McKenzie County
1300 12th Street SE, Suite 240
Watford City, ND 58854
Ph. 701-444-2600
county.mckenziecounty.net

MEETING AGENDA
PUBLIC WORKS SUBCOMMITTEE
April 8th, 2024 at 01:00 pm CT

ATTENDEES:

AGENDA ITEMS

Item 1. Cattle Guard Policy

Item 2. East Bridge Replacements – 43rd Street NW Box Culvert Review

Item 3. What are County Roads?

Item 1

McKenzie County
1300 12th Street SE, Suite 240
Watford City, ND 58854
Ph. 701-444-2600
county.mckenziecounty.net

MCKENZIE COUNTY ROAD AND BRIDGE DEPARTMENT
CATTLE GUARD POLICY

POLICY

The purpose of the Cattle Guard Policy is to regulate the location and specifications for new and existing installed across a County road or section line, whether improved or unimproved. A Cattle Guard Request Application is required from the Road and Bridge Department whenever an Applicant desires a new cattle guard to be installed. A new cattle guard is a cattle guard where one does not currently exist. The guidelines herein are provided to create consistent guidelines for the installation of cattle guards, promote safety for roadway users, and protect the public road system within McKenzie County.

GENERAL REQUIREMENTS

General Conditions:

1. An application requesting a new cattle guard across a County road or section line is to be submitted to the Road and Bridge Department. The request will then be brought before the McKenzie County Board of Commissioners (Commission) for final approval or denial.
2. Installation of a newly approved new cattle guard is to be completed by the Road and Bridge Department for County roads and by the Applicant for section lines. Installation of a new cattle guard without approval could result in additional fees, removal of said cattle guard, and future permit applications being denied.
3. Maintenance and replacement of a cattle guard is to be completed by the Road and Bridge Department for County roads and by the adjacent landowners for section lines. Applicant acknowledges that the County has no obligation to maintain or replace said cattle guard and it shall be at the sole discretion of the Road and Bridge Department. Applicant agrees to indemnify and hold harmless the County from any liability that may arise out of the installation, maintenance, and replacement of said cattle guard.
4. Installation and maintenance of the required adjacent gate and fencing is the responsibility of the adjacent landowners or Applicant, unless it is taken down or removed by the County during installation and/or maintenance of said cattle guard.
5. The Applicant is responsible for paying for the installation of the new cattle guard, as specified per the Fees section of this policy, and for the required gate and fencing adjacent to the cattle guard.
6. A Cattle Guard Request Application is not required if a landowner desires to install a cattle guard across a private approach that connects to a County road or section line. Said cattle guard should be located along the County's right of way line or outside of the County's right of way.
7. The desired new cattle guard location shall be staked prior to the Applicant submitting a Cattle Guard Request Application. A description of how the location is staked should be provided at the time of Application. Internal field reviews will not occur until a location is staked. Additional fees will be assessed if the County attempts to conduct a field review of a location and it is not staked.
8. The Commission has the authority to remove a cattle guard if it is not kept in repair, it is not being utilized, or it becomes necessary to remove the cattle guard and gateway for the purpose of improving the County road or section line.
   a. If it is determined that a cattle guard is to be removed, written notice by registered or certified mail must be sent to the adjacent landowners notifying the landowners that the cattle guard will be removed by the County in thirty (30) days from the date of mailing.

Application Submittals:

1. The following documents shall be submitted with the Cattle Guard Request Application:
    a. Landowner Permission Forms.
    b. Organized Township Permission Forms, if applicable.
    c. Map showing the requested location of the cattle guard.

Specifications for Cattle Guard:

1. Cattle guards are to be constructed per the USFS standard drawing and be capable of handling a HL-20 design loading.
2. Cattle guards must be at least the same width as the existing road, with a minimum required width of twenty-four (24) feet.
3. Cattle guard warning signs are to be placed approximately three hundred (300) feet from the cattle guard in either direction. Warning signs shall be installed per NDDOT and/or MUTCD standards.
4. Object Markers - Type 3 are to be installed per MUTCD standards on all four corners of a cattle guard.
5. A gate, which may be opened and closed easily by the public, is to be installed adjacent to the cattle guard. All gates and fencing within the right of way shall be per the NDDOT standard drawings. If gate and fence materials are utilized that do not meet fencing standards and pose a safety risk to road users, the Road and Bridge Department will notify the adjacent landowners that the gate and/or fence needs to be replaced within thirty (30) days from the date of mailing. If the gate and/or fence is not replaced, the Road and Bridge Department will notify the adjacent landowners that the County will complete the work and bill the adjacent landowners.

Installation and Replacement of Cattle Guards:

1. Installation of a new cattle guard is not allowed across a Major Collector road.
2. Replacement of an existing cattle guard across Major Collector roads should be reviewed to determine if the cattle guard is still necessary and being utilized as originally intended. If the cattle guard is no longer needed, the cattle guard should be removed.
3. If a Major Collector road is to be reconstructed, the County should work to eliminate cattle guards across the reconstructed roadway.
4. Installation of a new cattle guard across a County road should generally be discouraged and reviewed on a case by case basis.
    a. If open grazing does not currently exist along a stretch of roadway, new open grazing should not be created.
    b. If open grazing does currently exist along a stretch of roadway, a new cattle guard may be permitted.
5. An existing cattle guard loses its grandfathered status if it is ordered to be removed by the Commission or at the request of the adjacent landowners, and is not replaced.

FEES

The New Cattle Guard fee schedule is as follows:

- Application Fee	$50.00
- Cost of New Cattle Guard	$200.00 per foot across the roadway
- Unauthorized Cattle Guard	$1,000.00

ADOPTED DATE:

Item 2

TECHNICAL MEMORANDUM

To: Grace Demars, PE, McKenzie County

From: Jesse G. Kist, PE, AE2S Water Resources Engineer
Emily Nelson, EIT, AE2S Water Resources Engineer

Re: **McKenzie County – 43rd Street NW Box Culvert Review**

Date: January 11, 2024

1.0 Background

McKenzie County retained AE2S to review the design and performance of two reinforced concrete box (RCB) culvert crossings of 43rd Street NW over an unnamed tributary of Sand Creek in McKenzie County, North Dakota (Sections 29 & 32, T153N, R95W). AE2S was also tasked with identifying possible impacts at the crossings and developing conceptual mitigation options, if needed. The crossings in question were designed by Mountain Plains, LLC and constructed in 2023. **Figure 1** presents the general location of the two crossings and the identification used for each. The crossings will herein be referred to as 07.1 and 07.0 (last three digits of their IDs).

Figure 1 Crossing Locations

Based on review of the design plans, the culverts were designed such that the inverts were set one foot or more below the lowest surveyed pre-project stream elevation within the crossing footprint. Because the pre-project conditions (bridges) were subject to scour holes, the design placed the box culverts notably lower than the stream flow line of the channel.

The setting of culverts below a channel's flow line and the intentional placement of material within the bottom of the culvert is a common practice, typically referred to as culvert embedment. When embedding a culvert, it is important that the analysis performed to size the culvert accurately accounts for the placement of the culvert below the flow line and the corresponding embedment. The design of a culvert crossing should involve consideration of the stream flow line, assessment of scour potential, and estimation of deposition potential. These parameters should then be used to estimate the vertical adjustment potential (VAP), up and down, of the stream at the crossing location (see References 1 and 2). These bounds are not meant to reflect extremes, such as scour holes at crossings, but rather the typical profile variation in the stream. An example of a vertical adjustment range is presented in **Figure 2**. A culvert design should consider the lower bounds of the VAP when designing the culvert invert and the associated embedment, and it should consider the upper bounds of the VAP when assessing hydraulic capacity and design standards compliance. It is important to note, however, that crossings are, without question, designed and constructed frequently without consideration of these criteria, despite how beneficial their consideration may be.

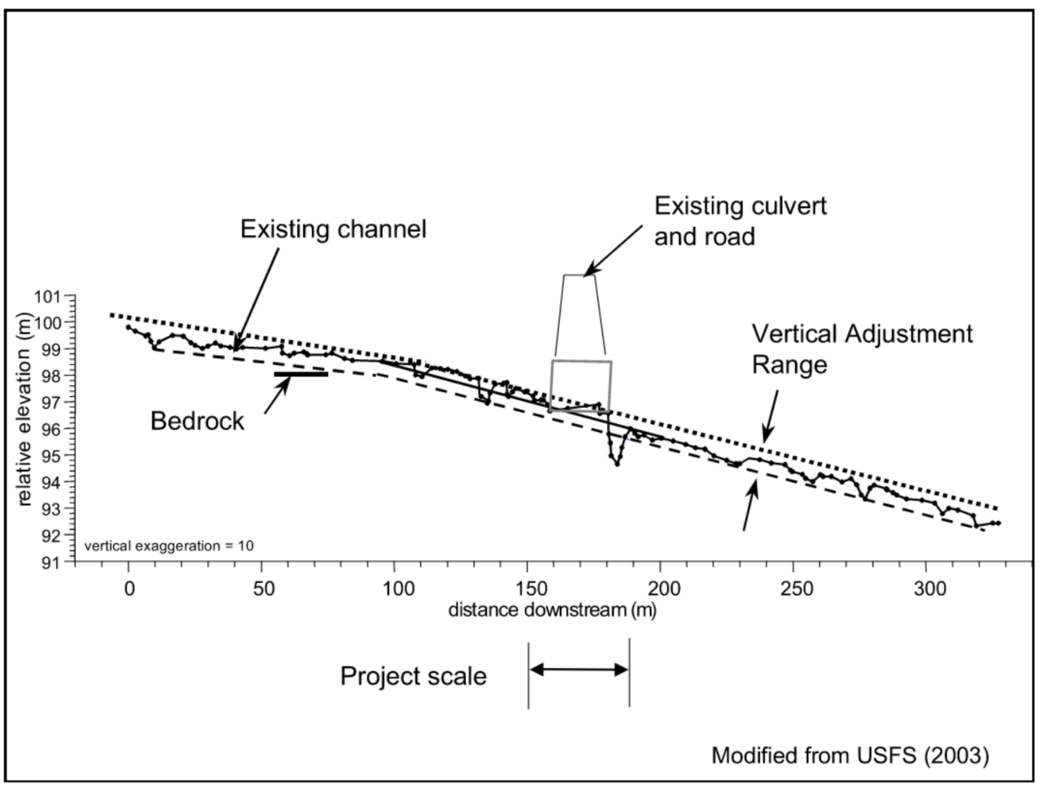


Figure 2 **Vertical Adjustment Range Example (from Vermont Fish & Wildlife)**

2.0 Site Hydrology

The crossings were constructed on an intermittent, vegetated, unnamed tributary of Sand Creek. The stream generally flows northwest to southeast before discharging into Sand Creek.

