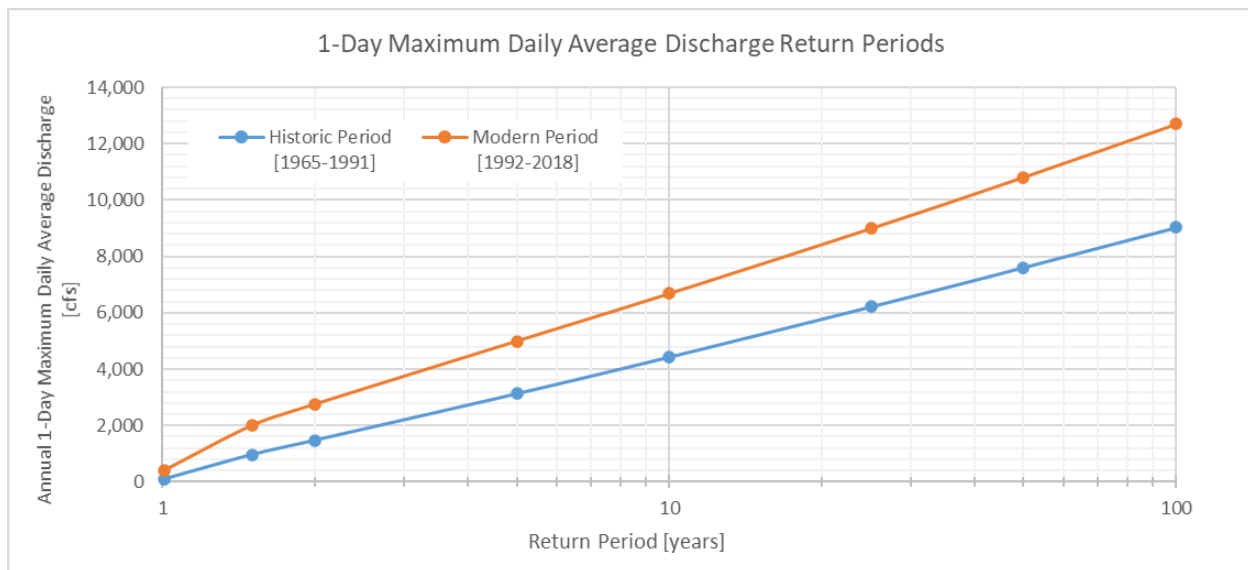


Figure A-5. Historical (1963-1990) versus modern (1991-2018) peak discharge return periods for the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

In addition, the number of years with discharges exceeding the historic peak discharge within a period, the average number of days above the historic peak discharge rates, and the average cumulative volume of discharge above the historic peak discharges are provide (**Table A-7**).

Table A-7. Riparian floodplain connectivity metrics for the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Flow Metric	Historic Period [1965-1991]	Modern Period [1992-2018]	% Diff. ¹	Altered Hydrology
5-Year Peak Discharge, Q(5) [cfs]	3,122	4,992	59.9%	+
Number of years with Discharge (Q) > Q _H (5)	5	11	120.0%	+
Average number of days per year Q > Q _H (5)	2	5	100.8%	+
Average annual cumulative volume > Q _H (5) [ac-ft]	4,764	13,460	182.5%	+
10-Year Peak Discharge, Q(10) [cfs]	4,422	6,682	51.1%	+
Number of years with Discharge (Q) > Q _H (10)	2	7	250.0%	+
Average number of days per year Q > Q _H (10)	2	3	100.0%	+
Average annual cumulative volume > Q _H (10) [ac-ft]	3,018	8,685	187.8%	+
25-Year Peak Discharge, Q(25) [cfs]	6,209	8,992	44.8%	+
Number of years with Discharge (Q) > Q _H (25)	0	3	NA	o
Average number of days per year Q > Q _H (25)	0	2	NA	o
Average annual cumulative volume > Q _H (25) [ac-ft]	0	7,103	NA	o
50-Year Peak Discharge, Q(50) [cfs]	7,602	10,811	42.2%	+
Number of years with Discharge (Q) > Q _H (50)	0	2	NA	o
Average number of days per year Q > Q _H (50)	0	2	NA	o
Average annual cumulative volume > Q _H (50) [ac-ft]	0	4,644	NA	o
100-Year Peak Discharge, Q(100) [cfs]	9,020	12,696	40.7%	+
Number of years with Discharge (Q) > Q _H (100)	0	1	NA	o
Average number of days per year Q > Q _H (100)	0	1	NA	o
Average annual cumulative volume > Q _H (100) [ac-ft]	0	3,530	NA	o

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

¹NA = No events occurred above return period discharge.

A.4 Geomorphic Stability and Capacity to Transport Sediment

The metrics pertaining to geomorphic stability and capacity to transport sediment are related to the channel forming discharge. An increase in these metrics would be interpreted as an increase in the risk of the stream channel susceptibility to erosion. These metrics include changes to the flow duration curves, the 1.5-year peak flow, the 2-year peak flow. The 1.5-year to 2-year peak flows are generally consider the

range of channel forming flow. In addition, the number of years within a period exceeding the historic peak flows, the average number of days above the historic peak flow rates, and the average volume of flow above the historic peak flows are provide (**Table A-8**). **Figure A-6** has the flow duration curves for the historic and modern periods and **Table A-8** provides a summary of flows for select percent exceedances. Both show that discharges across the flow spectrum have increased substantially.

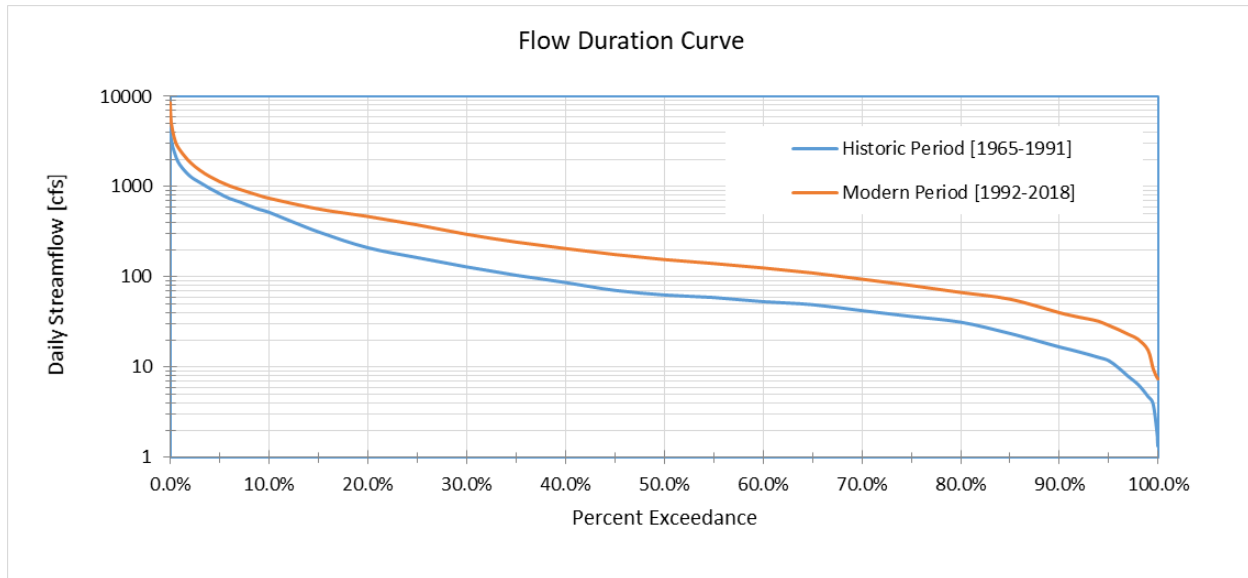


Figure A-6. Historical (1963-1990) versus modern (1991-2018) flow duration for the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Table A-8. Select summary of stream flows for various percent exceedance values from the flow duration curves for the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Percent Exceedance	Historic Period [1965-1991]	Modern Period [1992-2018]	% Diff.	Altered Hydrology
0.10%	3,426	5,151	50.4%	+
1.0%	1,760	2,510	42.7%	+
10.0%	528	739	40.0%	+
25.0%	166	375	125.9%	+
50.0%	64	155	142.2%	+
75.0%	43	94	118.6%	+
90.0%	17	40	135.3%	+
99.0%	5	15	219.5%	+
99.9%	2	8	303.0%	+

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

Table A-9 provides the 1.5-year and 2-year annual peak flows and flow statistics, including peak discharge, number of years with flow rates above the historic return period flow, average number of days per year above the historic return period flow, and average volume above the historic return period flow.

Table A-9. Geomorphic stability and capacity to transport sediment metrics for the Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Flow Metric	Historic Period [1965-1991]	Modern Period [1992-2018]	% Diff.	Altered Hydrology
1.5-Year Peak Discharge, $Q(1.5)$ [cfs]	961	1,995	107.7%	+
Number of years with Discharge (Q) > $Q_H(1.5)$	13	22	69.2%	+
Average number of days per year $Q > Q_H(1.5)$	24	30	24.6%	+
Average annual cumulative volume > $Q_H(1.5)$ [ac-ft]	29,093	48,650	67.2%	+
2-Year Peak Discharge, $Q(2)$ [cfs]	1,475	2,756	86.9%	+
Number of years with Discharge (Q) > $Q_H(2)$	11	21	90.9%	+
Average number of days per year $Q > Q_H(2)$	11	15	39.4%	+
Average annual cumulative volume > $Q_H(2)$ [ac-ft]	16,044	29,134	81.6%	+

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

A.5 Setting Goals

The following are the methods used to develop those goals. Goals for addressing the change in hydrology were estimated using four methods. Each method is based on different assumptions and a different set of metrics for a specific “altered hydrology” group. The first method is focused on the metric groups focused on aquatic habitat and also the geomorphic stability and ability to transport sediment, and uses the change in the cumulative volume for mean daily discharges exceeding the 1.5-year return period event. The cumulative total volume when the daily average discharge exceeds the 1.5-year peak discharge includes all flows above the 1.5-year peak, i.e. can include storms with much larger return periods. This method is based on the changes in the observed data, and since it includes all flows above the 1.5-year flow, relies on the two periods to have a similar distribution of flows. The storage goal based on observed flows is **19,557 AF or 0.39 inches** across the watershed.

The second method is based on the changes in hydrology across the entire annual hydrograph. This method integrates the differences in return period discharges between the modern and historic period (see **Table A-10**) and finding a probability-weighted representative change in flow rate. A volume is then found by assuming a flow period equal to the change in flow period for the 1.5-year flow (i.e. the change in the number of days above the 1.5-year flow; see **Table A-9**).

Table A-10. Estimated goal for the drainage area of the Wild Rice River at Twin Valley, MN (USGS Station 05062500) using Method 2.

Return Period	Historic Period Discharges (cfs)	Modern Period Discharges (cfs)	Difference (cfs)	Probability of Occurrence	Difference*Probability (cfs)
1.5	961	1,995	1035	0.67	689.8
2	1,475	2,756	1281	0.50	640.6
5	3,122	4,992	1869	0.20	373.9
10	4,422	6,682	2259	0.10	225.9
25	6,209	8,992	2783	0.04	111.3
50	7,602	10,811	3209	0.02	64.2
100	9,020	12,696	3676	0.01	36.8
				Sum (cfs):	2,143
				Sum (ac-ft/day):	4,251
Number of days:			6	Total Volume Goal:	25,118 AF (0.50 in.)

The third method is also based on addressing the effects through the entire flow range and is a revision to Method two. Method three incorporates the observed change in the timing of the peak discharge for each return period event. This method uses the probability-weighted representative change in flow rate and multiplies the flow rates by the change in the number of days exceeding the return period flow for each return period (see **Table A-11**).

Table A-11. Estimated goal for the drainage area of the Wild Rice River at Twin Valley, MN (USGS Station 05062500) using Method 3.

Return Period	Change in Flow ($Q_m - Q_h$) [cfs]	Probability of Occurrence	Probability Weighted Flow [AF/day]	Change in number of days above flow (days)	Storage Volume
1.5	1,035	0.67	1,368.6	6	8,087
2	1,281	0.50	1,271.0	4	5,370
5	1,869	0.20	741.8	2	1,794
10	2,259	0.10	448.3	2	672
25	2,783	0.04	220.8	2	368
50	3,209	0.02	127.3	2	255
100	3,676	0.01	72.9	1	73
				Total Volume Goal:	16,619 AF (0.33 in.)

The fourth method integrates the changes in the FDC (see **Figure A-6**) and the probability of occurrence of each flow. The fourth method estimated a storage goal of **25,475 AF, or 0.51 inches**, across the watershed.

APPENDIX B: METRICS OF ALTERED HYDROLOGY FOR THE WILD RICE RIVER AT HENDRUM, MN (USGS# 05064000)

The following provides the summary statistics used to determine the altered hydrology metrics and develop the volume reduction goals. A summary of these statistic is shown in **Table 3** in **Section 3.2**.

B.1 Condition of Aquatic Habitat

The condition of aquatic habitat includes a group of metrics that primarily reflect the flow characteristics of the annual hydrograph, needed to maintain adequate habitat for fish and aquatic life. The 30-day low flow, the 7-day low flow, and the median November mean daily discharge are metrics used to represent changes in the availability of flow for aquatic habitat.

B.1.1 Annual minimum 30-day mean daily discharge

The annual minimum 30-day mean daily discharge is the minimum of the 30-day moving mean daily discharge within a year (an annual minimum series). **Figure B-1** shows the annual minimum 30-day mean daily discharge for select return periods (1.01-year, 1.5-year, 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year). **Table B-1** summarizes the data shown in **Figure B-1**.

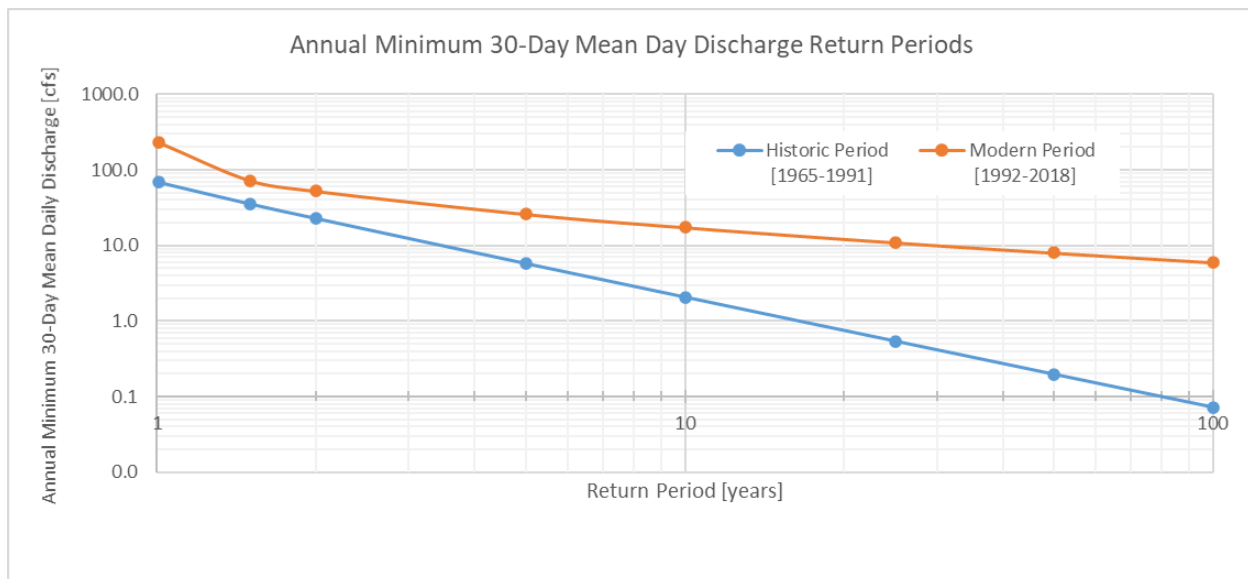


Figure B-1. Historical versus modern annual minimum 30-day mean daily discharge versus return period for the Wild Rice River at Hendrum, MN (USGS Station 05064000).

Table B-1. Summary of annual minimum 30-day mean daily discharge by return periods for Wild Rice River at Twin Valley, MN (USGS Station 05062500).

Return Period	Historic Period [1965-1991]	Modern Period [1992-2018]	% Diff	Altered Hydrology Criterion
1.01	68.2	231.3	239.3%	+
1.5	35.5	72.7	104.9%	+
2	22.8	52.6	131.0%	+
5	5.8	26.1	352.9%	+
10	2.1	17.4	740.9%	+
25	0.5	11.0	1930.8%	+
50	0.2	8.0	3975.8%	+
100	0.1	6.0	8225.0%	+

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

B.1.2 Annual Minimum 7-Day Mean Daily Discharge

Like the annual minimum 30-day mean daily discharge, the annual minimum 7-day mean daily discharge is the minimum of the 7-day moving average flow in the year. **Figure B-2** shows the annual minimum 7-day mean daily discharges for select return periods (1.01-year, 1.5-year, 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year). **Table B-2** summarizes the data shown in **Figure B-2**.

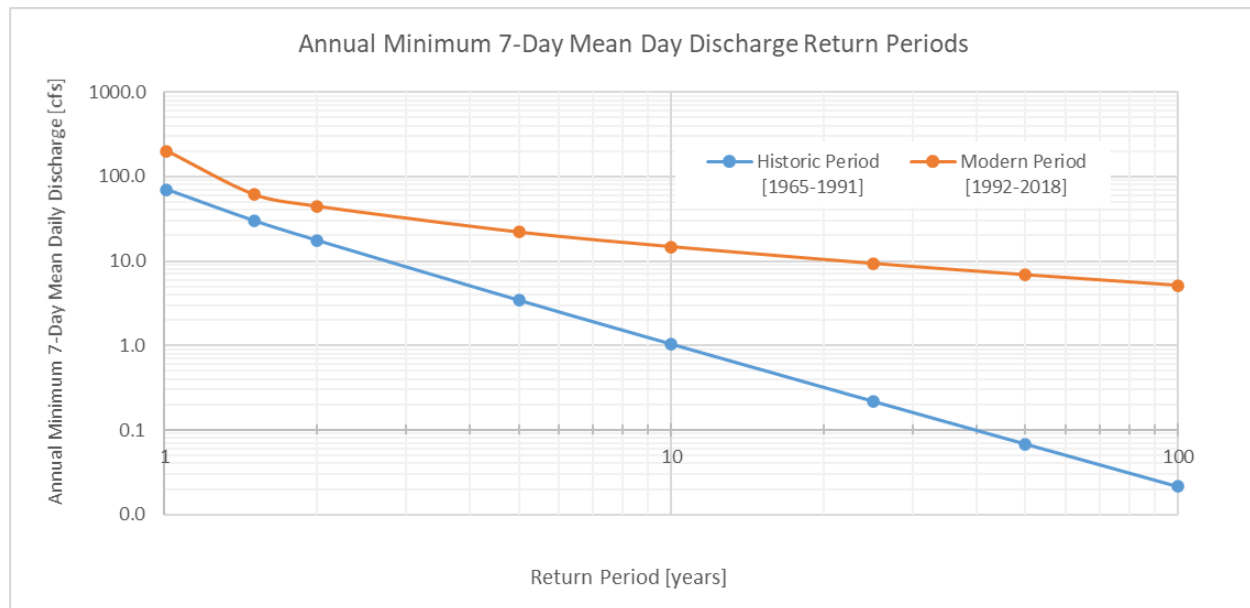


Figure B-2. Historical versus modern annual minimum 7-day mean daily discharge return periods for the Wild Rice River at Hendrum, MN (USGS Station 05064000).

Table B-2. Summary of annual minimum 7-day mean daily discharge return periods for the Wild Rice River at Hendrum, MN (USGS Station 05064000).

Return Period	Historic Period [1965-1991]	Modern Period [1992-2018]	% Diff	Altered Hydrology Criterion
1.0101	70.2	199.1	183.7%	+
1.5	30.1	61.2	103.3%	+
2	17.5	44.2	152.1%	+
5	3.4	22.0	540.2%	+
10	1.0	14.8	1317.9%	+
25	0.2	9.4	4171.8%	+
50	0.1	6.9	9977.8%	+
100	0.0	5.2	24016.1%	+

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

B.1.3 November Median Daily Discharge

The median daily mean discharge for November is another indicator of baseflow. This metric is intended to represent baseflow condition during the winter months. **Table B-3** provides the median November flow for each period.

Table B-3. Historical and modern median November flow for the Wild Rice River at Hendrum, MN (USGS Station 05064000).

Return Period	Historic Period [1965-1991]	Modern Period [1992-2018]	% Diff.	Altered Hydrology Criterion
Period median November flow [cfs]	100.0	208.0	108.0%	+

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

B.2 Aquatic Organism Life Cycle

The shape of the annual hydrograph and timing of discharges are associated with ecological cues. Metrics related to the aquatic organism life cycle include the shape of the annual hydrographs, timing of the annual minimum flow, and timing of the annual peak flow.

B.1.4 Annual Distribution of Discharges

The annual distribution of runoff is shown two ways: as average monthly runoff volume in acre-feet per month (**Figure B-3**) and as a percentage of average annual runoff volume (**Figure B-4**). **Table B-4** summarized the data used to generate **Figures B-3** and **B-4**.

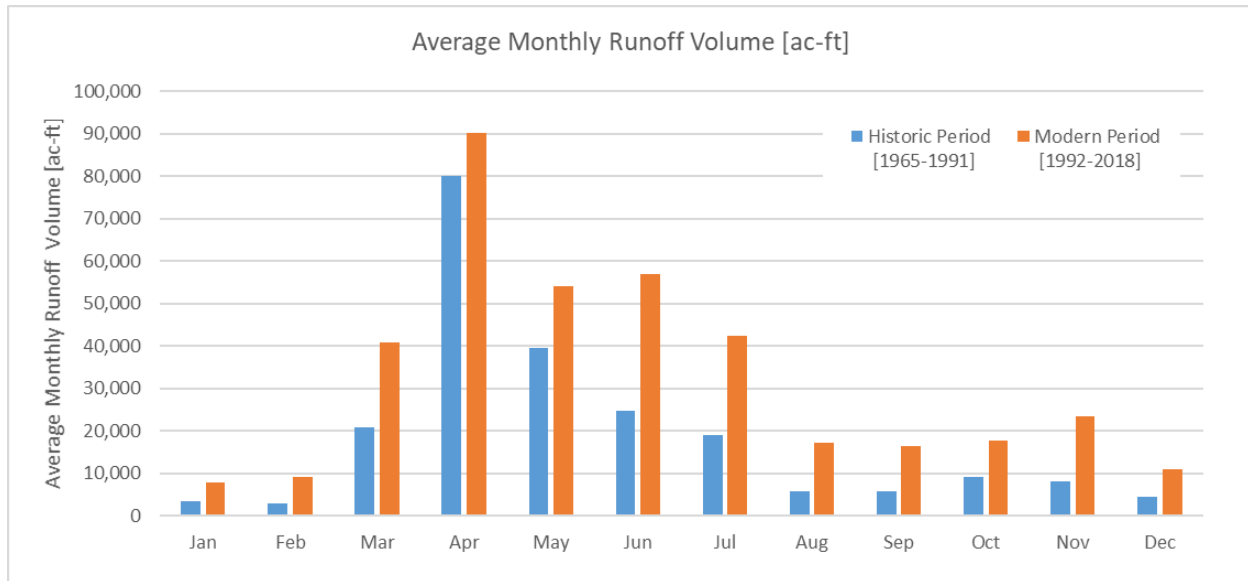


Figure B-3. Average monthly runoff volume [ac-ft] in the Wild Rice River at Hendrum, MN (USGS Station 05064000).

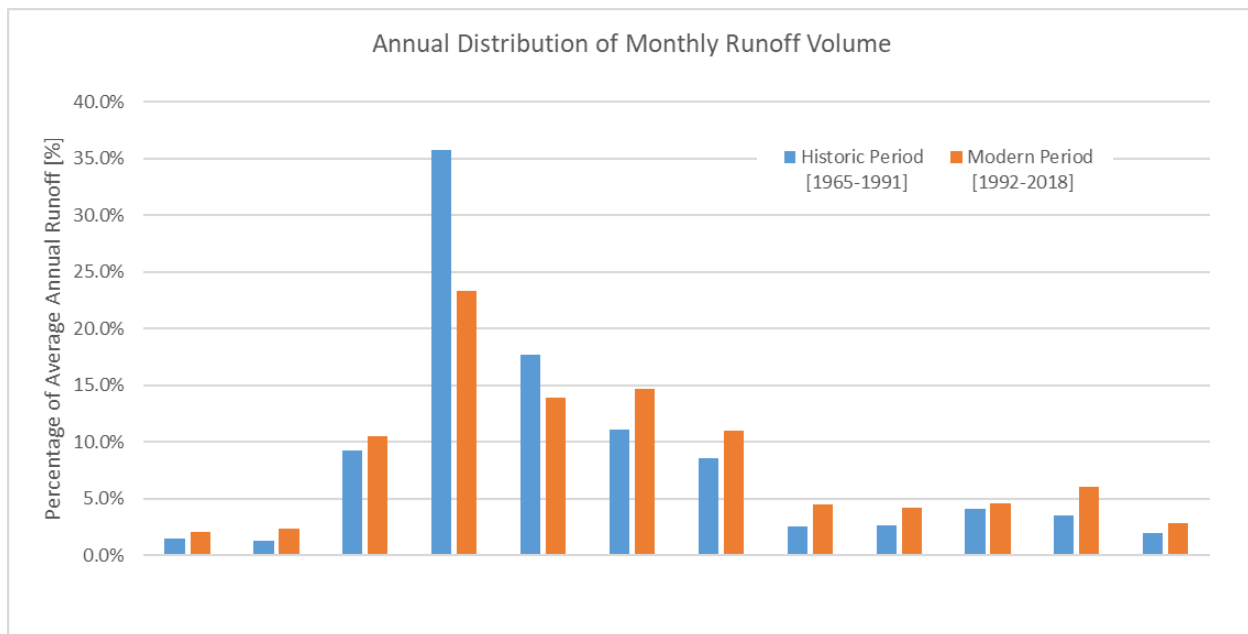


Figure B-4. Annual distribution of average monthly runoff volume as a percentage of annual total volume in the Wild Rice River at Hendrum, MN (USGS Station 05064000).

Table B-4. Average monthly runoff volume and annual distribution of monthly runoff volumes in the Wild Rice River at Hendrum, MN (USGS Station 05064000).

Month	Average Monthly Volumes [ac-ft]				Distribution of Annual Volume			
	Historic Period [1965-1991]	Modern Period [1992-2018]	% diff.	AH	Historic Period [1965-1991]	Modern Period [1992-2018]	% diff.	AH
Jan	3,305	7,868	138.1%	+	1.5%	2.0%	37.5%	+
Feb	2,965	9,245	211.8%	+	1.3%	2.4%	80.1%	+
Mar	20,769	40,793	96.4%	+	9.3%	10.5%	13.4%	+
Apr	80,002	90,193	12.7%	+	35.8%	23.3%	-34.9%	-
May	39,627	54,008	36.3%	+	17.7%	13.9%	-21.3%	-
Jun	24,817	56,924	129.4%	+	11.1%	14.7%	32.5%	+
Jul	19,079	42,418	122.3%	+	8.5%	11.0%	28.4%	+
Aug	5,678	17,283	204.4%	+	2.5%	4.5%	75.8%	+
Sep	5,857	16,443	180.7%	+	2.6%	4.2%	62.1%	+
Oct	9,137	17,800	94.8%	+	4.1%	4.6%	12.5%	+
Nov	7,981	23,329	192.3%	+	3.6%	6.0%	68.8%	+
Dec	4,487	11,034	145.9%	+	2.0%	2.8%	42.0%	+

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

AH means altered hydrology criterion

B.1.5 Timing of Annual Maximum and Minimum Flows

The timing of the annual maximum daily discharge and annual minimum daily discharge are important metrics of the annual distribution of flows. The timing of the annual maximum typically occurs during the spring flood and the timing of the annual minimum usually occurs during the winter months. **Table B-5** provides statistics on the Julian day of the annual maximum flow and **Table B-6** provides the Julian day for the annual minimum flow. The statistics include the average (mean), the median, and the standard deviation of the Julian days when the maximum or minimum flow occur.

Table B-5. Julian Day of annual maximum in the Wild Rice River at Hendrum, MN (USGS Station 05064000).

Statistic	Historic Period [1965-1991]	Modern Period [1992-2018]	% diff.	AH
Average	2-May	20-May	14.29%	+
Median	12-Apr	30-Apr	17.07%	+
Standard Deviation	44 days	63 days	43.85%	+

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

Based on 365-day year

Table B-6. Julian Day of annual minimum flow in the Wild Rice River at Hendrum, MN (USGS Station 05064000).