The 25-, 50-, 100-, and 500-year recurrence-interval stream flow at each crossing is presented in **Table 1**. The flows presented in **Table 1** were obtained using the USGS Stream Stats tool and are consistent with the flow rates used by Mountain Plains, LLC in the design of the crossings. McKenzie County Design Standards require that a no overtopping occur at a crossing during the 50-year storm event. Because the county's standard is more stringent than ND Stream Crossing Standards, the design storm for the crossings is the 50-year storm.

Table 1 *- Stream Flow at Crossings*

Event Recurrence-Interval	Flow at Crossings	
	07.0	07.1
25-year	518 cfs	512 cfs
50-year	663 cfs	656 cfs
100-year	815 cfs	806 cfs
500-year	1,170 cfs	1,160 cfs

3.0 Pre-Construction Hydraulics

An analysis was performed to review and estimate the pre-project hydraulics at each crossing. A pre-project survey was performed by Mountain Plains and provided to AE2S by McKenzie County. This survey includes information on the pre-project land surface and bridge structures. While this survey provided valuable information, some assumptions were required for analysis of the pre-project conditions. Additionally, to be consistent with the crossing design models, this analysis was performed using the Federal Highway Administration's (FHWA) HY-8 software which is intended to be used for analysis of culvert crossings. To estimate the hydraulics of the bridge in HY-8, the pre-project bridges were modeled as box culverts sized to match the bridge opening using manning's coefficients representative of the earthen bottom and wooden sides that existed with the bridge crossings. The intent of these analyses was to understand the approximate headwater elevation upstream of each crossing during various flow events prior to the crossing replacement project. The approximated headwater elevations are presented in **Table 2** and **Table 3,** and model inputs from HY-8 are provided as **Attachment #1**. These headwater elevations are based on assumptions and intended only to provide approximations of the pre-project headwater elevations.

Table 2 *- MCK-27-153-07.0 Pre-Project Bridge Approximated Headwater Elevations*

Event	Flow (cfs)	Headwater Elevation[1, 2] (ft, msl)
25-year	518	2,213.22
50-year	663	2,213.90
100-year	815	2,214.58
500-year	1,170	2,216.09

1. Overtopping elevation estimated to be 2,220.0'.
2. Tailwater elevation modeled as 2,209.38'.

Table 3 *- MCK-27-153-07.1 Pre-Project Bridge Approximated Headwater Elevations*

Event	Flow (cfs)	Headwater Elevation[1, 2] (ft, msl)
25-year	512	2,218.47
50-year	656	2,219.22
100-year	806	2,219.98
500-year	1,160	2,221.74

1. Overtopping elevation estimated to be 2,223.4'.
2. Tailwater elevation modeled as 2,214.50'.

4.0 Project Design Modeling by Mountain Plains

The post-construction parameters used in the HY-8 hydraulic models developed by Mountain Plains, LLC for design of the crossings are summarized in **Table 4,** and screenshots from the HY-8 models are included in **Attachment #2**. The red shading in **Table 4** and red circles in **Attachment #2** indicate the parameters that were deemed inconsistent with the design plans or topographic survey. The pre-project topographic survey data (McKenzie Bridges – East Original Topo.dwg) included survey downstream of each crossing about 150 feet. This data was used to identify the approximate elevations that flows need to overcome downstream of each culvert to continue downstream. **Table 5** presents the same parameters as **Table 4** but with corrections recommended by AE2S shaded in green. It should be noted that the HY-8 modeling performed by AE2S utilized the design culvert inverts, rather than the as-built inverts from the KLJ Engineering survey. The as-built inverts were reviewed and found to be very close to the design elevations, generally within about 0.1 feet. This difference was deemed insignificant and unimpactful to the modeling and recommendations of this study. The as-built survey by KLJ appears to have utilized a drone to obtain site LiDAR, which is less reliable for stream invert elevations.

Table 4 *- Summary of Crossing Design Model Attributes (HY-8)*[1]

ID	Pipe	Size (ft)	Embedment Depth (in)	Manning's "n"	Crest Elev. (ft, msl)	Wingwall Flare	Inverts [US/DS] (ft, msl)	Modeled TW[2] Channel Invert (ft, msl)
07.0	RCB	10x10	0	0.012	2,222.1	30 - 75°	2,207.0/ 2,206.5	2,208.0
07.1	RCB	10x10	0	0.012	2,224.5	30 - 75°	2,209.7/ 2,209.2	2,210.5

1. Columns shaded red indicate parameters deemed to be inconsistent with the crossing design plans.
2. TW = tailwater

Table 5 *- Summary of Updated Crossing Model Attributes by AE2S (HY-8)*[1]

ID	Pipe	Size (ft)	Embedment Depth (in)	Manning's "n" [sides/ Bottom]	Crest Elev. (ft, msl)	Wingwall Flare	Inverts [US/DS] (ft, msl)	Modeled TW[2] Channel Invert (ft, msl)
07.0	RCB	10x10	Variable	0.012/ 0.030	2,220.1	0°	2,207.0/ 2,206.5	2,209.00(3)
07.1	RCB	10x10	Variable	0.012/ 0.030	2,224.0	0°	2,209.7/ 2,209.2	2,214.50(4)

1. *Columns shaded green indicate parameters updated by AE2S.*
2. *TW = tailwater*
3. *Estimated based on survey, design, and as-built files.*
4. *From the pre-project survey by Mountain Plains, LLC.*

As indicated by the parameters shaded red in **Table 4** and circled in red on **Attachment #2**, the HY-8 models developed by Mountain Plains, LLC were found to contain several errors that are discussed below:

- The downstream channel elevations used by the model to determine tailwater conditions do not match the downstream channel elevation shown on the design plans or found in the existing conditions survey.

- Despite being set notably below the stream flow line, the modeled culverts did not incorporate any embedment depth within the culvert bottom. This may overestimate culvert conveyance by assuming a smooth concrete bottom, as opposed to a dirt/cobble bottom which has greater roughness.

- The roadway overtopping elevations used by Mountain Plains, LLC to present design standard compliance and determine freeboard was based on the roadway elevation immediately above the box culverts, rather than the lowest adjacent overtopping elevation. This resulted in exaggerated freeboard being presented in the hydraulic reports.

- The box culverts were modeled using entrance loss coefficients consistent with wingwall end sections having a 30- to 75-degree flare, as opposed to the straight wingwalls that were designed and constructed. This exaggerated the crossing conveyance due to flared wingwalls being more efficient and having a lower loss coefficient than straight wingwalls.

The issues discussed above resulted in culvert modeling by Mountain Plains, LLC that was inconsistent with the design, and a modeling approach that didn't account for potential implications associated with sediment accumulation within the box culverts. While sediment accumulation depth and likelihood are uncertain, consideration of the impacts associated with sedimentation within the culverts would have been appropriate given the placement of the culverts notably below the stream flow line. In addition to, and independent of, sediment accumulation, it is likely that ice buildup will occur within the culverts and the closed basins surrounding each culvert. While not a year-round concern, ice accumulation may significantly reduce crossing conveyance during spring runoff events which can at times represent the annual peak flow event in North Dakota streams.

5.0 AE2S Modeling

AE2S developed HY-8 models to assess crossing performance with the corrected input data presented in **Table 5** and to analyze crossing performance under various embedment scenarios. The HY-8 model inputs for these scenarios are presented in **Attachment #3**, and the resulting headwater elevations are presented in **Table 6** and **Table 7** with red shading used to indicate roadway overtopping. The tables demonstrate that crossing 07.0 meets the design standards even under the most extreme embedment scenario analyzed. Crossing 07.1 satisfies design standards in embedment scenarios up to about 49 inches (not in table) before violating the standards and overtopping the roadway in the 50-year event.

***Table 6** - MCK-27-153-07.0 Headwater Elevations with Embedment*

Event	Flow (cfs)	Pre-Project Headwater (ft)	Headwater (ft) with Variable Embedment[1, 2]					
			0″	6″	12″	18″	24″	30″[(3)]
25-yr	518	2,213.22	2,214.84	2,215.35	2,215.87	2,216.37	2,216.87	2,217.37
50-yr	663	2,213.90	2,216.25	2,216.78	2,217.28	2,217.78	2,218.28	2,218.78
100-yr	815	2,214.58	2,217.05	2,218.16	2,218.66	*2,219.16*	*2,219.68*	*2,220.37*
500-yr	1,170	2,216.09	*2,220.49*	*2,220.87*	*2,221.21*	*2,221.52*	*2,221.81*	*2,222.08*
Design Standard Compliance?		✓	✓	✓	✓	✓	✓	✓

1. *Red shading indicates road overtopping.*
2. *Road overtopping: ~2,220.1′.*
3. *Represents full embedment to the estimated downstream outflow elevation estimate of 2,209.00'.*

***Table 7** - MCK-27-153-07.1 Headwater Elevations with Embedment*

Event	Flow (cfs)	Pre-Project Headwater (ft)	Headwater (ft) with Variable Embedment[1, 2]						
			0″	12″	24″	36″	48″	60″	63.4″[(3)]
25-yr	512	2,218.47	2,218.72	2,219.14	2,219.68	2,220.51	2,221.54	2,223.32	*2,224.00**
50-yr	656	2,219.22	2,219.65	2,220.22	2,220.94	2,221.94	2,223.73	*2,224.87**	*2,225.09**
100-yr	806	2,219.98	2,220.65	2,221.37	2,222.30	*2,224.06*	*2,224.97*	*2,225.64*	*2,225.81*
500-yr	1,160	2,221.74	2,223.32	*2,224.60*	*2,225.33*	*2,225.94*	*2,226.51*	*2,227.04*	*2,227.19*
Design Standard Compliance?		✓	✓	✓	✓	✓	✓	X	X

* *Indicates that the headwater violates McKenzie County Design Standards.*
1. *Red shading indicates road overtopping.*
2. *Road overtopping: ~2,224.0′.*
3. *Represents full embedment to the estimated downstream outflow elevation estimate of 2,214.50'.*

6.0 Crossing Impacts & Concerns

Several concerns regarding the crossings and potential negative impacts have been identified during this study and conversations with McKenzie County. This section identifies the primary concerns and provides discussion on each.

County Design Standards Compliance:

Despite modeling errors placing the crossings significantly below the stream flow line without analysis to ensure proper function, the analysis performed during this study suggest that County Design Standards are satisfied for both crossings, so long as sediment and ice accumulations remain below a depth of about 42 inches within crossing 07.0 and 49 inches within crossing 07.1. It should be noted, however, that while the design standards are generally achieved, the crossing overtopping frequency and headwater elevations were found to be notably higher than what was presented in the hydraulic reports.

Nuisance Ponding:

The placement of the box culverts below the stream flow line results in a closed basin scenario at each crossing due to the downstream channel being higher than the invert of the culvert. This causes water to pond at the crossings during stream flow and for some time following flow events. **Figure 3**, at the end of this section, presents approximated inundation extents at each crossing for both pre- and post-project conditions. **Figure 3** also presents approximated infiltration times based on an assumption of zero inflow and using infiltration rates obtained from Web Soil Survey for the inundated areas. Water quality degradation, including algae, bacteria, and odor formation are also nuisance concerns, in addition to potential insect breeding, particularly mosquitos.

Erosion Concerns:

Concerns have been raised by McKenzie County regarding the potential for increased downstream erosion due to the box culvert design. AE2S recommends monitoring the site for erosion concerns; however, review of the constructed crossings did not identify a notably increased risk for erosion in the stream downstream of the crossings. Despite a lack of concern for the downstream channels, review of the rip rap aprons that were designed at each of the crossings suggests that the outfall armoring at the crossings is undersized relative to HEC-14 guidelines and may require improvement if erosion is observed.

Sediment Accumulation:

Sediment accumulation may occur over time within the culverts due to their placement below the stream flow line. Sediment accumulation within the culverts, referred to as embedment, is not inherently problematic and provides environmental benefits (CDFG, 2002; USACE, 2021; USFWS, 2022; Bates and Kern, 2022), specifically for fish, turtles, and other aquatic wildlife. Nevertheless, as sediment accumulates, conveyance is reduced, leading to increased headwater elevations which can increase inundation, road overtopping frequency, and risk of noncompliance with design standards. It should be noted, however, that sediment accumulation may be self-limiting due to high flow velocity through the culvert routinely providing a scouring effect. Sediment accumulation is unlikely to occur rapidly and can be monitored overtime and maintained, as needed.

Ice Accumulation:

Ice accumulation may occur within the closed basin surrounding the culverts, particularly in the region that lies below the stream flow line. Freeze-thaw cycles throughout the winter could conceivably lead to ice accumulations that could occasionally decrease crossing conveyance. The occurrence and magnitude of ice accumulation will vary and be dependent on several factors including, but not limited to, soil conditions, number of freeze-thaw cycles, snowfall, and rate of the spring melt. It should be noted that ice impacts are not a specific consideration in typical crossing designs, nor are they specified in McKenzie County's Design Standards or ND Stream Crossing Standards. Nevertheless, typical crossings are not constructed so notably below the stream flow line without embedment.

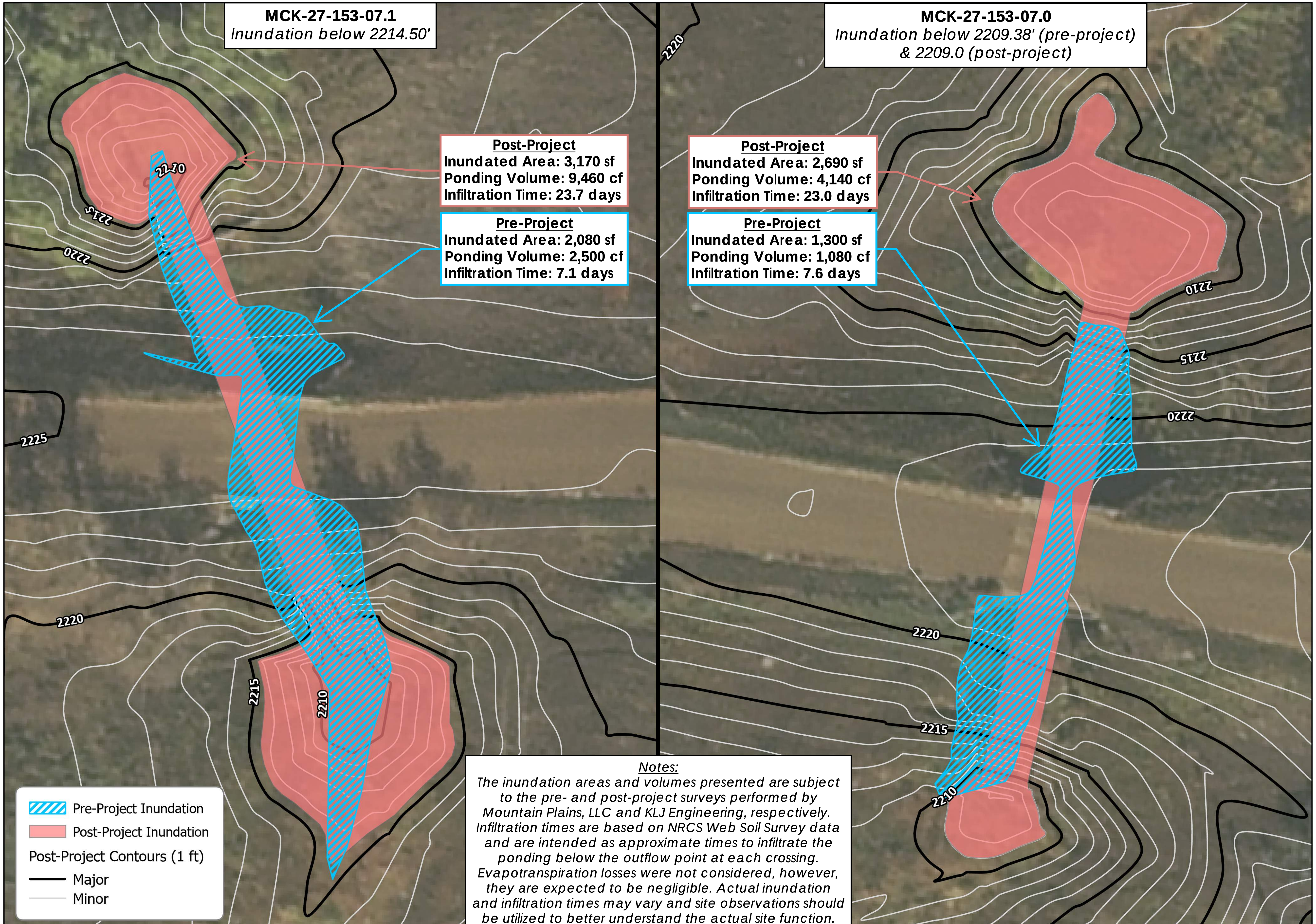
Increased Inundation:

Based on the analyses performed, the constructed crossings likely result in minor headwater increases compared to the pre-project conditions with additional increases as sedimentation occurs within the crossings or during periods of ice accumulation. An access road located north of 43rd Street NW and east of crossing 07.1 appears to be susceptible to inundation when headwater elevations at crossing 07.1 are above ~2,222' and a residence on the north side of 43rd Street, between the two crossings, appears to be susceptible to impacts when water surface elevations exceed about 2,223.5'. Increased inundation resulting at these crossings is likely to be of relatively short duration. Any changes made to the crossings that could increase inundation should first be coordinated with the impacted property owners.

Cattle Crossings:

The design plans by Mountain Plains, LLC indicate that crossings 07.0 and 07.1 were intended to function as cattle crossings. In addition to notes on the design plans indicating this, McKenzie County noted that adjacent landowners understood that the culverts would serve as cattle crossings. Due to the culverts being designed notably below the stream flow line, McKenzie County is concerned that the crossings will not adequately function as cattle crossings. The review performed for this study suggests that the crossings are subject to notable inundation depths during, and following, runoff events. This will likely lead to challenges for cattle attempting to traverse the box culverts as water depths may be a deterrent or even a hazard. Additionally, the potential for frequent inundation may lead to saturated ground conditions, causing rutting and damage to the soil and vegetation if cattle are frequenting the areas to use the culverts as cattle crossings or watering holes.

www.ae2s.com | Advanced Engineering and Environmental Services, LLC

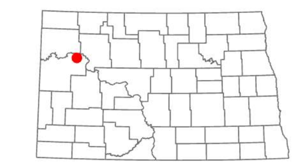


N

0 10 20

Feet

1 inch equals 20 feet



Locator Map Not to Scale

McKenzie County, ND

Figure 3

PRE- & POST-PROJECT INUNDATION

MCKENZIE COUNTY
BOX CULVERT REVIEW

Date: 1/5/2024

Information depicted may include data unverified by AE2S. Any reliance upon such data is at the user's own risk. AE2S does not warrant this map or its features are either spatially or temporally accurate.

Coordinate System: NAD 1983 StatePlane North Dakota North FIPS 3301 Feet Intl | Edited by: JKist | C:\Users\jkist\AE2S\McKenzie County - Box Culvert Review - Documents\04.0 Project Work\GIS\McKenzieCo_RCBs.aprx | Combined_Inundation

7.0 Review of Mitigation Options

The crossings in question were constructed in 2023. Nevertheless, resetting, replacing, or adding to the crossings remain options to correct the previously discussed issues; however, doing so would likely be expensive and require road closures, permits, and engineering. Resetting of the constructed culverts may be constrained by depth of cover, leading to challenges with eliminating nuisance ponding, and it would likely fail to provide the conveyance necessary to prevent a headwater increase from existing conditions. Culvert replacement could achieve design standards, eliminate nuisance ponding, and prevent a rise in upstream headwater elevation. Preliminary review suggests that double, or dual cell culverts would likely be needed to achieve the desired results. One conceptional scenario is a double culvert crossing, each with a rise of 8' and a span of 8-10', with 18-inches of embedment, generally matching the stream flow line. This replacement scenario could be achieved by resetting the existing culverts and constructing additional conveyance in parallel, but this remains an expensive option.