Statistic	Historic Period [1965-1991]	Modern Period [1992-2018]	% diff.	AH
Average	22-Aug	13-Sep	9.57%	o
Median	21-Sep	27-Sep	2.08%	o
Standard Deviation	75 days	67 days	-10.92%	-

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period
o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period
- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period
Based on 365-day year

B.3 Riparian Floodplain (Lateral) Connectivity (Peak Flows)

The riparian floodplain connectivity metrics represent the frequency and duration of flooding of the riparian area and the lateral connectivity between the stream and the riparian area. Functions include energy flow, deposition of sediment, channel formation and surface water – groundwater interactions. The riparian floodplain connectivity metrics include the discharge rates for the 10-year, the 25-year, the 50-year, and the 100-year peak discharges. The annual peak discharge rates for select return periods (1.01-year, 1.5-year, 2-year, 5-year, 10-year, 25-year, 50-year, 100-year, and 200-year) are shown in **Figure B-5**.

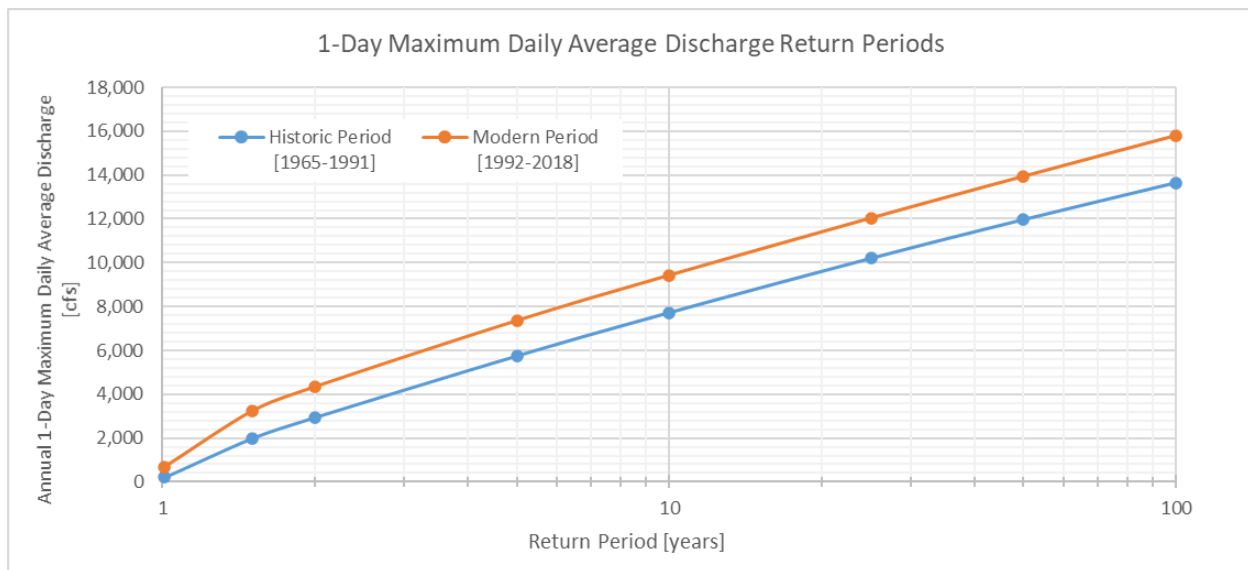


Figure B-5. Historical (1963-1990) versus modern (1991-2018) peak discharge return periods for the Wild Rice River at Hendrum, MN (USGS Station 05064000).

In addition, the number of years with discharges exceeding the historic peak discharge within a period, the average number of days above the historic peak discharge rates, and the average cumulative volume of discharge above the historic peak discharges are provide (**Table B-7**).

Table B-7. Riparian floodplain connectivity metrics for the Wild Rice River at Hendrum, MN (USGS Station 05064000).

Flow Metric	Historic Period [1965-1991]	Modern Period [1992-2018]	% Diff. ¹	Altered Hydrology
5-Year Peak Discharge, Q(5) [cfs]	5,750	7,355	27.9%	+
Number of years with Discharge (Q) > Q _H (5)	5	9	80.0%	+
Average number of days per year Q > Q _H (5)	6	9	41.6%	+
Average annual cumulative volume > Q _H (5) [ac-ft]	17,697	32,081	81.3%	+
10-Year Peak Discharge, Q(10) [cfs]	7,729	9,427	22.0%	+
Number of years with Discharge (Q) > Q _H (10)	3	7	133.3%	+
Average number of days per year Q > Q _H (10)	3	5	66.7%	+
Average annual cumulative volume > Q _H (10) [ac-ft]	4,710	8,711	85.0%	+
25-Year Peak Discharge, Q(25) [cfs]	10,201	12,037	18.0%	+
Number of years with Discharge (Q) > Q _H (25)	0	1	NA	o
Average number of days per year Q > Q _H (25)	0	1	NA	o
Average annual cumulative volume > Q _H (25) [ac-ft]	0	197	NA	o
50-Year Peak Discharge, Q(50) [cfs]	11,967	13,946	16.5%	+
Number of years with Discharge (Q) > Q _H (50)	0	0	NA	o
Average number of days per year Q > Q _H (50)	0	0	NA	o
Average annual cumulative volume > Q _H (50) [ac-ft]	0	0	NA	o
100-Year Peak Discharge, Q(100) [cfs]	13,643	15,808	15.9%	+
Number of years with Discharge (Q) > Q _H (100)	0	0	NA	o
Average number of days per year Q > Q _H (100)	0	0	NA	o
Average annual cumulative volume > Q _H (100) [ac-ft]	0	0	NA	o

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

¹NA = No events occurred above return period discharge.

B.4 Geomorphic Stability and Capacity to Transport Sediment

The metrics pertaining to geomorphic stability and capacity to transport sediment are related to the channel forming discharge. An increase in these metrics would be interpreted as an increase in the risk of the stream channel susceptibility to erosion. These metrics include changes to the flow duration curves, the 1.5-year peak flow, the 2-year peak flow. The 1.5-year to 2-year peak flows are generally consider the

range of channel forming flow. In addition, the number of years within a period exceeding the historic peak flows, the average number of days above the historic peak flow rates, and the average volume of flow above the historic peak flows are provide (**Table B-8**). **Figure B-6** has the flow duration curves for the historic and modern periods and **Table B-8** provides a summary of flows for select percent exceedances. Both show that discharges across the flow spectrum have increased substantially.

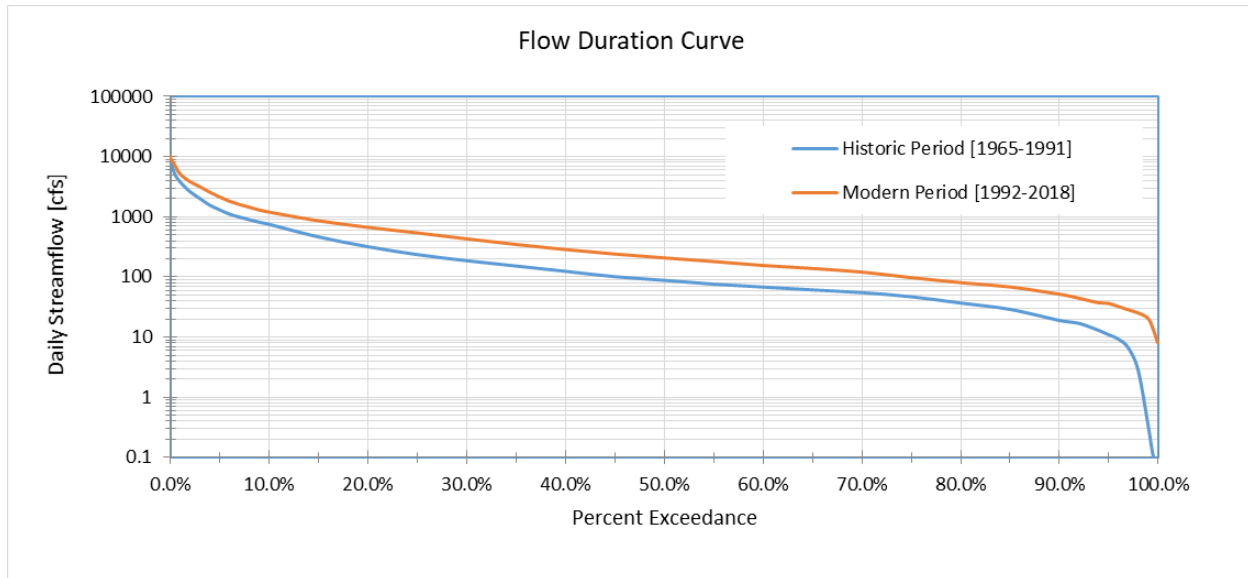


Figure B-6. Historical (1963-1990) versus modern (1991-2018) flow duration for the Wild Rice River at Hendrum, MN (USGS Station 05064000).

Table B-8. Select summary of stream flows for various percent exceedance values from the flow duration curves for the Wild Rice River at Hendrum, MN (USGS Station 05064000).

Percent Exceedance	Historic Period [1965-1991]	Modern Period [1992-2018]	% Diff.	Altered Hydrology
0.10%	7,634	8,971	17.5%	+
1.0%	3,775	5,188	37.4%	+
10.0%	746	1,200	60.9%	+
25.0%	235	540	129.8%	+
50.0%	88	207	135.2%	+
75.0%	55	120	118.2%	+
90.0%	19	51	170.0%	+
99.0%	0	20	5688.9%	+
99.9%	0	9	10562.5%	+

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o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

Table B-9 provides the 1.5-year and 2-year annual peak flows and flow statistics, including peak discharge, number of years with flow rates above the historic return period flow, average number of days per year above the historic return period flow, and average volume above the historic return period flow.

Table B-9. Geomorphic stability and capacity to transport sediment metrics for the Wild Rice River at Hendrum, MN (USGS Station 05064000).

Flow Metric	Historic Period [1965-1991]	Modern Period [1992-2018]	% Diff.	Altered Hydrology
1.5-Year Peak Discharge, $Q(1.5)$ [cfs]	1,984	3,219	62.3%	+
Number of years with Discharge (Q) > Q_H (1.5)	16	22	37.5%	+
Average number of days per year $Q > Q_H$ (1.5)	17	24	40.5%	+
Average annual cumulative volume > Q_H (1.5) [ac-ft]	55,105	92,599	68.0%	+
2-Year Peak Discharge, $Q(2)$ [cfs]	2,949	4,337	47.1%	+
Number of years with Discharge (Q) > Q_H (2)	14	20	42.9%	+
Average number of days per year $Q > Q_H$ (2)	11	17	58.4%	+
Average annual cumulative volume > Q_H (2) [ac-ft]	35,230	61,519	74.6%	+

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period

o symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period

- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

B.5 Setting Goals

The following are the methods used to develop those goals. Goals for addressing the change in hydrology were estimated using four methods. Each method is based on different assumptions and a different set of metrics for a specific “altered hydrology” group. The first method is focused on the metric groups focused on aquatic habitat and also the geomorphic stability and ability to transport sediment, and uses the change in the cumulative volume for mean daily discharges exceeding the 1.5-year return period event. The cumulative total volume when the daily average discharge exceeds the 1.5-year peak discharge includes all flows above the 1.5-year peak, i.e. can include storms with much larger return periods. This method is based on the changes in the observed data, and since it includes all flows above the 1.5-year flow, relies on the two periods to have a similar distribution of flows. The storage goal based on observed flows is **19,557 AF or 0.39 inches** across the watershed.

The second method is based on the changes in hydrology across the entire annual hydrograph. This method integrates the differences in return period discharges between the modern and historic period (see **Table B-10**) and finding a probability-weighted representative change in flow rate. A volume is then found by assuming a flow period equal to the change in flow period for the 1.5-year flow (i.e. the change in the number of days above the 1.5-year flow; see **Table B-9**).

Table B-10. Estimated goal for the drainage area of the Wild Rice River at Hendrum, MN (USGS Station 05064000) using Method 2.

Return Period	Historic Period Discharges (cfs)	Modern Period Discharges (cfs)	Difference (cfs)	Probability of Occurrence	Difference*Probability (cfs)
1.5	1,984	3,219	1235	0.67	823.3
2	2,949	4,337	1388	0.50	694.0
5	5,750	7,355	1604	0.20	320.9
10	7,729	9,427	1698	0.10	169.8
25	10,201	12,037	1836	0.04	73.5
50	11,967	13,946	1979	0.02	39.6
100	13,643	15,808	2165	0.01	21.7
			2,143	Sum (cfs):	2,143
			4,251	Sum (ac-ft/day):	4,251
Number of days:			7	Total Volume Goal:	29,782 AF (0.36 in.)

The third method is also based on addressing the effects through the entire flow range and is a revision to Method two. Method three incorporates the observed change in the timing of the peak discharge for each return period event. This method uses the probability-weighted representative change in flow rate and multiplies the flow rates by the change in the number of days exceeding the return period flow for each return period (see **Table B-11**).

Table B-11. Estimated goal for the drainage area of the Wild Rice River at Hendrum, MN (USGS Station 05064000) using Method 3.

Return Period	Change in Flow ($Q_m - Q_h$) [cfs]	Probability of Occurrence	Probability Weighted Flow [AF/day]	Change in number of days above flow (days)	Storage Volume
1.5	1,235	0.67	1,633.4	7	11,443
2	1,388	0.50	1,377.0	6	8,508
5	1,604	0.20	636.6	3	1,641
10	1,698	0.10	336.9	2	674
25	1,836	0.04	145.7	1	146
50	1,979	0.02	78.5	0	0
100	2,165	0.01	43.0	0	0
				Total Volume Goal:	22,412 AF (0.27 in.)

The fourth method integrates the changes in the FDC (see **Figure B-6**) and the probability of occurrence of each flow. The fourth method estimated a storage goal of **36,095 AF, or 0.43 inches**, across the watershed.



APPENDIX F

Engineer's Opinion of Probable Cost

UPPER RIDGE ROCK ARCH RAPIDS OPINION OF PROBABLE COST

Upper Ridge Rock Arch Rapids (Total)

No.	Bid Item	Unit	Quantity	Unit Price	Total Costs
1	Rock Weir (36" to 72")	LF	6,533	\$ 80.00	\$ 522,640.00
2	Riprap Class V	CY	21,628	\$ 120.00	\$ 2,595,360.00
3	Riprap Class II	CY	7,212	\$ 90.00	\$ 649,080.00
4	Common Fill	CY	0	\$ 8.00	\$ -
5	Tree and Brush Removal	AC	9.9	\$ 10,000.00	\$ 99,200.00
6	Floating Silt Curtain (erosion control)	LF	800	\$ 20.00	\$ 16,000.00
7	Mobilization	LS	1	\$ 195,293.75	\$ 195,293.75
8	Seeding and Mulching "Riparian Mix"	AC	15.73	\$ 1,500.00	\$ 23,595.00
Total Construction Cost					\$ 4,101,168.75
Contingencies (30%)					\$ 1,230,350.63
Legal, Admin, Permitting, and Engineering (Final Design, Construction Staking, Construction Observation, Closeout)					\$ 799,727.91
Permanent Right-of-Way		AC	13.68	\$ 1,600.00	\$ 21,888.00
Temporary Right-of-Way		AC	9.15	\$ 250.00	\$ 2,287.50
Total Project Costs					\$ 6,155,422.78

Upper Ridge Rock Arch Rapids 1

No.	Bid Item	Unit	Quantity	Unit Price	Cost
1	Rock Weir (36" to 72")	LF	1,062	\$ 80.00	\$ 84,960.00
2	Riprap Class V	CY	3,791	\$ 120.00	\$ 454,920.00
3	Riprap Class II	CY	1,264	\$ 90.00	\$ 113,760.00
4	Common Fill	CY	0	\$ 8.00	\$ -
5	Tree and Brush Removal	AC	1.65	\$ 10,000.00	\$ 16,500.00
6	Floating Silt Curtain (erosion control)	LF	100	\$ 20.00	\$ 2,000.00
7	Mobilization	LS	1	\$ 33,708.25	\$ 33,708.25
8	Seeding and Mulching "Riparian Mix"	AC	1.35	\$ 1,500.00	\$ 2,025.00
Total Construction Cost					\$ 707,873.25

Upper Ridge Rock Arch Rapids 2

No.	Bid Item	Unit	Quantity	Unit Price	Cost
1	Rock Weir (36" to 72")	LF	1,050	\$ 80.00	\$ 84,000.00
2	Riprap Class V	CY	3,514	\$ 120.00	\$ 421,680.00
3	Riprap Class II	CY	1,172	\$ 90.00	\$ 105,480.00
4	Common Fill	CY	0	\$ 8.00	\$ -
5	Tree and Brush Removal	AC	0.88	\$ 10,000.00	\$ 8,800.00
6	Floating Silt Curtain (erosion control)	LF	100	\$ 20.00	\$ 2,000.00
7	Mobilization	LS	1	\$ 31,300.50	\$ 31,300.50
8	Seeding and Mulching "Riparian Mix"	AC	2.7	\$ 1,500.00	\$ 4,050.00
Total Construction Cost					\$ 657,310.50

Upper Ridge Rock Arch Rapids 3

No.	Bid Item	Unit	Quantity	Unit Price	Cost
1	Rock Weir (36" to 72")	LF	910	\$ 80.00	\$ 72,800.00
2	Riprap Class V	CY	2,606	\$ 120.00	\$ 312,720.00
3	Riprap Class II	CY	869	\$ 90.00	\$ 78,210.00
4	Common Fill	CY	0	\$ 8.00	\$ -
5	Tree and Brush Removal	AC	0.85	\$ 10,000.00	\$ 8,500.00
6	Floating Silt Curtain (erosion control)	LF	100	\$ 20.00	\$ 2,000.00
7	Mobilization	LS	1	\$ 23,841.25	\$ 23,841.25
8	Seeding and Mulching "Riparian Mix"	AC	1.73	\$ 1,500.00	\$ 2,595.00
Total Construction Cost					\$ 500,666.25

Upper Ridge Rock Arch Rapids 4

No.	Bid Item	Unit	Quantity	Unit Price	Cost
1	Rock Weir (36" to 72")	LF	512	\$ 80.00	\$ 40,960.00
2	Riprap Class V	CY	2,017	\$ 120.00	\$ 242,040.00
3	Riprap Class II	CY	673	\$ 90.00	\$ 60,570.00
4	Common Fill	CY	0	\$ 8.00	\$ -
5	Tree and Brush Removal	AC	1.19	\$ 10,000.00	\$ 11,900.00
6	Floating Silt Curtain (erosion control)	LF	100	\$ 20.00	\$ 2,000.00
7	Mobilization	LS	1	\$ 18,008.50	\$ 18,008.50
8	Seeding and Mulching "Riparian Mix"	AC	1.8	\$ 1,500.00	\$ 2,700.00
Total Construction Cost					\$ 378,178.50

Upper Ridge Rock Arch Rapids 5

No.	Bid Item	Unit	Quantity	Unit Price	Cost
1	Rock Weir (36" to 72")	LF	649	\$ 80.00	\$ 51,920.00
2	Riprap Class V	CY	2,051	\$ 120.00	\$ 246,120.00
3	Riprap Class II	CY	684	\$ 90.00	\$ 61,560.00
4	Common Fill	CY	0	\$ 8.00	\$ -
5	Tree and Brush Removal	AC	1.16	\$ 10,000.00	\$ 11,600.00
6	Floating Silt Curtain (erosion control)	LF	100	\$ 20.00	\$ 2,000.00
7	Mobilization	LS	1	\$ 18,733.50	\$ 18,733.50
8	Seeding and Mulching "Riparian Mix"	AC	0.98	\$ 1,500.00	\$ 1,470.00
Total Construction Cost					\$ 393,403.50

Upper Ridge Rock Arch Rapids 6

No.	Bid Item	Unit	Quantity	Unit Price	Cost
1	Rock Weir (36" to 72")	LF	638	\$ 80.00	\$ 51,040.00
2	Riprap Class V	CY	2,102	\$ 120.00	\$ 252,240.00
3	Riprap Class II	CY	701	\$ 90.00	\$ 63,090.00
4	Common Fill	CY	0	\$ 8.00	\$ -
5	Tree and Brush Removal	AC	1.08	\$ 10,000.00	\$ 10,800.00
6	Floating Silt Curtain (erosion control)	LF	100	\$ 20.00	\$ 2,000.00
7	Mobilization	LS	1	\$ 19,154.25	\$ 19,154.25
8	Seeding and Mulching "Riparian Mix"	AC	2.61	\$ 1,500.00	\$ 3,915.00
Total Construction Cost					\$ 402,239.25

Upper Ridge Rock Arch Rapids 7

No.	Bid Item	Unit	Quantity	Unit Price	Cost
1	Rock Weir (36" to 72")	LF	928	\$ 80.00	\$ 74,240.00
2	Riprap Class V	CY	2,835	\$ 120.00	\$ 340,200.00
3	Riprap Class II	CY	945	\$ 90.00	\$ 85,050.00
4	Common Fill	CY	0	\$ 8.00	\$ -
5	Tree and Brush Removal	AC	1.39	\$ 10,000.00	\$ 13,900.00
6	Floating Silt Curtain (erosion control)	LF	100	\$ 20.00	\$ 2,000.00
7	Mobilization	LS	1	\$ 25,860.25	\$ 25,860.25
8	Seeding and Mulching "Riparian Mix"	AC	1.21	\$ 1,500.00	\$ 1,815.00
Total Construction Cost					\$ 543,065.25

Upper Ridge Rock Arch Rapids 8

No.	Bid Item	Unit	Quantity	Unit Price	Cost
1	Rock Weir (36" to 72")	LF	784	\$ 80.00	\$ 62,720.00
2	Riprap Class V	CY	2,712	\$ 120.00	\$ 325,440.00
3	Riprap Class II	CY	904	\$ 90.00	\$ 81,360.00
4	Common Fill	CY	0	\$ 8.00	\$ -
5	Tree and Brush Removal	AC	1.72	\$ 10,000.00	\$ 17,200.00
6	Floating Silt Curtain (erosion control)	LF	100	\$ 20.00	\$ 2,000.00
7	Mobilization	LS	1	\$ 24,687.25	\$ 24,687.25
8	Seeding and Mulching "Riparian Mix"	AC	3.35	\$ 1,500.00	\$ 5,025.00
Total Construction Cost					\$ 518,432.25

BEACH RIDGE ROCK ARCH RAPIDS OPINION OF PROBABLE COST

Beach Ridge Rock Arch Rapids (Total)

No.	Bid Item	Unit	Quantity	Unit Price	Total Costs
1	Rock Weir (36" to 72")	LF	5,565	\$ 80.00	\$ 445,200.00
2	Riprap Class V	CY	22,964	\$ 120.00	\$ 2,755,680.00
3	Riprap Class II	CY	7,658	\$ 90.00	\$ 689,220.00
4	Common Fill	CY	660	\$ 8.00	\$ 5,280.00
5	Tree and Brush Removal	AC	6.8	\$ 10,000.00	\$ 68,000.00
6	Floating Silt Curtain (erosion control)	LF	600	\$ 20.00	\$ 12,000.00
7	Mobilization	LS	1	\$ 199,781.50	\$ 199,781.50
8	Seeding and Mulching "Riparian Mix"	AC	13.5	\$ 1,500.00	\$ 20,250.00
Total Construction Cost					\$ 4,195,411.50
Contingencies (30%)					\$ 1,258,623.45
Legal, Admin, Permitting, and Engineering (Final Design, Construction Staking, Construction Observation, Closeout)					\$ 818,105.24
Permanent Right-of-Way		AC	12.32	\$ 1,600.00	\$ 19,712.00
Temporary Right-of-Way		AC	6.67	\$ 250.00	\$ 1,667.50
Total Project Costs					\$ 6,293,519.69

Beach Ridge Rock Arch Rapids 1

No.	Bid Item	Unit	Quantity	Unit Price	Cost
1	Rock Weir (36" to 72")	LF	882	\$ 80.00	\$ 70,560.00
2	Riprap Class V	CY	3,883	\$ 120.00	\$ 465,960.00
3	Riprap Class II	CY	1,295	\$ 90.00	\$ 116,550.00
4	Common Fill	CY	117	\$ 8.00	\$ 936.00
5	Tree and Brush Removal	AC	0.5	\$ 10,000.00	\$ 5,000.00
6	Floating Silt Curtain (erosion control)	LF	100	\$ 20.00	\$ 2,000.00
7	Mobilization	LS	1	\$ 33,290.30	\$ 33,290.30
8	Seeding and Mulching "Riparian Mix"	AC	3.2	\$ 1,500.00	\$ 4,800.00
Total Construction Cost					\$ 699,096.30

Beach Ridge Rock Arch Rapids 2

No.	Bid Item	Unit	Quantity	Unit Price	Cost
1	Rock Weir (36" to 72")	LF	945	\$ 80.00	\$ 75,600.00
2	Riprap Class V	CY	4,390	\$ 120.00	\$ 526,800.00
3	Riprap Class II	CY	1,464	\$ 90.00	\$ 131,760.00
4	Common Fill	CY	242	\$ 8.00	\$ 1,936.00
5	Tree and Brush Removal	AC	1.0	\$ 10,000.00	\$ 10,000.00
6	Floating Silt Curtain (erosion control)	LF	100	\$ 20.00	\$ 2,000.00
7	Mobilization	LS	1	\$ 40,000.00	\$ 40,000.00
8	Seeding and Mulching "Riparian Mix"	AC	1.5	\$ 1,500.00	\$ 2,250.00
Total Construction Cost					\$ 787,863.30

Beach Ridge Rock Arch Rapids 3

No.	Bid Item	Unit	Quantity	Unit Price	Cost
1	Rock Weir (36" to 72")	LF	1,134	\$ 80.00	\$ 90,720.00
2	Riprap Class V	CY	3,749	\$ 120.00	\$ 449,880.00
3	Riprap Class II	CY	1,250	\$ 90.00	\$ 112,500.00
4	Common Fill	CY	0	\$ 8.00	\$ -
5	Tree and Brush Removal	AC	1.1	\$ 10,000.00	\$ 11,000.00
6	Floating Silt Curtain (erosion control)	LF	100	\$ 20.00	\$ 2,000.00
7	Mobilization	LS	1	\$ 36,000.00	\$ 36,000.00
8	Seeding and Mulching "Riparian Mix"	AC	3.9	\$ 1,500.00	\$ 5,850.00
Total Construction Cost					\$ 705,547.50

Beach Ridge Rock Arch Rapids 4

No.	Bid Item	Unit	Quantity	Unit Price	Cost
1	Rock Weir (36" to 72")	LF	992	\$ 80.00	\$ 79,360.00
2	Riprap Class V	CY	4,147	\$ 120.00	\$ 497,640.00
3	Riprap Class II	CY	1,383	\$ 90.00	\$ 124,470.00
4	Common Fill	CY	283	\$ 8.00	\$ 2,264.00
5	Tree and Brush Removal	AC	1.7	\$ 10,000.00	\$ 17,000.00
6	Floating Silt Curtain (erosion control)	LF	100	\$ 20.00	\$ 2,000.00
7	Mobilization	LS	1	\$ 38,000.00	\$ 38,000.00
8	Seeding and Mulching "Riparian Mix"	AC	1.6	\$ 1,500.00	\$ 2,400.00
Total Construction Cost					\$ 761,390.70

Beach Ridge Rock Arch Rapids 5

No.	Bid Item	Unit	Quantity	Unit Price	Cost
1	Rock Weir (36" to 72")	LF	682	\$ 80.00	\$ 54,560.00
2	Riprap Class V	CY	3,035	\$ 120.00	\$ 364,200.00
3	Riprap Class II	CY	1,012	\$ 90.00	\$ 91,080.00
4	Common Fill	CY	0	\$ 8.00	\$ -
5	Tree and Brush Removal	AC	1.4	\$ 10,000.00	\$ 14,000.00
6	Floating Silt Curtain (erosion control)	LF	100	\$ 20.00	\$ 2,000.00
7	Mobilization	LS	1	\$ 28,000.00	\$ 28,000.00
8	Seeding and Mulching "Riparian Mix"	AC	1.7	\$ 1,500.00	\$ 2,550.00
Total Construction Cost					\$ 554,809.50