Due to the challenge and expense of resetting, replacing, or adding to the crossings, potential mitigation options were considered that do not involve resetting, replacing, or adding to the crossings. Three primary mitigation options were considered and are discussed in this section.

Mitigation Option 1 - Downstream Channel Grading:
The pre-project topographic survey data (McKenzie Bridges – East Original Topo.dwg) included survey downstream of each crossing about 150 feet. This data was used in conjunction with LiDAR data to assess the downstream channel profile. The topo data suggests that high points existed downstream of both crossings, more notably downstream of crossing 07.1, and that the removal of these high points could reduce ponding at the crossings. LiDAR data also identifies these same high points, however, data from LiDAR can be problematic in wet, heavily vegetated areas, such as streams. As such, the LiDAR was used as a supplement for trend review, but it should not be used as a substitute for survey in the stream. Actual stream elevations may vary by several feet from what is presented by LiDAR.

Review of as-built information by KLJ Engineering suggests that the pre-project high point of ~2,209.38' downstream of crossing 07.0 was likely removed as part of the grading that occurred with the crossing replacement project. Channel grading downstream of crossing 07.0 may be possible to reduce ponding, however, a stream profile survey is necessary to understand that potential.

The pre-project high point of ~2,214.5 downstream of crossing 07.1 appears to remain in the post-project conditions and may be able to be lowered to approximately 2,213' (see **Figure 4**). These estimates are based on the limited pre-project topographic survey by Mountain Plains, LLC. Prior to pursuing a grading project, a stream profile survey should be performed to better understand the stream profile and to ensure a grading project would provide desirable results.

Channel grading may impact regulatory wetlands and be subject to Section 404 permitting through the U.S. Army Corps of Engineers (USACE) which may subject a grading project to certain limitations. 404 permitting implications should be considered prior to and during a design project and the permit must be obtained prior to proceeding with construction.

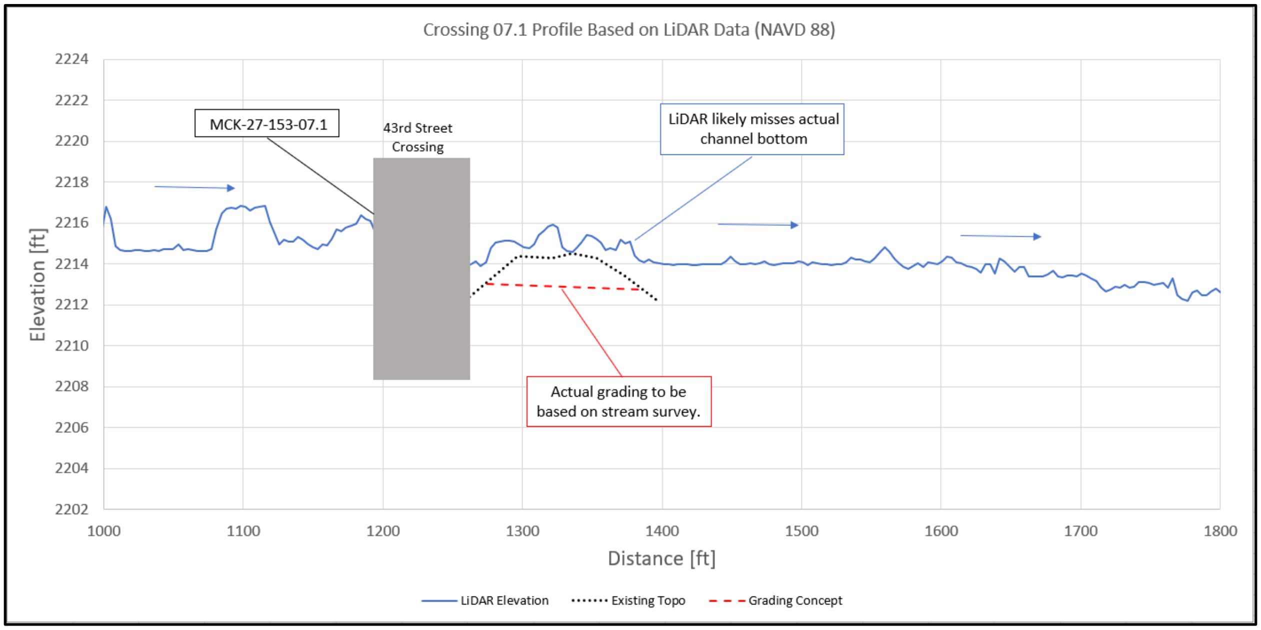


Figure 4 Crossing 07.1 Stream Profile and Grading Concept

Mitigation Option 2 - Culvert Embedding:
Intentional embedment of the crossings could reduce or eliminate nuisance ponding at the crossings. **Table 6** and **Table 7** present the approximate headwater elevations resulting from embedment alone and **Table 8** presents headwater elevations for crossing 07.1 resulting from various embedment depths in conjunction with the downstream channel grading discussed in Mitigation Option 1. A screenshot of the HY-8 model inputs used to develop **Table 8** are presented in **Attachment #4**. Embedment may result in impacts to jurisdictional wetlands and be subject to Section 404 permitting through the USACE.

***Table 8** – MCK-27-153-07.1 with Channel Grading & Embedment*

Event	Flow (cfs)	Pre-Project Headwater (ft)	Headwater (ft) with Downstream Grading & Variable Embedment[1, 2, 3]			
			0″ Embedment	18″ Embedment	36″ Embedment	45.6″ Embedment[4]
25-yr	512	2,218.47	2,217.89	2,219.01	2,220.54	2,221.34
50-yr	656	2,219.22	2,219.06	2,220.42	2,221.95	2,223.32
100-yr	806	2,219.98	2,220.29	2,221.80	*2,224.06*	*2,224.17*
500-yr	1,160	2,221.74	*2,223.58*	*2,224.99*	*2,225.94*	*2,226.40*
Design Standard Compliance?		✓	✓	✓	✓	✓

1. *Red shading indicates road overtopping.*
2. *Road overtopping: ~2,224.0′.*
3. *Modeled with downstream channel high point lowered from 2,214.50′ to 2,213′.*
4. *Represents full embedment with downstream channel lowered to 2,213′.*

Increased headwaters associated with embedment of the crossings would need to be considered and properly coordinated with impacted landowners. An access road located north of 43rd Street NW and east of crossing 07.1 is subject to inundation from headwater elevations exceeding an elevation of about 2,222′ and a residence north of 43rd Street, between the crossings, may be subject to impacts when water surface elevations exceed about 2,223.5′. These specific considerations, in addition to the overall impact of inundation on private property should be considered before any action is taken.

Mitigation Option 3 – Road Raising:
Embedment could cause noncompliance with McKenzie County design standards which are based on road overtopping frequency. Raising the road overtopping elevation could reduce the overtopping frequency, however, also increases headwater elevations. Raising the road elevation of 43rd Street is not a recommended mitigation option due to the potential to increase the upstream water surface elevation in high flow events, potentially increasing impacts to private property. Raising the road overtopping elevations may be acceptable but should be thoroughly vetted to ensure that headwater related impacts do not occur.

8.0 Summary & Recommendations

Two stream crossings on 43rd Street NW in McKenzie County were designed by Mountain Plains, LLC and constructed in 2023 with inverts notably lower than both the approximated stream flow line and the receiving downstream channel elevation. Review of the models developed by Mountain Plains, LLC found that their modeling didn't use the appropriate downstream (tailwater) channel elevations, didn't consider the potential for sediment/ice accumulation in the culverts, improperly modeled the inlet end sections as flared rather than straight, and used incorrect road overtopping elevations. Model updates to correct these errors were performed by AE2S and the crossings, as constructed, were found to comply with McKenzie County design standards unless significant sediment or ice accumulates in them. Despite this, the culverts as designed may lead to frequent ponding of water at the crossings which was identified by McKenzie County as undesirable and a potential nuisance to adjacent properties.

Resetting, replacing, or adding culverts to the constructed crossings are options, however, due to the likely expense and challenges associated with those options, an alternative approach is recommended below and summarized in **Figure 5** at the end of this section.

Recommended Approach:
Step #1: Monitor the crossings for nuisance ponding and ice accumulations following the monitoring and inspection plan below. An inspection log is provided in Appendix 1.

Monitoring & Inspection Plan:

- ***Who?***
  - Monitoring activities should be performed by McKenzie County staff. Assistance and insight could be provided by adjacent property owners, if deemed acceptable by McKenzie County.
- ***When?***
  - Inspections are recommended weekly during wet periods and biweekly during dry periods.
  - Inspections should be performed within 48 hours of rain events exceeding 2 inches in 24 hours.
- ***What?***
  - Observe and document water or ice levels at the time of inspection, including a photograph. This is likely best accomplished by installing a staff gage on a wingwall at each crossing to allow the depth to be read by staff from dry ground.
  - Inspect for culvert sediment accumulation when possible. If sediment is present, measure the average sediment depth.

- Inspect the upstream side for identifiable high-water marks and document and photograph findings. High-water marks may be distinguished by mud and debris lines or matting of vegetation.

- When ponding is low or nonexistent, the condition of vegetation surrounding the upstream and downstream culvert ends should be inspected and photographed. Vegetation damage, sediment accumulation, or other notable observations should be documented.

- Document observable nuisances, such as:
    - Odor from stagnant ponding water;
    - Notable insect presence, particularly mosquitos;
    - Water quality degradation (discoloration, algae, etc.); and
    - Other identified nuisances.

If the magnitude and duration of ponding water, ice accumulations, or other impacts are deemed unacceptable by McKenzie County, proceed with Steps #2-5.

Step #2: Obtain a stream survey of the channel thalweg between crossing 07.1 and 07.0 as well as ~350 feet downstream of crossing 07.0. Use the survey information to verify whether the outflow elevations at the crossings can be effectively lowered with localized channel grading.