Beach Ridge Rock Arch Rapids 6

No.	Bid Item	Unit	Quantity	Unit Price	Cost
1	Rock Weir (36" to 72")	LF	930	\$ 80.00	\$ 74,400.00
2	Riprap Class V	CY	3,760	\$ 120.00	\$ 451,200.00
3	Riprap Class II	CY	1,254	\$ 90.00	\$ 112,860.00
4	Common Fill	CY	18	\$ 8.00	\$ 144.00
5	Tree and Brush Removal	AC	1.1	\$ 10,000.00	\$ 11,000.00
6	Floating Silt Curtain (erosion control)	LF	100	\$ 20.00	\$ 2,000.00
7	Mobilization	LS	1	\$ 35,000.00	\$ 35,000.00
8	Seeding and Mulching "Riparian Mix"	AC	1.6	\$ 1,500.00	\$ 2,400.00
Total Construction Cost					\$ 686,704.20

LAKE PLAIN - CHANNEL RESTORATION OPINION OF PROBABLE COST

No.	Bid Item	Unit	Quantity	Unit Price	Cost
1	Channel Excavation (stripping incidental)	CY	2,311,046	\$ 4.50	\$ 10,399,707.00
2	Class V Riprap	CY	1,080	\$ 120.00	\$ 129,600.00
3	Class IV Riprap	CY	6,670	\$ 100.00	\$ 667,000.00
4	Class II Riprap	CY	416	\$ 90.00	\$ 37,440.00
5	Class I Riprap	CY	2,684	\$ 80.00	\$ 214,720.00
6	Rock Weir (36" - 72")	CY	329	\$ 80.00	\$ 26,320.00
7	Sod mat	SY	28,621	\$ 12.00	\$ 343,452.00
8	Tree and Brush Removal	AC	26.0	\$ 10,000.00	\$ 260,000.00
9	Mobilization	LS	1.0	\$ 655,708.45	\$ 655,708.45
10	Seeding and Mulching "Riparian Mix"	AC	185.0	\$ 1,500.00	\$ 277,500.00
11	Seeding and Mulching "Mesic Prairie Mix"	AC	82.0	\$ 1,500.00	\$ 123,000.00
12	Seeding and Mulching "Cover Crop Mix"	AC	312.0	\$ 1,000.00	\$ 312,000.00
13	24" CMP	LF	5,542.0	\$ 40.00	\$ 221,680.00
14	36" CMP	LF	1,270.0	\$ 65.00	\$ 82,550.00
15	24" Flap Gate	EA	24.0	\$ 550.00	\$ 13,200.00
16	36" Flap Gate	EA	6.0	\$ 1,000.00	\$ 6,000.00
Total Construction Cost					\$ 13,769,877.45
Contingencies (30%)					\$ 4,130,963.24
Legal, Admin, Permitting, and Engineering (Final Design, Construction Staking, Construction Observation, Closeout)					\$ 2,685,126.10
Permanent Right-of-Way		AC	145	\$ 4,500.00	\$ 652,500.00
Temporary Right-of-Way		AC	312	\$ 500.00	\$ 156,000.00
Total Project Costs					\$ 21,394,466.79