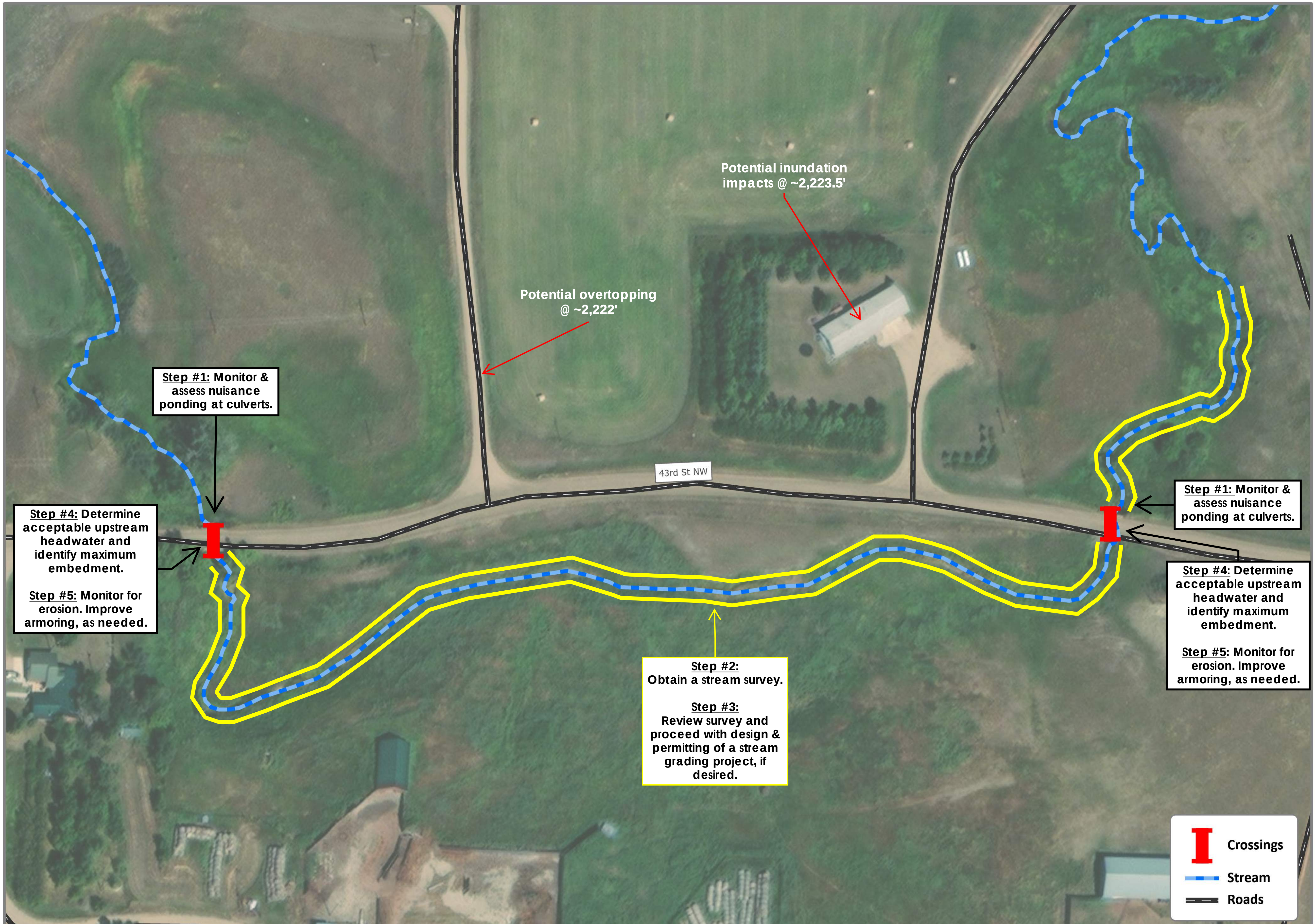
Step #3: If stream survey verifies that ponding reductions could be achieved at one or both crossings, update the hydraulic analysis accordingly, and proceed with design and permitting of channel grading improvements, if desired.

Step #4: Determine acceptable upstream headwater elevations and identify the maximum embedment depth that, in conjunction with the grading potential identified in Steps #2 & #3, can be implemented without exceeding the acceptable headwater elevations. If the grading potential identified in step 3 is similar to the assumptions discussed in Mitigation Option #1, **Table 8** may be referenced to identify acceptable embedment depths.

a. Embedment material should be sized based on review of culvert velocities under the corresponding embedment scenario to prevent resuspension and scouring of the embedment material.

Step #5: If modifications are constructed, or if erosion occurs downstream of crossings, install rip rap armoring downstream of each crossing based on HEC-14 criteria to reduce risk of erosion at the pipe outfalls.

www.ae2s.com | Advanced Engineering and Environmental Services, LLC



N

0 50 100
Feet

1 inch equals 100 feet

Locator Map Not to Scale

McKenzie County, ND

Figure 5
RECOMMENDATION OVERVIEW

MCKENZIE COUNTY
BOX CULVERT REVIEW

Date: 1/5/2024

Information depicted may include data unverified by AE2S. Any reliance upon such data is at the user's own risk. AE2S does not warrant this map or its features are either spatially or temporally accurate.
Coordinate System: NAD 1983 StatePlane North Dakota North FIPS 3301 Feet | Edited by: JKist | C:\Users\jkist\AE2S\McKenzie County - Box Culvert Review - Documents\04.0 Project Work\GIS\McKenzieCo_RCBs.aprx | Rec_Figure

9.0 Data

Various data sources were used for the development of this memorandum and the corresponding analyses. Key data sources used are described below. Elevations referenced throughout this memorandum are in NAVD88 datum. It should be noted that many of the documents below, including the plans and analysis by Mountain Plains, LLC and the survey information provided by KLJ Engineering do not state a vertical datum; however, certain elevation data presented in those documents was compared to the LiDAR surface, which is known to be in NAVD88, and it was determined that those documents appear to be in NAVD88.

- Plans (dated 9/14/2022) & Addendum (dated 10/27/2022) by Mountain Plains, LLC
- Hydraulic reports by Mountain Plains, LLC (dated May 7, 2021)
- HY-8 models by Mountain Plains, LLC
- Existing conditions survey files (McKenzie Bridges – East Original Topo.dwg)
- As-built information by KLJ Engineering
- Site photographs provided by McKenzie County
- NRCS Web Soil Survey
- USGS Stream Stats
- LiDAR from NDDWR MapService

10.0 References

1. Bates, Kozmo Ken and Rich Kern. 2022. Guidelines for the Design of Stream/Road Crossings for Passage of Aquatic Organisms in Vermont. *Vermont Fish and Wildlife.*

2. United States Fish and Wildlife Service (USFWS). 2022. Culvert Design Guidelines for Ecological Function. *USFWS.*

APPENDICES

Appendix 1: Box Culvert Inspection Log

Date: **Inspector:** ***Inspector Notes:***	☐ Water Depth: _______ ☐ Ice Depth: _________	☐ Culvert Sediment Depth: ________ ☐ Site Photos Taken?	Vegetation at Culvert Ends: ☐ Good ☐ Okay ☐ Poor/Dead ☐ Other?	Nuisances: ☐ Odor ☐ Insects ☐ Poor Water Quality ☐ Other?
Date: **Inspector:** ***Inspector Notes:***	☐ Water Depth: _______ ☐ Ice Depth: _________	☐ Culvert Sediment Depth: ________ ☐ Site Photos Taken?	Vegetation at Culvert Ends: ☐ Good ☐ Okay ☐ Poor/Dead ☐ Other?	Nuisances: ☐ Odor ☐ Insects ☐ Poor Water Quality ☐ Other?
Date: **Inspector:** ***Inspector Notes:***	☐ Water Depth: _______ ☐ Ice Depth: _________	☐ Culvert Sediment Depth: ________ ☐ Site Photos Taken?	Vegetation at Culvert Ends: ☐ Good ☐ Okay ☐ Poor/Dead ☐ Other?	Nuisances: ☐ Odor ☐ Insects ☐ Poor Water Quality ☐ Other?
Date: **Inspector:** ***Inspector Notes:***	☐ Water Depth: _______ ☐ Ice Depth: _________	☐ Culvert Sediment Depth: ________ ☐ Site Photos Taken?	Vegetation at Culvert Ends: ☐ Good ☐ Okay ☐ Poor/Dead ☐ Other?	Nuisances: ☐ Odor ☐ Insects ☐ Poor Water Quality ☐ Other?
Date: **Inspector:** ***Inspector Notes:***	☐ Water Depth: _______ ☐ Ice Depth: _________	☐ Culvert Sediment Depth: ________ ☐ Site Photos Taken?	Vegetation at Culvert Ends: ☐ Good ☐ Okay ☐ Poor/Dead ☐ Other?	Nuisances: ☐ Odor ☐ Insects ☐ Poor Water Quality ☐ Other?

ATTACHMENTS

Attachment #1: HY-8 Inputs for AE2S Pre-Project Bridge Review

Crossing Properties

Name: 53-07.0 (Pre-Project Bridge)

Parameter	Value	Units
DISCHARGE DATA		
Discharge Method	Minimum, Design, and Maximum	
Minimum Flow	663.000	cfs
Design Flow	815.000	cfs
Maximum Flow	1170.000	cfs
TAILWATER DATA		
Channel Type	Trapezoidal Channel	
Bottom Width	12.000	ft
Side Slope (H:V)	4.000	_:1
Channel Slope	0.0080	ft/ft
Manning's n (channel)	0.030	
Channel Invert Elevation	2209.380	ft
Rating Curve	View...	
ROADWAY DATA		
Roadway Profile Shape	Constant Roadway Elevation	
First Roadway Station	0.000	ft
Crest Length	20.000	ft
Crest Elevation	2220.000	ft
Roadway Surface	Gravel	
Top Width	22.000	ft

Culvert Properties

07.0 Pre-Project Bridge

Add Culvert

Duplicate Culvert

Delete Culvert

Parameter	Value	Units
CULVERT DATA		
Name	07.0 Pre-Project Bridge	
Shape	Concrete Box	
Material	Concrete	
Span	20.000	ft
Rise	13.000	ft
Embedment Depth	12.000	in
Manning's n (Top/Sides)	0.012	
Manning's n (Bottom)	0.030	
Culvert Type	Straight	
Inlet Configuration	Square Edge (30-75º flare) Wingwall (Ke=0.4)	
Inlet Depression?	No	
SITE DATA		
Site Data Input Option	Culvert Invert Data	
Inlet Station	0.000	ft
Inlet Elevation	2207.000	ft
Outlet Station	22.000	ft
Outlet Elevation	2207.000	ft
Number of Barrels	1	
Computed Culvert Slope	0.000000	ft/ft

Crossing Properties

Name: 53-07.1 (Pre-Existing Bridge)

Parameter	Value	Units
DISCHARGE DATA		
Discharge Method	Minimum, Design, and Maximum	
Minimum Flow	656.000	cfs
Design Flow	806.000	cfs
Maximum Flow	1160.000	cfs
TAILWATER DATA		
Channel Type	Trapezoidal Channel	
Bottom Width	12.000	ft
Side Slope (H:V)	4.000	_:1
Channel Slope	0.0070	ft/ft
Manning's n (channel)	0.030	
Channel Invert Elevation	2214.500	ft
Rating Curve	View...	
ROADWAY DATA		
Roadway Profile Shape	Constant Roadway Elevation	
First Roadway Station	0.000	ft
Crest Length	30.000	ft
Crest Elevation	2223.400	ft
Roadway Surface	Gravel	
Top Width	18.000	ft

Culvert Properties

07.1 Pre-Project Bridge

Add Culvert

Duplicate Culvert

Delete Culvert

Parameter	Value	Units
CULVERT DATA		
Name	07.1 Pre-Project Bridge	
Shape	Concrete Box	
Material	Concrete	
Span	15.000	ft
Rise	12.500	ft
Embedment Depth	12.000	in
Manning's n (Top/Sides)	0.012	
Manning's n (Bottom)	0.030	
Culvert Type	Straight	
Inlet Configuration	Square Edge (30-75º flare) Wingwall (Ke=0.4)	
Inlet Depression?	No	
SITE DATA		
Site Data Input Option	Culvert Invert Data	
Inlet Station	0.000	ft
Inlet Elevation	2211.000	ft
Outlet Station	21.000	ft
Outlet Elevation	2211.000	ft
Number of Barrels	1	
Computed Culvert Slope	0.000000	ft/ft

Attachment #2: HY-8 Inputs from Mountain Plains Models

Crossing Properties

Name: MCK-27-153-07.0

Parameter	Value	Units
DISCHARGE DATA		
Discharge Method	Minimum, Design, and Maximum	
Minimum Flow	75.600	cfs
Design Flow	663.000	cfs
Maximum Flow	1170.000	cfs
TAILWATER DATA		
Channel Type	Trapezoidal Channel	
Bottom Width	12.000	ft
Side Slope (H:V)	4.000	_:1
Channel Slope	0.0080	ft/ft
Manning's n (channel)	0.030	
Channel Invert Elevation	2208.000	ft
Rating Curve	View...	
ROADWAY DATA		
Roadway Profile Shape	Constant Roadway Elevation	
First Roadway Station	1537.000	ft
Crest Length	-1507.000	ft
Crest Elevation	2222.100	ft
Roadway Surface	Gravel	
Top Width	22.000	ft

Culvert Properties

Culvert 1

Add Culvert | Duplicate Culvert | Delete Culvert

Parameter	Value	Units
CULVERT DATA		
Name	Culvert 1	
Shape	Concrete Box	
Material	Concrete	
Span	10.000	ft
Rise	10.000	ft
Embedment Depth	0.000	in
Manning's n	0.012	
Culvert Type	Straight	
Inlet Configuration	Square Edge (30-75º flare) Wingwall (Ke=0.4)	
Inlet Depression?	No	
SITE DATA		
Site Data Input Option	Culvert Invert Data	
Inlet Station	0.000	ft
Inlet Elevation	2207.016	ft
Outlet Station	76.000	ft
Outlet Elevation	2206.484	ft
Number of Barrels	1	
Computed Culvert Slope	0.007000	ft/ft

Crossing Properties

Name: MCK-27-153-07.1

Parameter	Value	Units
DISCHARGE DATA		
Discharge Method	Minimum, Design, and Maximum	
Minimum Flow	74.400	cfs
Design Flow	656.000	cfs
Maximum Flow	1160.000	cfs
TAILWATER DATA		
Channel Type	Trapezoidal Channel	
Bottom Width	12.000	ft
Side Slope (H:V)	4.000	_:1
Channel Slope	0.0070	ft/ft
Manning's n (channel)	0.030	
Channel Invert Elevation	2210.500	ft
Rating Curve	View...	
ROADWAY DATA		
Roadway Profile Shape	Constant Roadway Elevation	
First Roadway Station	575.000	ft
Crest Length	-545.000	ft
Crest Elevation	2224.500	ft
Roadway Surface	Gravel	
Top Width	22.000	ft

Culvert Properties

Culvert 1

Add Culvert | Duplicate Culvert | Delete Culvert

Parameter	Value	Units
CULVERT DATA		
Name	Culvert 1	
Shape	Concrete Box	
Material	Concrete	
Span	10.000	ft
Rise	10.000	ft
Embedment Depth	0.000	in
Manning's n	0.012	
Culvert Type	Straight	
Inlet Configuration	Square Edge (30-75º flare) Wingwall (Ke=0.4)	
Inlet Depression?	No	
SITE DATA		
Site Data Input Option	Culvert Invert Data	
Inlet Station	0.000	ft
Inlet Elevation	2209.746	ft
Outlet Station	76.000	ft
Outlet Elevation	2209.214	ft
Number of Barrels	1	
Computed Culvert Slope	0.007000	ft/ft

Attachment #3: HY-8 Inputs for AE2S Model Updates

Crossing Properties

Name: -27-153-07.0 (AE2S Update)

Parameter	Value	Units
DISCHARGE DATA		
Discharge Method	Minimum, Design, and Maximum	
Minimum Flow	663.000	cfs
Design Flow	815.000	cfs
Maximum Flow	1170.000	cfs
TAILWATER DATA		
Channel Type	Trapezoidal Channel	
Bottom Width	12.000	ft
Side Slope (H:V)	4.000	_:1
Channel Slope	0.0080	ft/ft
Manning's n (channel)	0.030	
Channel Invert Elevation	2209.000	ft
Rating Curve	View...	
ROADWAY DATA		
Roadway Profile Shape	Constant Roadway Elevation	
First Roadway Station	0.000	ft
Crest Length	30.000	ft
Crest Elevation	2220.100	ft
Roadway Surface	Gravel	
Top Width	22.000	ft

Culvert Properties

07.0 AE2S Updated Model (R

Add Culvert

Duplicate Culvert

Delete Culvert

Parameter	Value	Units
CULVERT DATA		
Name	07.0 AE2S Updated Model (Review Embedment)	
Shape	Concrete Box	
Material	Concrete	
Span	10.000	ft
Rise	10.000	ft
Embedment Depth	24.000 ← Varies	in
Manning's n (Top/Sides)	0.012	
Manning's n (Bottom)	0.030	
Culvert Type	Straight	
Inlet Configuration	Square Edge (0º flare) Wingwall (Ke=0.7)	
Inlet Depression?	No	
SITE DATA		
Site Data Input Option	Culvert Invert Data	
Inlet Station	0.000	ft
Inlet Elevation	2207.016	ft
Outlet Station	76.000	ft
Outlet Elevation	2206.484	ft
Number of Barrels	1	
Computed Culvert Slope	0.007000	ft/ft

Crossing Properties

Name: -27-153-07.1 (AE2S Update)

Parameter	Value	Units
DISCHARGE DATA		
Discharge Method	Minimum, Design, and Maximum	
Minimum Flow	656.000	cfs
Design Flow	806.000	cfs
Maximum Flow	1160.000	cfs
TAILWATER DATA		
Channel Type	Trapezoidal Channel	
Bottom Width	12.000	ft
Side Slope (H:V)	4.000	_:1
Channel Slope	0.0070	ft/ft
Manning's n (channel)	0.030	
Channel Invert Elevation	2214.500	ft
Rating Curve	View...	
ROADWAY DATA		
Roadway Profile Shape	Constant Roadway Elevation	
First Roadway Station	0.000	ft
Crest Length	30.000	ft
Crest Elevation	2224.000	ft
Roadway Surface	Gravel	
Top Width	22.000	ft