APPENDIX G

Site Reconnaissance Photos – May 28, 2019

1 - County Road 14 Downstream



2 - County Road 14 Upstream



3 - County Road 128 Downstream



4 - County Road 128 Upstream



5 - 193 Downstream



6 - 193 Bridge



7 - 193 Upstream



8 - County Road 138 Downstream



9 - County Road 138 Upstream



10 - 290th Downstream 1



11 - 290th Downstream 2



12 - 290th Upstream



13 - County Road 101 Downstream



14 - County Road 101 Upstream



15 - County Road 110 Downstream



16 - County Road 110 Upstream



17 - County Road 27 Downstream



18 - County Road 27 Upstream



19 - 220th Downstream



20 - 220th Upstream



21 - 270th Downstream



22 - 270th Upstream



23 - County Road 157 Downstream



24 - County Road 157 Upstream



25 - 7 Upstream



26 - 330th Downstream



27 - 330th Upstream



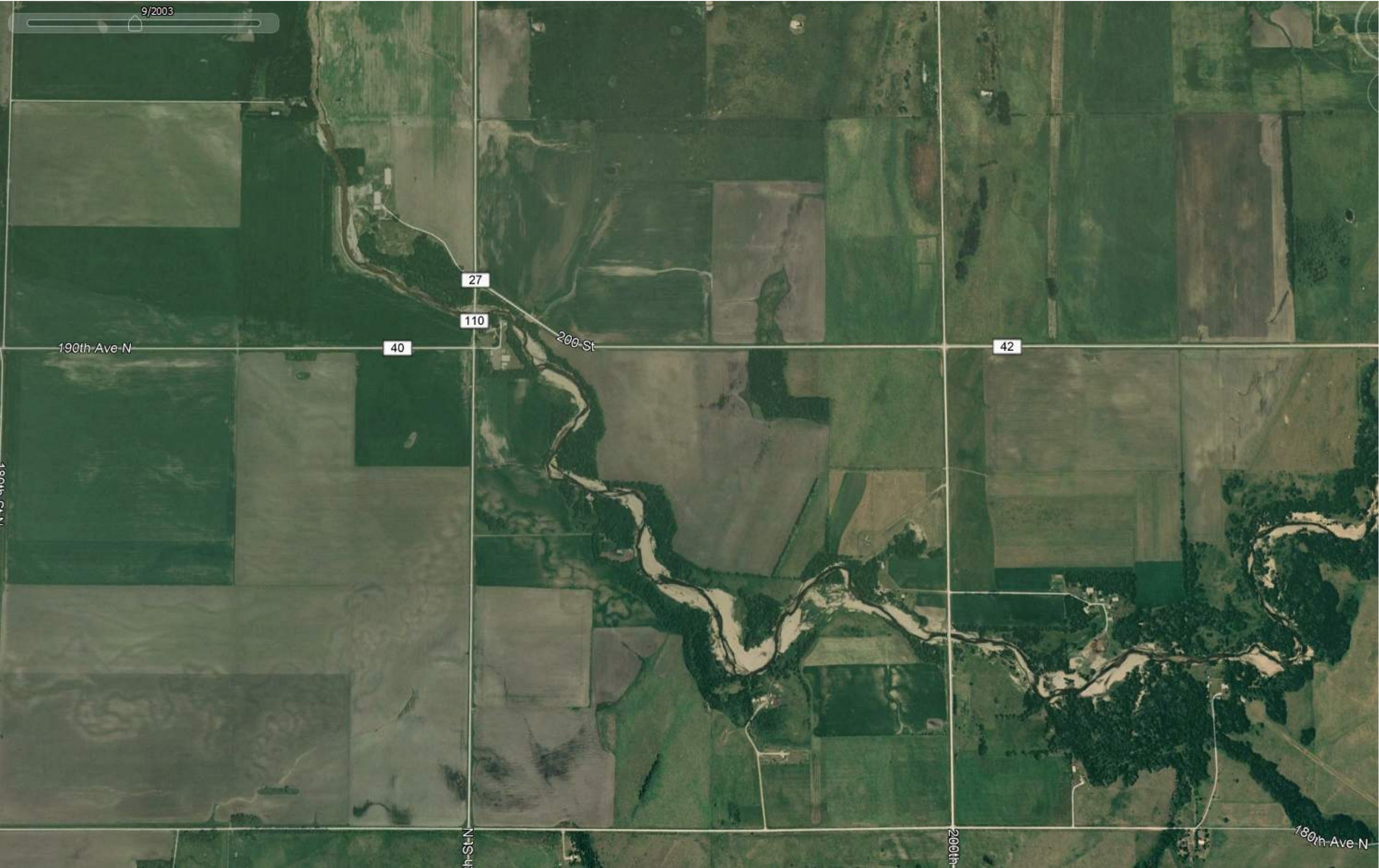


APPENDIX H

Aerial Imagery Comparison

Aerial Comparison #1 - Year 1991













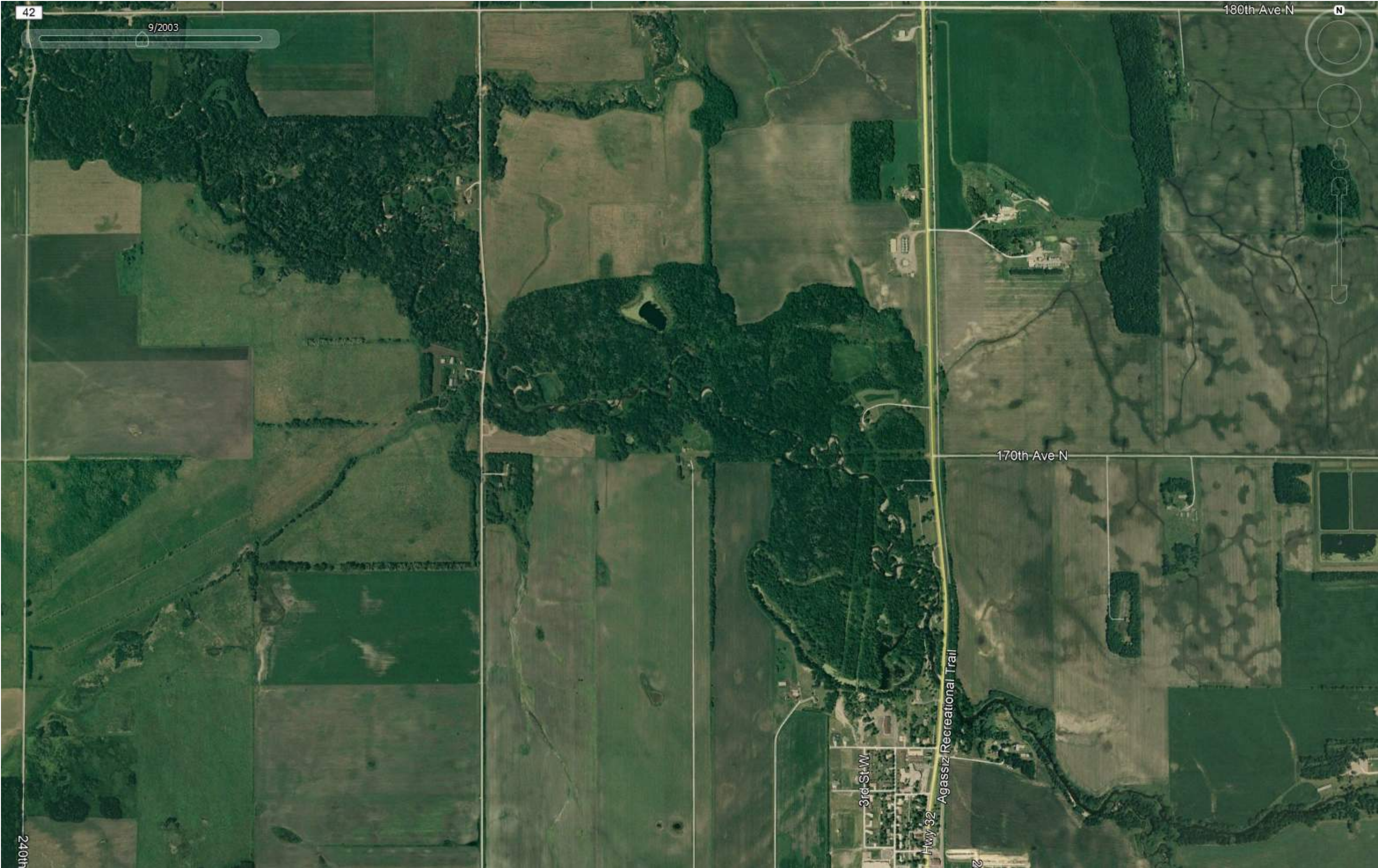




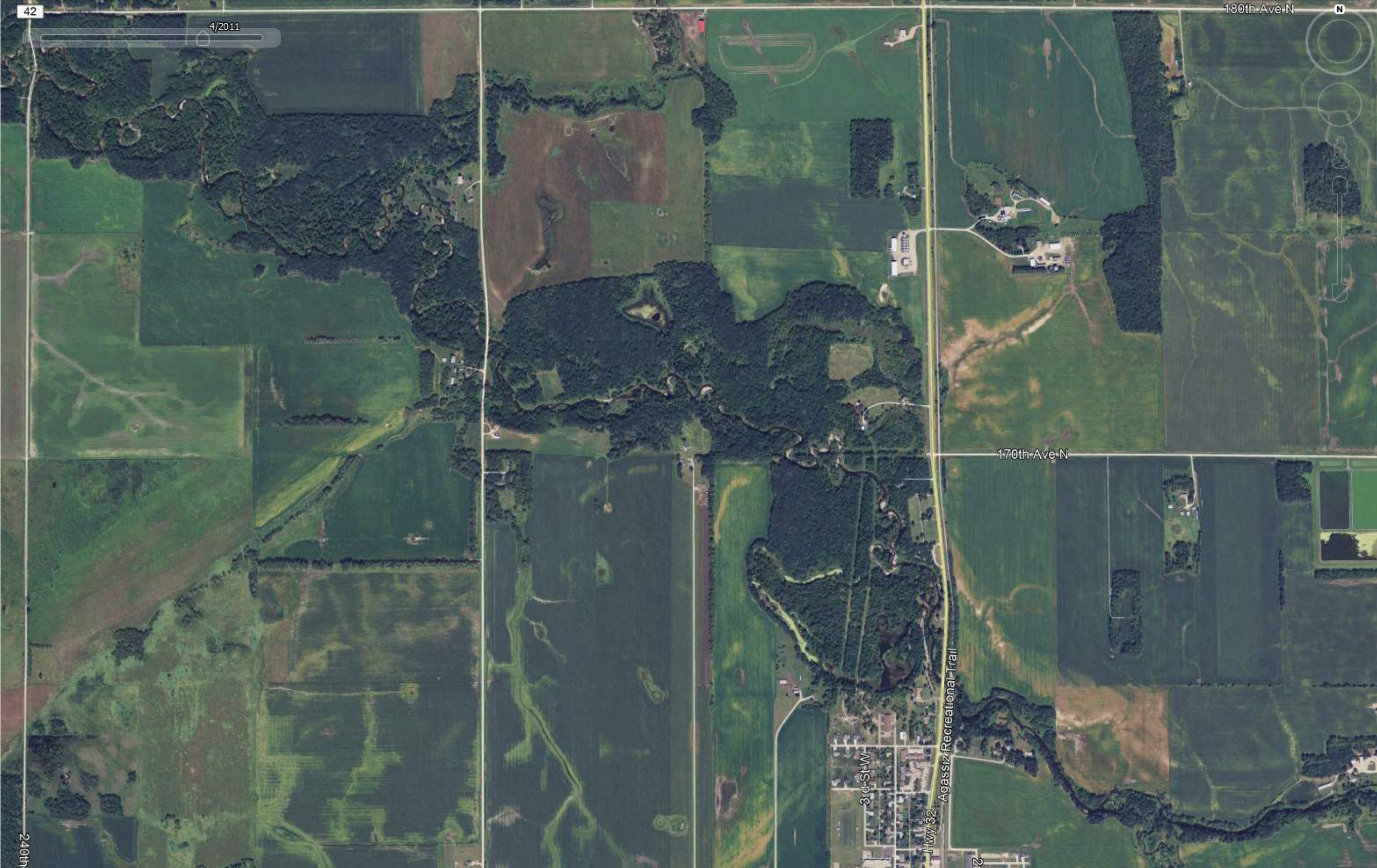
Aerial Comparison #3 - Year 1991



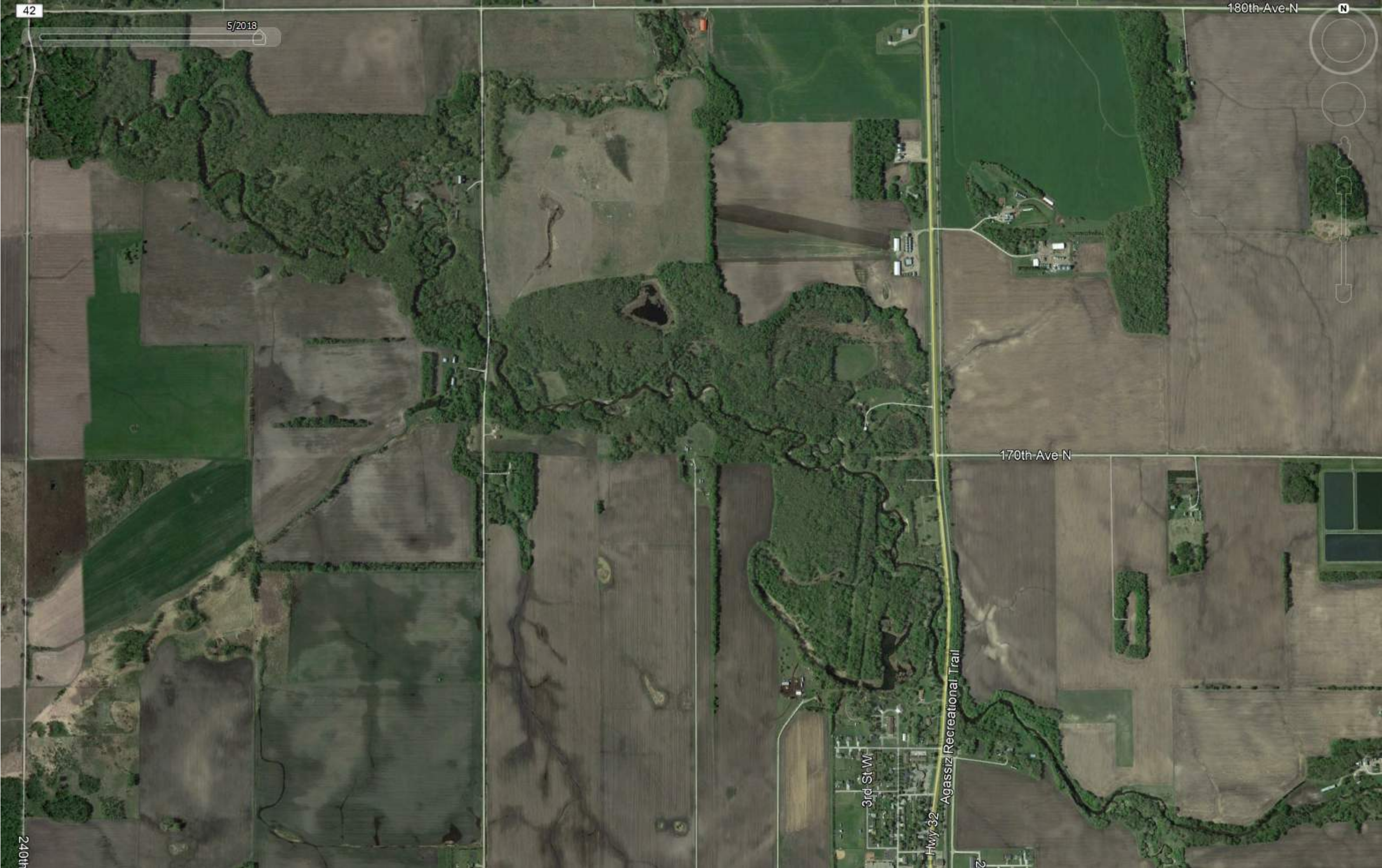
Aerial Comparison #3 - Year 2003



Aerial Comparison #3 - Year 2011

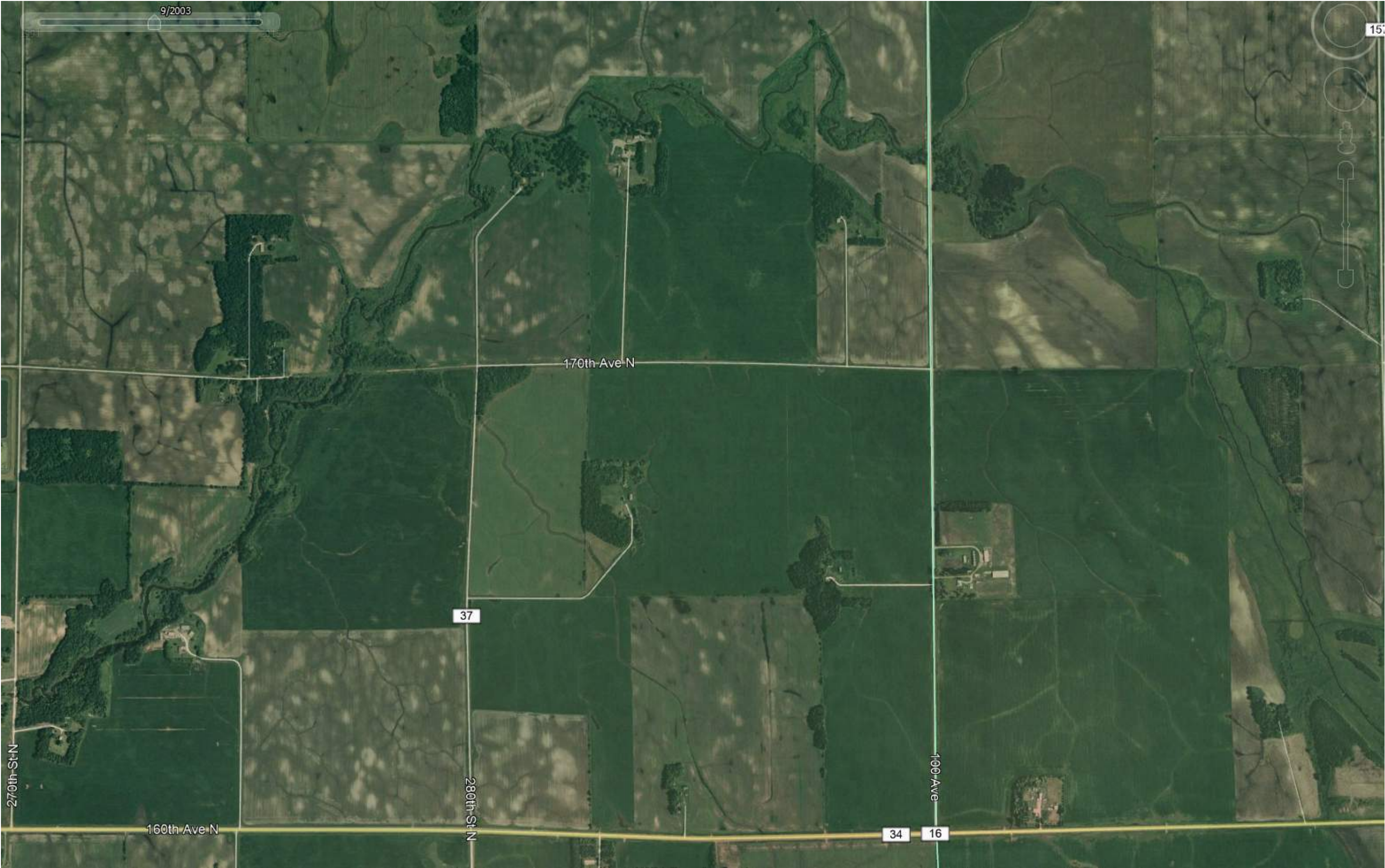


Aerial Comparison #3 - Year 2018



Aerial Comparison #4 - Year 1991



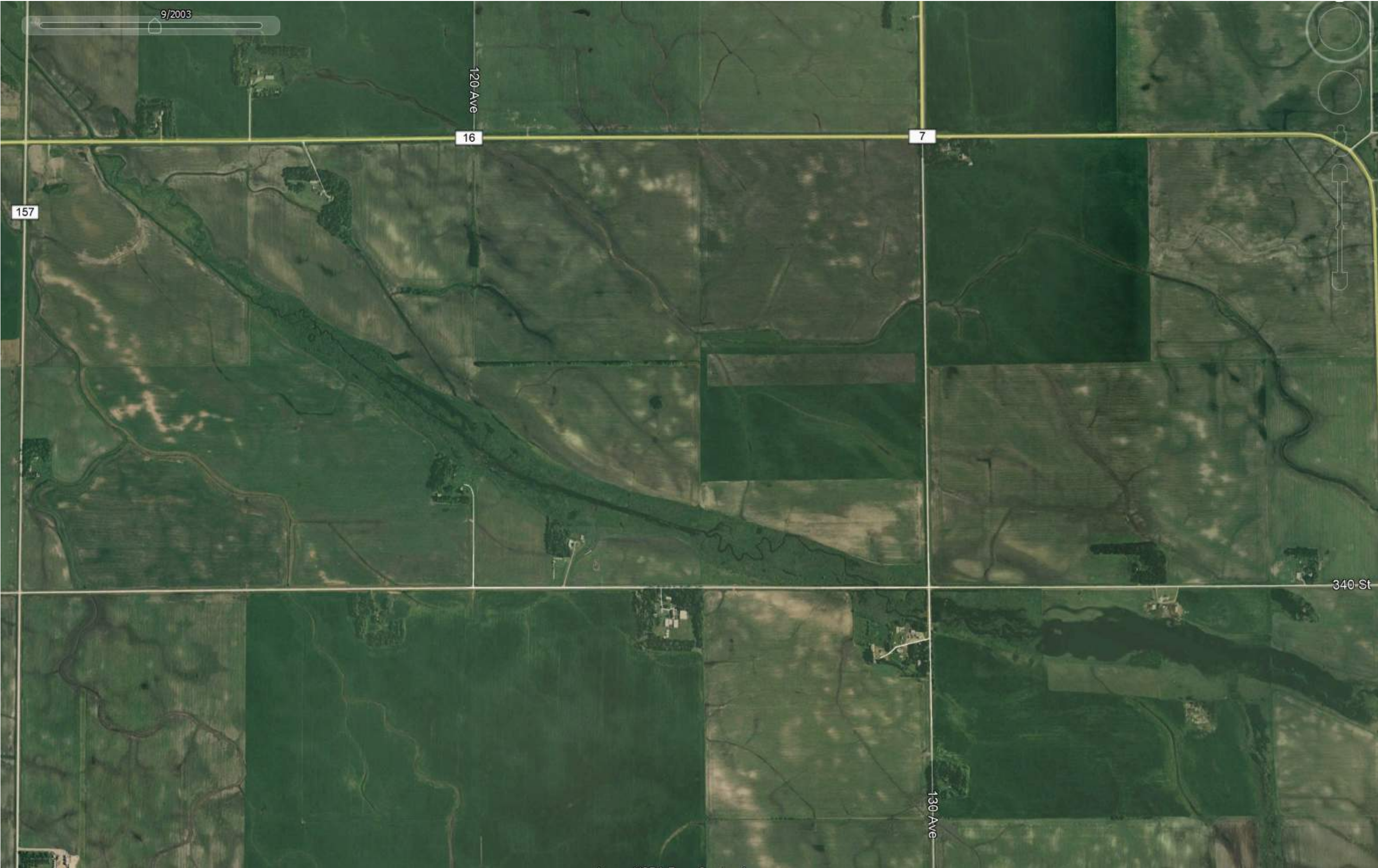






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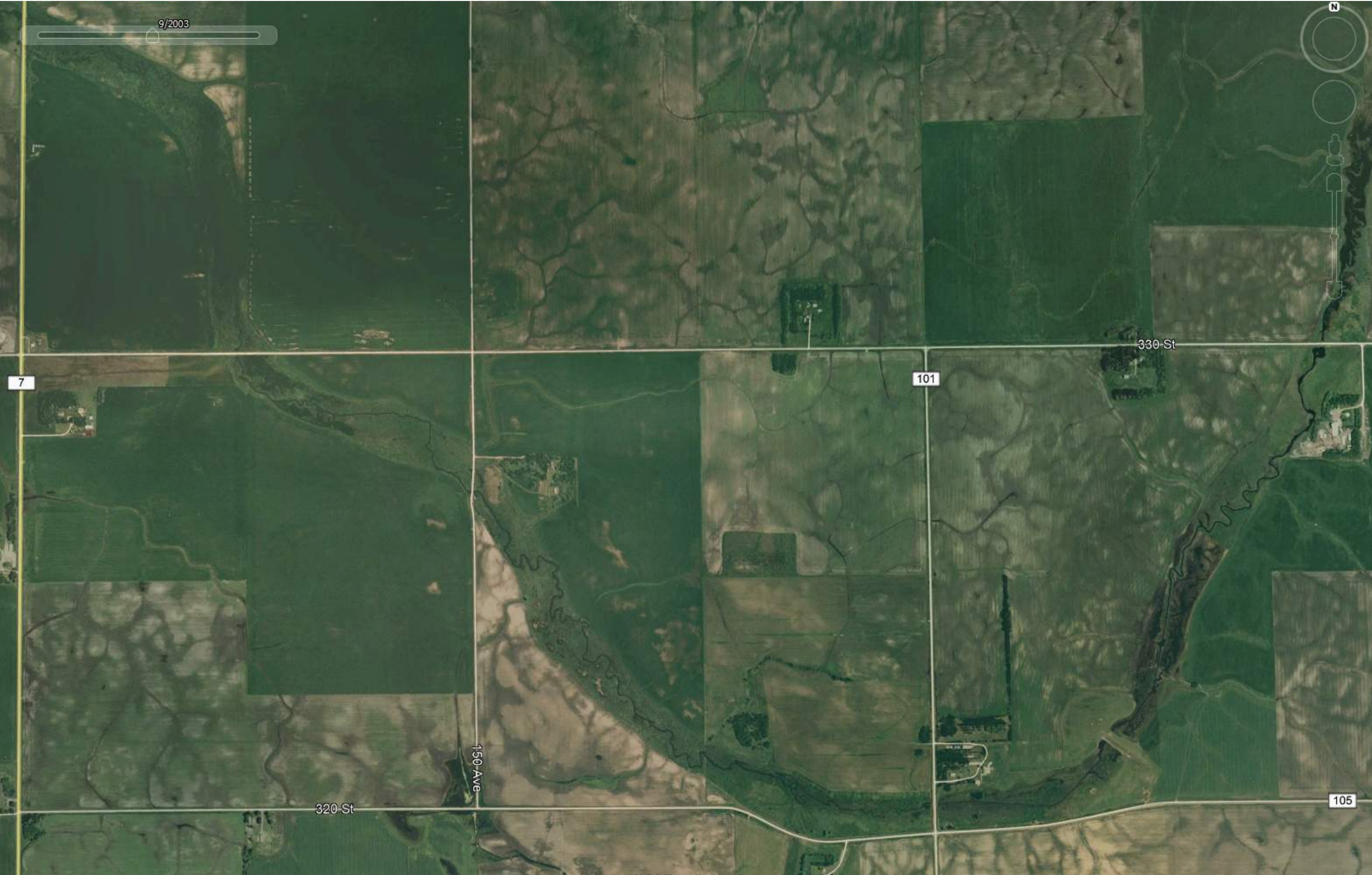