Culvert Properties

07.1 AE2S Updated Model (R

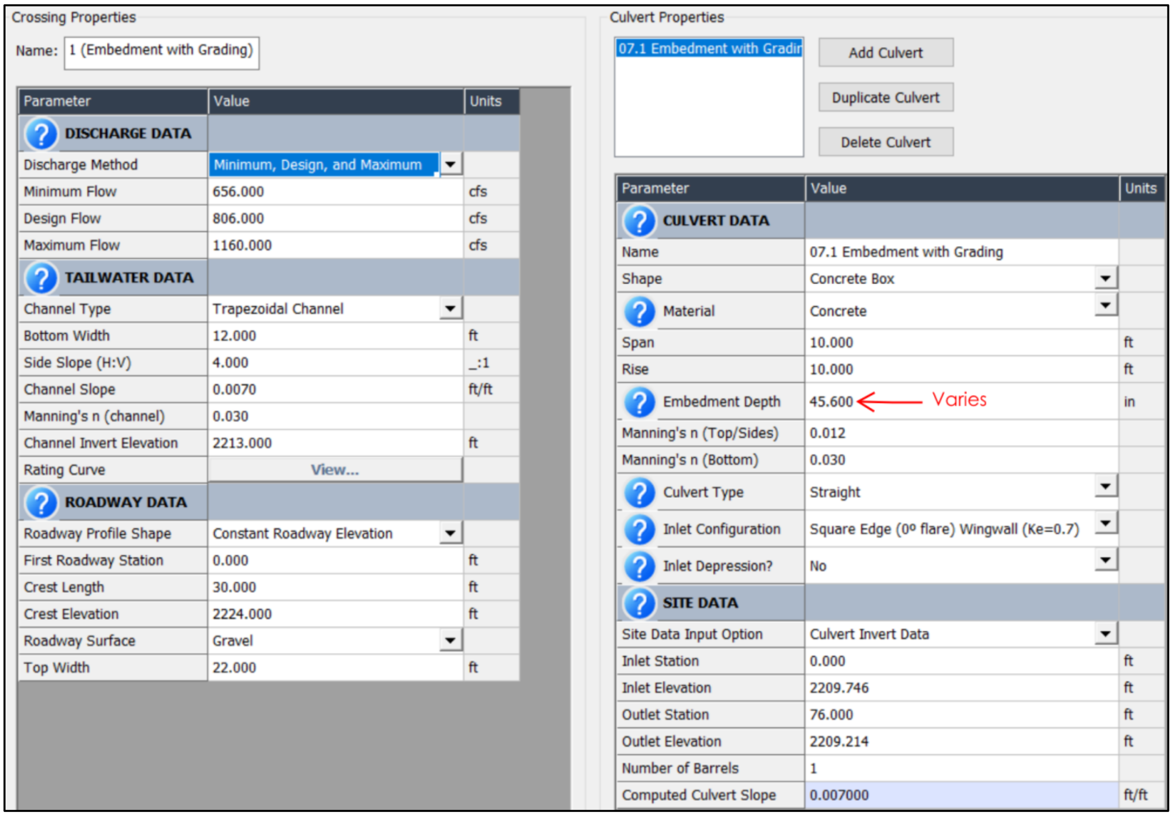
Add Culvert

Duplicate Culvert

Delete Culvert

Parameter	Value	Units
CULVERT DATA		
Name	07.1 AE2S Updated Model (Review Embedment)	
Shape	Concrete Box	
Material	Concrete	
Span	10.000	ft
Rise	10.000	ft
Embedment Depth	24.000 ← Varies	in
Manning's n (Top/Sides)	0.012	
Manning's n (Bottom)	0.030	
Culvert Type	Straight	
Inlet Configuration	Square Edge (0º flare) Wingwall (Ke=0.7)	
Inlet Depression?	No	
SITE DATA		
Site Data Input Option	Culvert Invert Data	
Inlet Station	0.000	ft
Inlet Elevation	2209.746	ft
Outlet Station	76.000	ft
Outlet Elevation	2209.214	ft
Number of Barrels	1	
Computed Culvert Slope	0.007000	ft/ft

Attachment #4: HY-8 Inputs for AE2S Model Updates with 07.1 Grading Concept



Crossing Properties

Name: 1 (Embedment with Grading)

Parameter	Value	Units
DISCHARGE DATA		
Discharge Method	Minimum, Design, and Maximum	
Minimum Flow	656.000	cfs
Design Flow	806.000	cfs
Maximum Flow	1160.000	cfs
TAILWATER DATA		
Channel Type	Trapezoidal Channel	
Bottom Width	12.000	ft
Side Slope (H:V)	4.000	_:1
Channel Slope	0.0070	ft/ft
Manning's n (channel)	0.030	
Channel Invert Elevation	2213.000	ft
Rating Curve	View...	
ROADWAY DATA		
Roadway Profile Shape	Constant Roadway Elevation	
First Roadway Station	0.000	ft
Crest Length	30.000	ft
Crest Elevation	2224.000	ft
Roadway Surface	Gravel	
Top Width	22.000	ft

Culvert Properties

07.1 Embedment with Gradir

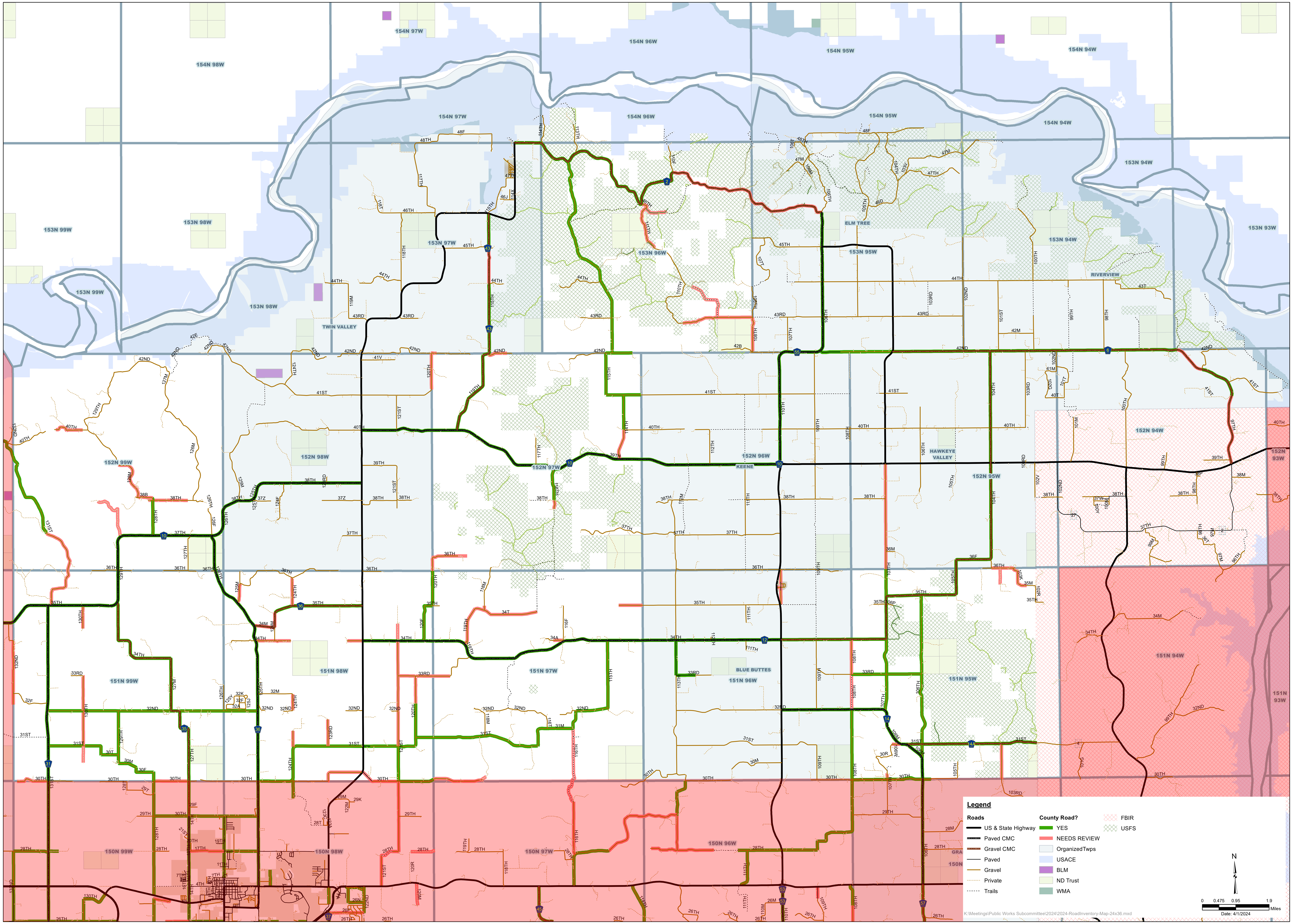
Add Culvert

Duplicate Culvert

Delete Culvert

Parameter	Value	Units
CULVERT DATA		
Name	07.1 Embedment with Grading	
Shape	Concrete Box	
Material	Concrete	
Span	10.000	ft
Rise	10.000	ft
Embedment Depth	45.600 ← Varies	in
Manning's n (Top/Sides)	0.012	
Manning's n (Bottom)	0.030	
Culvert Type	Straight	
Inlet Configuration	Square Edge (0º flare) Wingwall (Ke=0.7)	
Inlet Depression?	No	
SITE DATA		
Site Data Input Option	Culvert Invert Data	
Inlet Station	0.000	ft
Inlet Elevation	2209.746	ft
Outlet Station	76.000	ft
Outlet Elevation	2209.214	ft
Number of Barrels	1	
Computed Culvert Slope	0.007000	ft/ft