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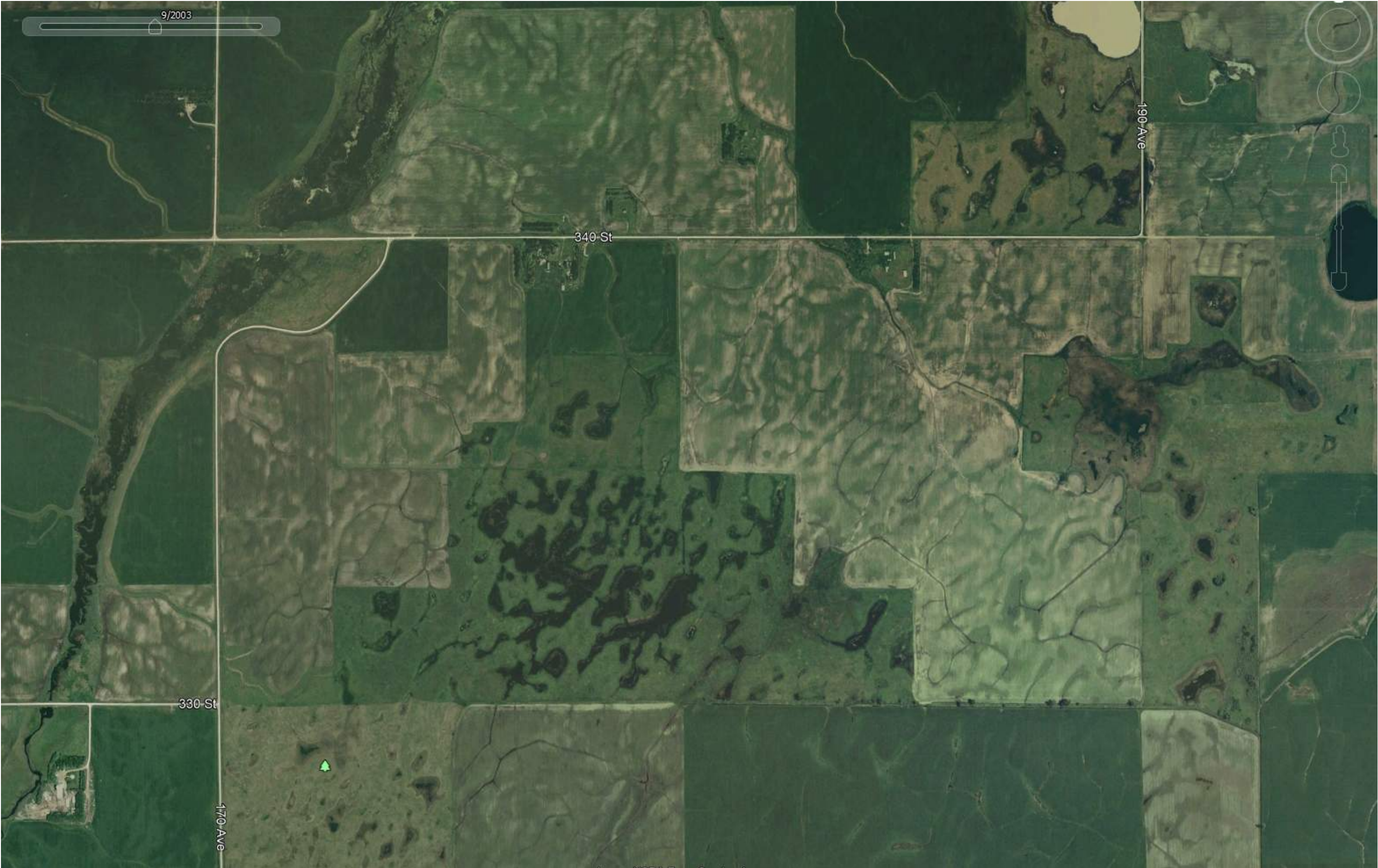


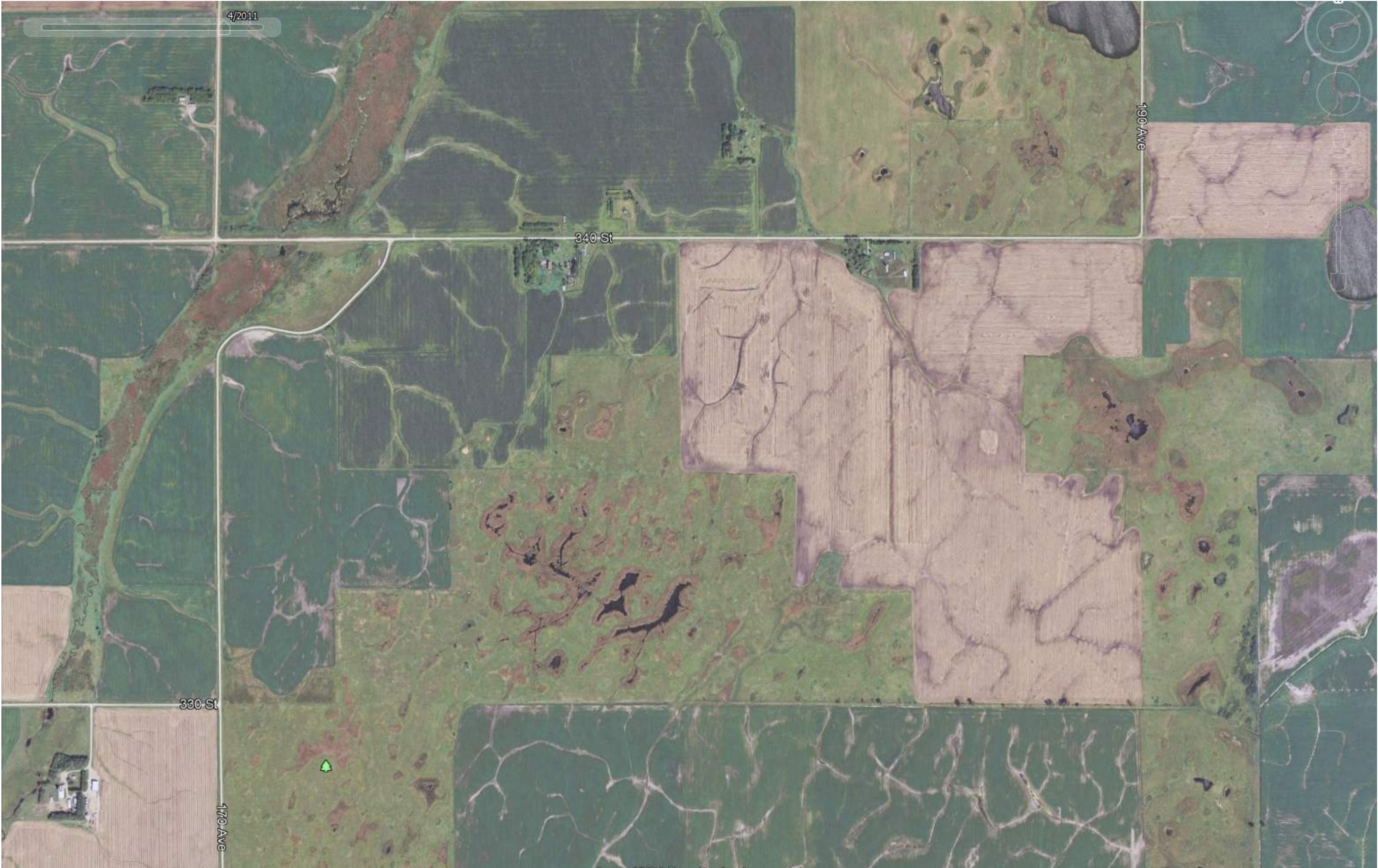










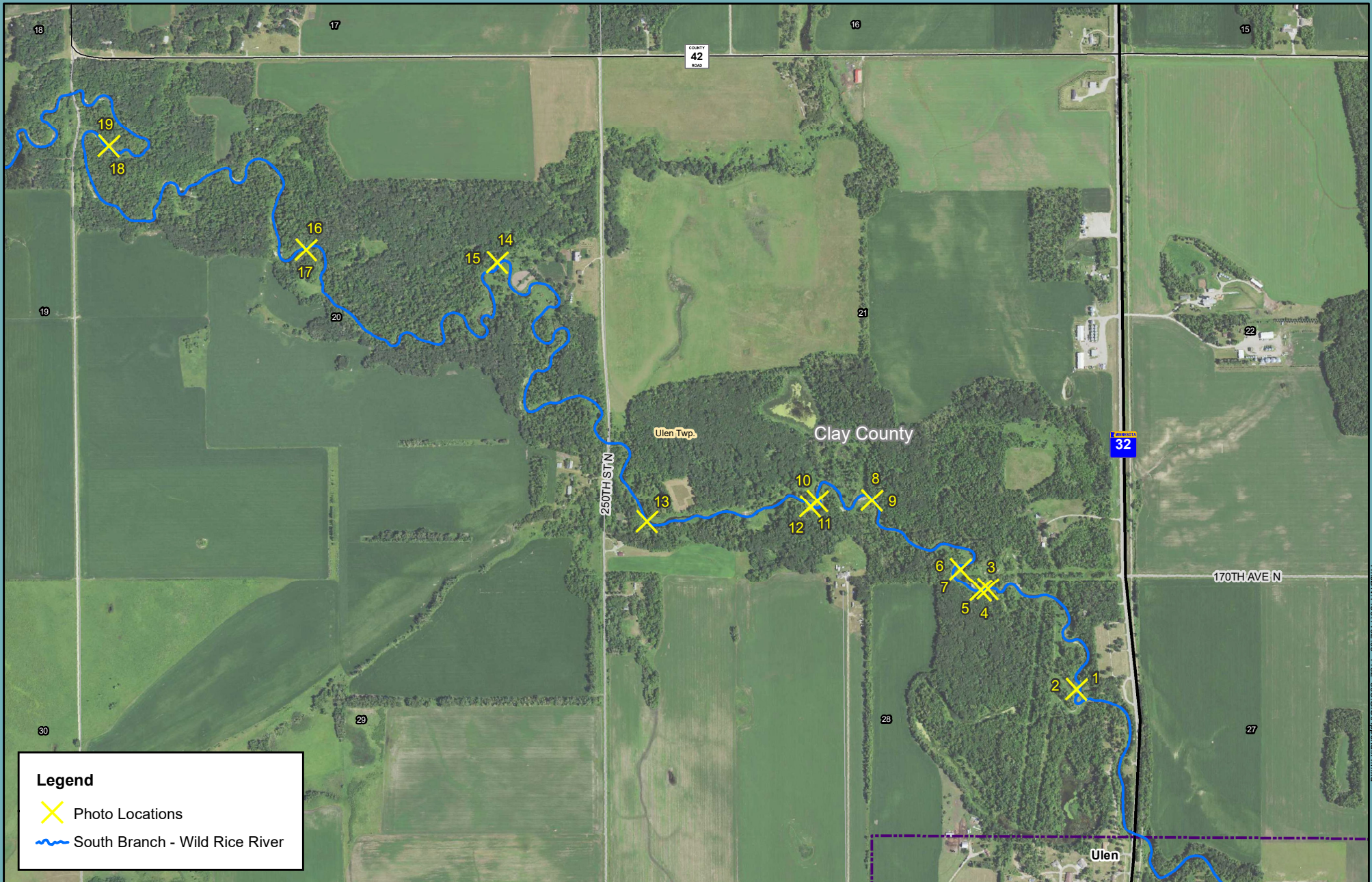






APPENDIX I

Site Reconnaissance Photos – August 5, 2019



Legend

- X Photo Locations
- ~ South Branch - Wild Rice River

Appendix I: Site Reconnaissance Photos - August 5, 2019

Feasibility Study Report
 South Branch Wild Rice River Restoration & Sediment Reduction
 Wild Rice River Watershed District