Item 3



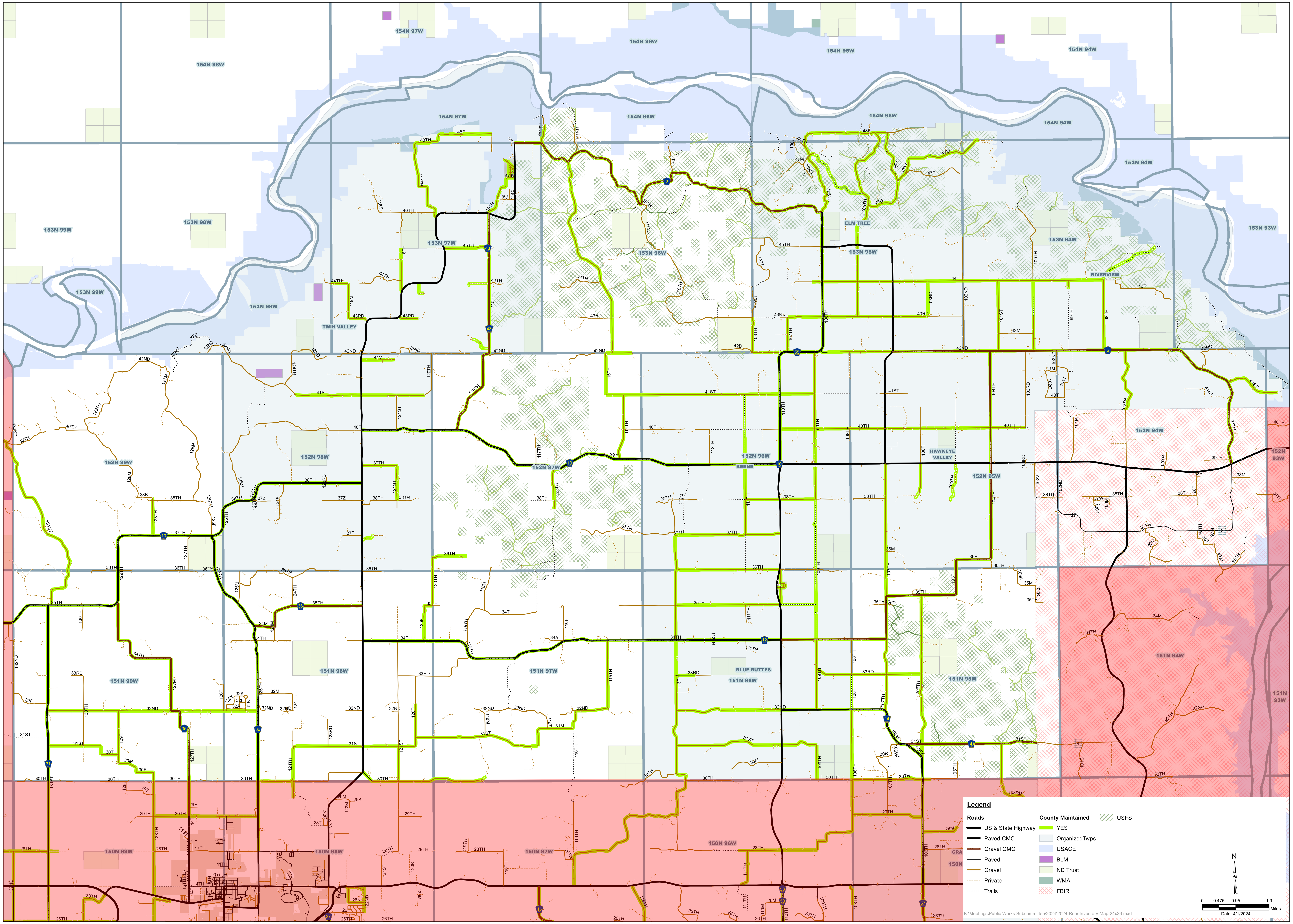
FOR INFORMATIONAL PURPOSES ONLY

MCKENZIE COUNTY

Road and Bridge Department

WHAT ARE COUNTY ROADS
COUNTY ROADS?
PAGE 7A

McKENZIE COUNTY
EST. 1905
STATE OF NORTH DAKOTA



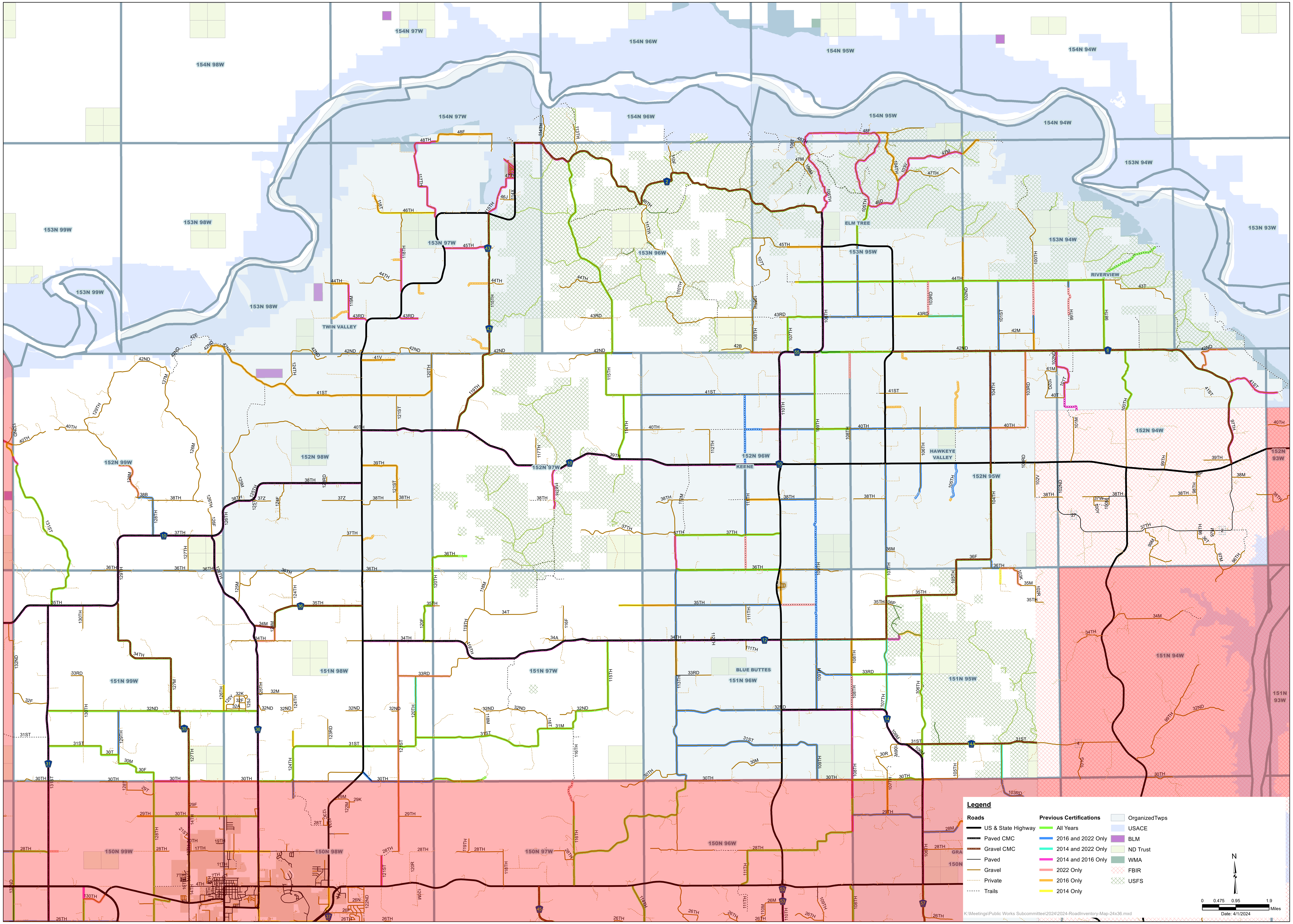
FOR INFORMATIONAL PURPOSES ONLY

MCKENZIE COUNTY

Road and Bridge Department

WHAT ARE COUNTY ROADS
COUNTY MAINTAINED
PAGE 7B

McKENZIE COUNTY
EST. 1905
STATE OF NORTH DAKOTA



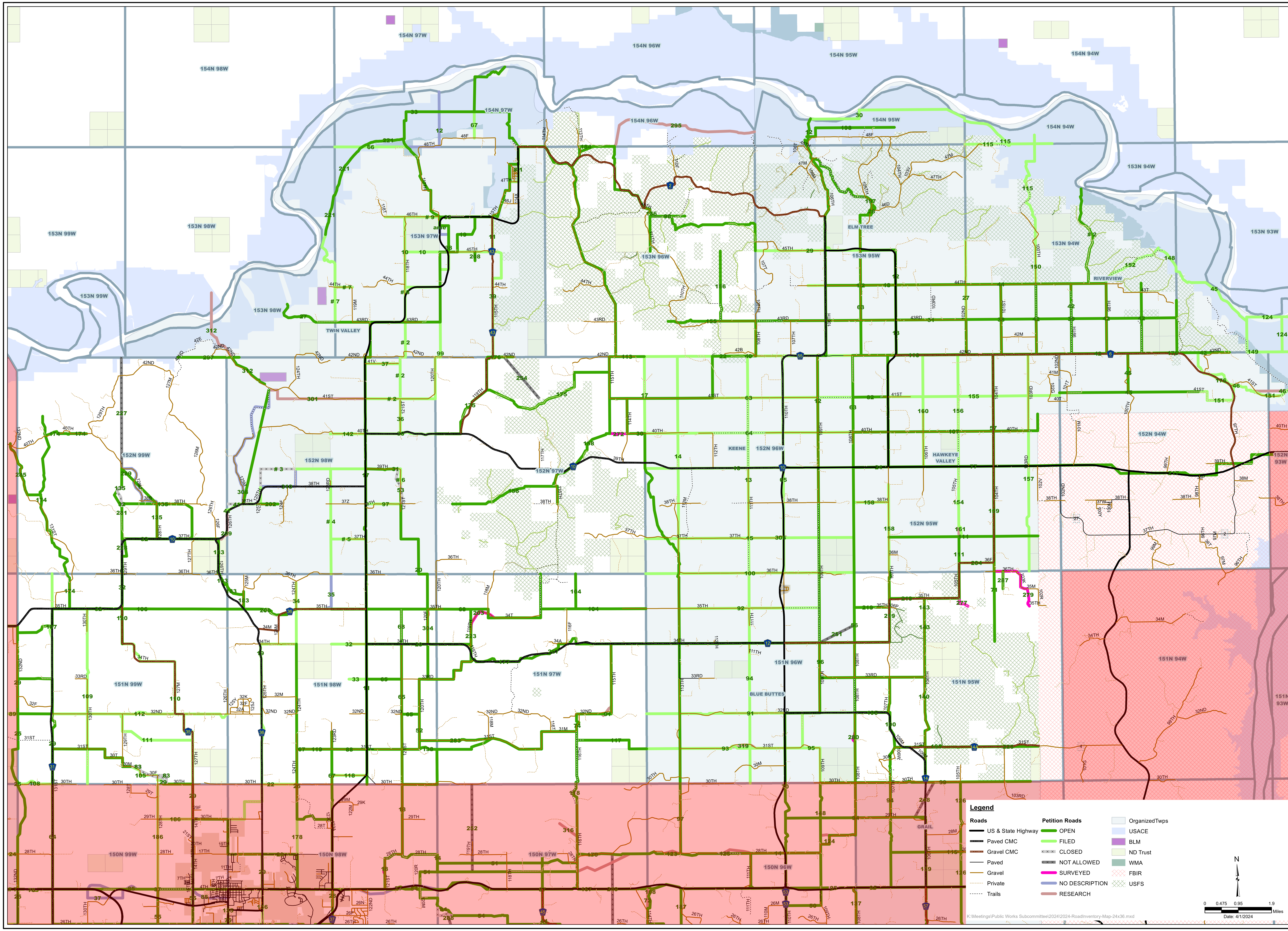
FOR INFORMATIONAL PURPOSES ONLY

MCKENZIE COUNTY

Road and Bridge Department

WHAT ARE COUNTY ROADS
PREVIOUS CERTIFICATIONS
PAGE 7C

McKENZIE COUNTY
EST. 1905
STATE OF NORTH DAKOTA



FOR INFORMATIONAL PURPOSES ONLY

MCKENZIE COUNTY
Road and Bridge Department

WHAT ARE COUNTY ROADS
ROADS FROM ROAD BOOKS
PAGE 7D