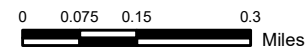


Photo 1



Photo 2



Photo 3



Photo 4

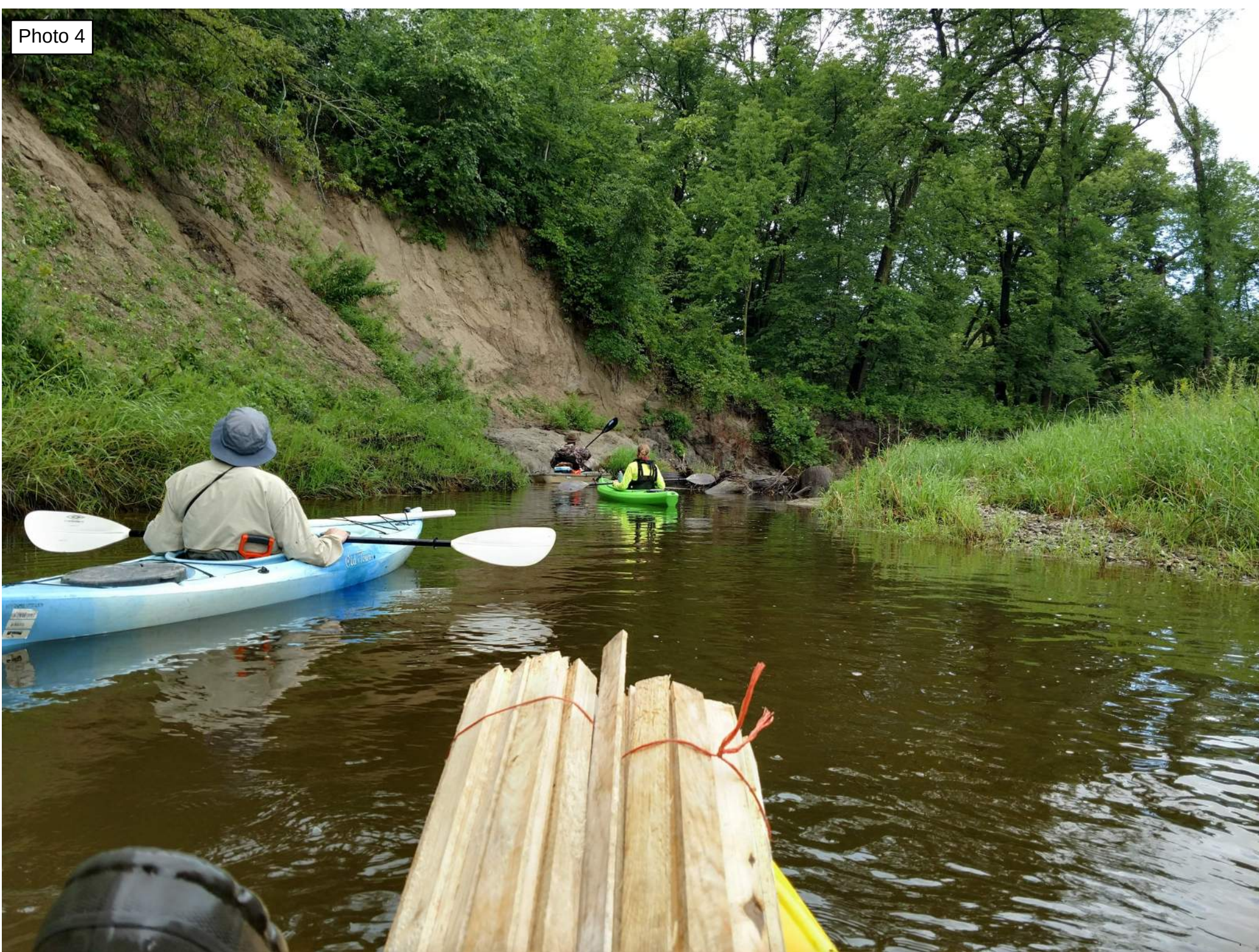


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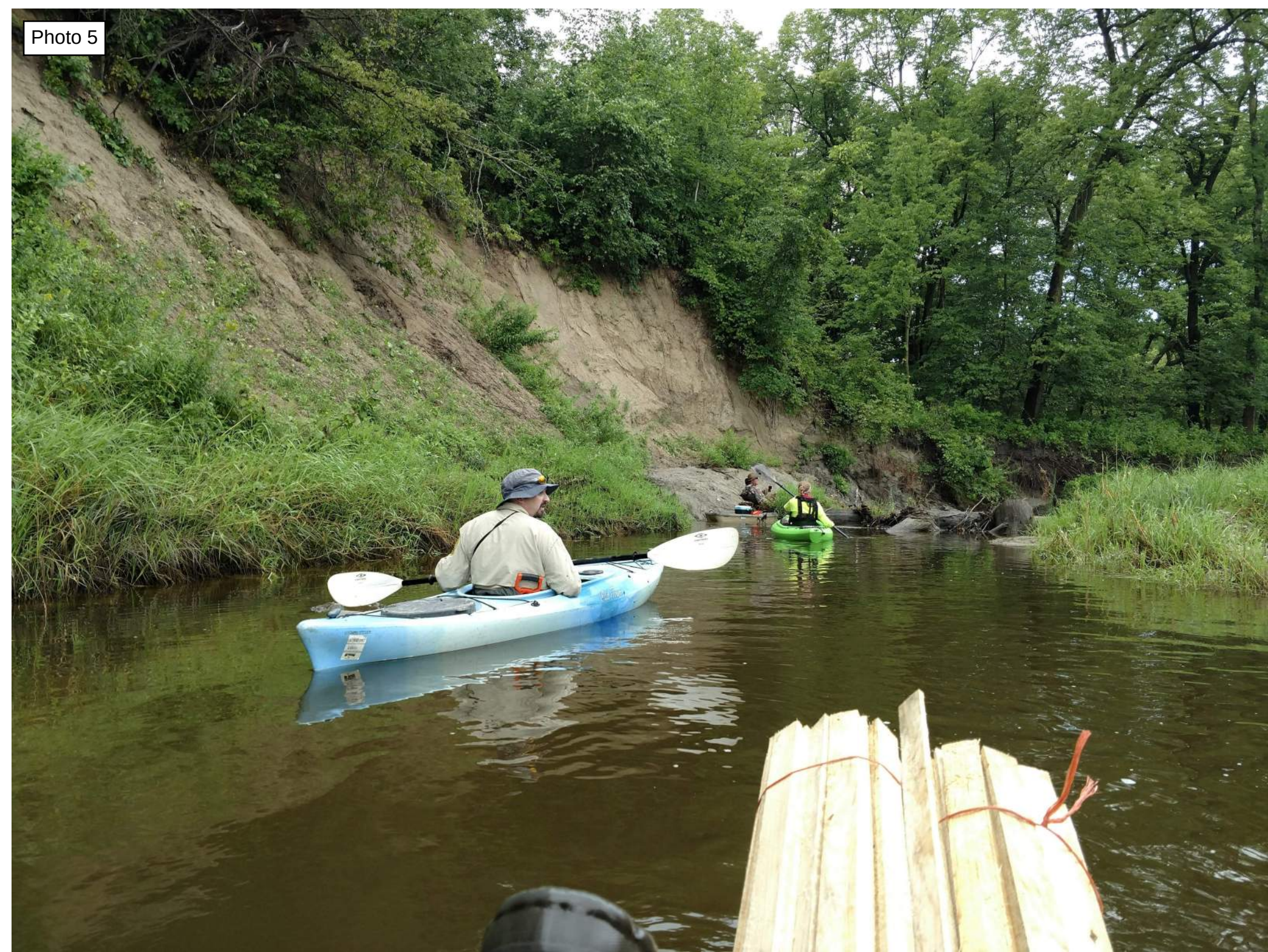


Photo 6



Photo 7



Photo 8



Photo 9



Photo 10



BRIEFLE
X-35

Photo 11



Photo 12



Photo 13



Photo 14

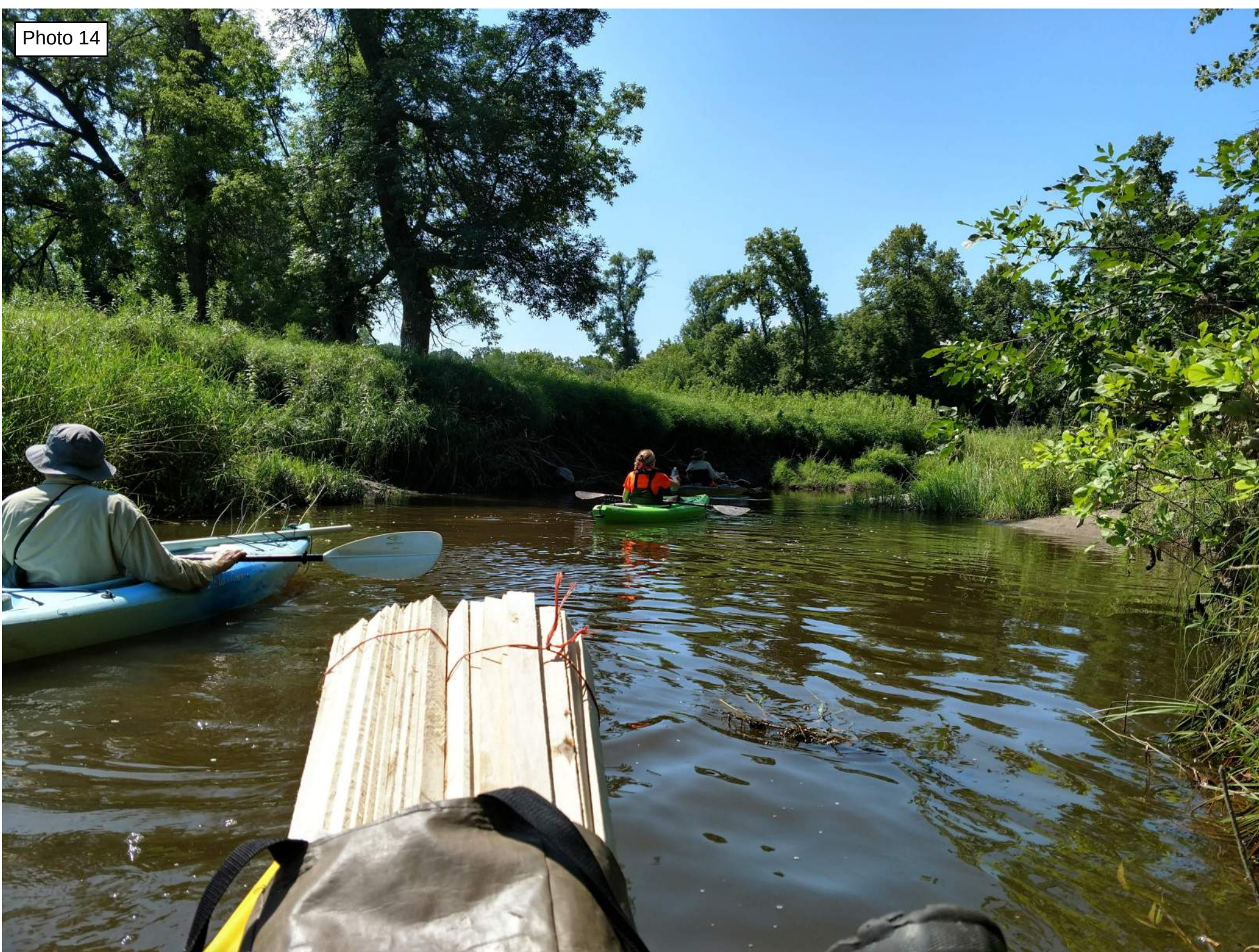


Photo 15



Photo 16

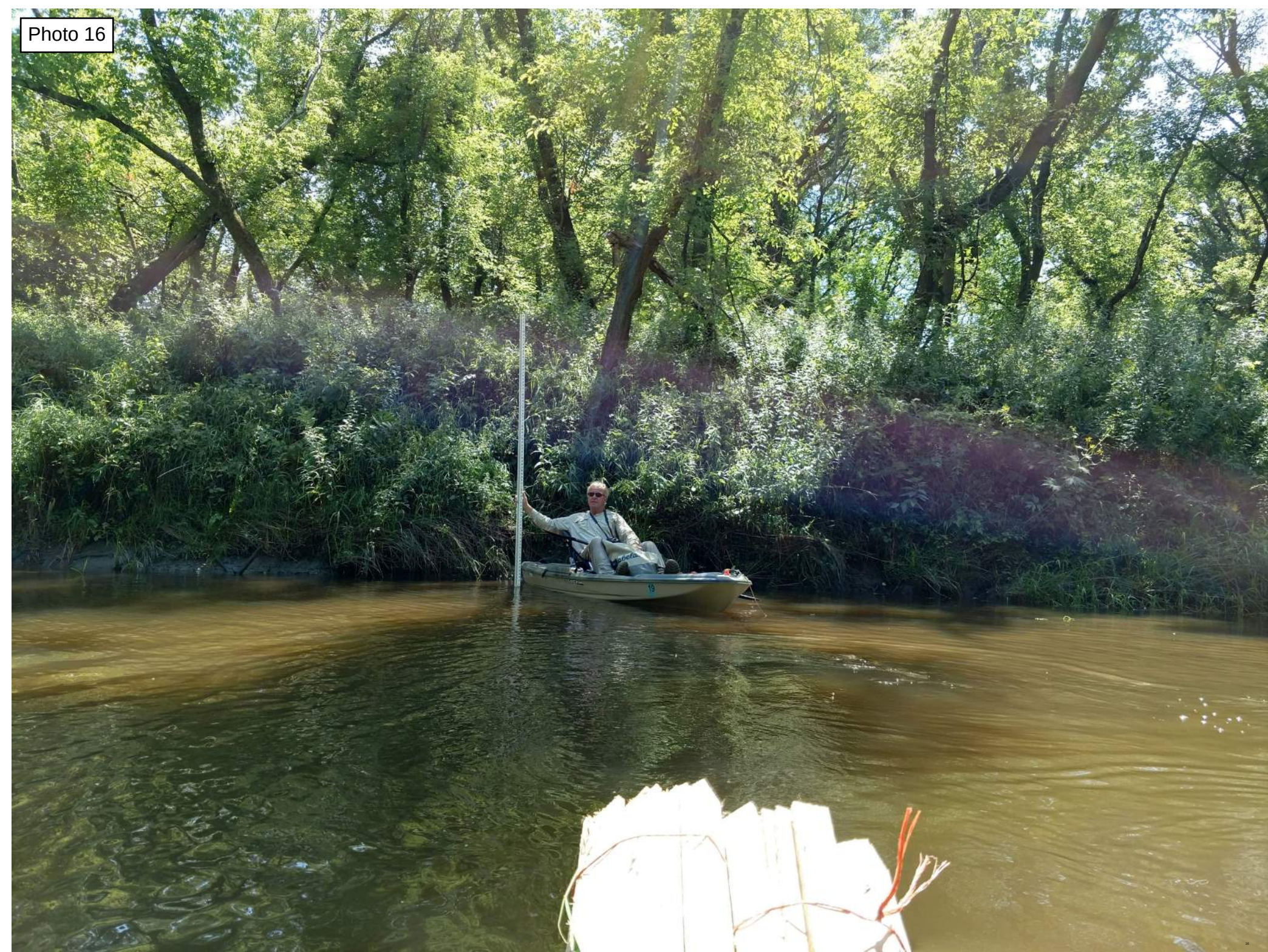


Photo 17



Photo 18



Photo 19

