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Memorandum

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To: David Ammerman, PE (Gulf Interstate)

From: David Vance, PG[1]; Jeremy Yeglin, PE[2]; and Robert Dunn

Cc: Al Preston, PhD, PE[3]; Brandon Klenzendorf, PhD, PE[4]; Muhammed Mustafa, PhD, PE[3]; and Morgan L'Hoste (EIT); Jai Panthail

Subject: Hydrotechnical Assessment (Missouri River HDD Crossing)
Geosyntec Project No. TXG0320

INTRODUCTION

The following is a summary of the hydrotechnical assessment for Gulf Interstate Engineering, Inc's (Gulf Interstate) proposed Missouri River horizontal directional drilling (HDD) crossing, which is part of the 2,000-mile pipeline system being installed by Summit Carbon Solutions in North Dakota. The crossing is located at milepost (MP) 11.5 in Morton and Burleigh Counties, North Dakota. Geosyntec completed this hydrotechnical assessment to evaluate the lateral setbacks and riverine scour and define the lateral and depth hazards the river possesses at the proposed crossing. The methods, calculations, results, and recommendations of this assessment are described herein.

DATA SOURCES REVIEWED

The following data sources have been reviewed as part of the hydrotechnical assessment as of the date of this memorandum:

- 2016 1-meter (m) resolution LiDAR from the state of North Dakota's LiDAR database; collected by the U.S. Army Corps of Engineers (St. Louis District).

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[1] Licensed in GA
[2] Licensed in ND, TX, and OK
[3] Licensed in CA
[4] Licensed in TX and LA

- Bathymetric survey data collected by TRC Companies (TRC).
- Available Google Earth™ aerial imagery, generally spanning the timeline from September 1997 to September 2021.
- United States Geologic Survey (USGS) 7.5 minute topographic quadrangle maps for the segment.
- USGS StreamStats: Streamflow Statistics and Spatial Analysis Tools for Water-Resources Applications (https://streamstats.usgs.gov/ss/).
- Federal Emergency Management Agency (FEMA) *Burleigh County, North Dakota and Incorporated Areas Flood Insurance Study dated August 4, 2014.*

METHODS

Geosyntec conducted a scour analysis and lateral migration assessment of the Missouri River crossing. The methodology for the scour analysis and lateral migration assessment is described below.

Scour Analysis

The scour analysis consisted of evaluating appropriate burial depth based on the depth of anticipated total (vertical) scour at the Missouri River crossing location. Scour calculations required hydraulic analyses for each crossing. The methodology and results of the hydraulic and scour analyses are summarized below.

- Longitudinal peak flows associated with the 100-year return period were taken from the *FEMA Burleigh County, North Dakota and Incorporated Areas Flood Insurance Study* dated August 4, 2014. The 100-year peak flow used for the hydraulic modeling was 94,000 cubic feet per second (cfs).
- Site-specific cross sections of the active channel were cut upstream, downstream, and at the cross location from a mosaic digital elevation model (DEM) of the North Dakota LiDAR and the TRC bathymetric survey data.
- Longitudinal slope of 0.30% was measured from the TRC bathymetry data.
- Median grain size (D_{50}) of the stream bed was estimated to be 1 millimeter (mm), which is representative of a coarse/very coarse sand bed dominated system.
- Manning's n-value was estimated to be 0.035, which is a conservative estimate for large rivers.

Hydraulic analysis was performed using the Hydrologic Engineering Center River Analysis System (HEC-RAS) software program to calculate hydraulic parameters (e.g., flow depth, width, velocity, and effective shear stress) for the peak flows derived from the hydrologic analysis. The flow profiles modeled include peak discharges associated with the 100-year return period. The one-dimensional (1-D) HEC-RAS models were populated with channel geometry parameters (i.e., longitudinal slope and cross section), and Manning's roughness described above. The HEC-RAS models are representative of normal flow depth calculations at each stream crossing and contain three cross sections (upstream, at crossing, and downstream). The cross section geometry is based on the LiDAR and bathymetry data and is representative for the crossing. Normal depth boundary conditions were assigned to the downstream cross section and were set to the longitudinal slope.

Total scour (z_{ts}) is the total depth of scour at a given location. It is applied to the thalweg of the channel and is the sum of all scour components that are applicable for the given location. Scour components considered include the following, which are described in the subsequent sections:

- Long-Term Degradation (z_{lt})
- General Scour (z_{gs})
- Bend Scour (z_{bs})
- Local Scour (z_{ls})
- Contraction Scour (z_{cs})
- Bedform Scour (z_{bfs})

Note these components of scour were included where applicable. For the Missouri River, bedform scour was not considered applicable and therefore not included in total scour. The scour components were calculated using applicable scour equations. If multiple scour equations were considered applicable for a component of scour, results were averaged. The average scour value for each component was then summed to generate total scour (z_{ts}) depth. The components of scour are described below.

Long Term Degradation ($\mathbf{z_{lt}}$)

Long-Term degradation (z_{lt}) is the progressive lowering of the channel bed due to scour. This permanent or continuing degradation is an indicator that a change in the stream's discharge and sediment load characteristics is taking place. Degradation of the stream bed occurs due to downstream bed elevation changes or excess sediment-transporting capacity relative to the size of bed-material (e.g., resistance to movement) and quantity of bed-material sediment delivered from upstream reaches. Degradation continues until the existing longitudinal slope of the channel decreases to an equilibrium (stable) slope or until an armor layer (i.e., comprised of gravel and/or cobble-sized particles) that mitigates long term degradation develops on the stream bed.

Typically, long-term degradation scour is calculated by multiplying the channel distance to the nearest downstream grade control point (e.g., exposed bedrock or manmade drop structure) by the difference in the existing and equilibrium longitudinal slopes. This estimation requires understanding the distance to a grade level control, a process that requires individual assessment at each stream with access to extended portions of the stream upstream and downstream of the pipeline crossing. For this assessment, data is not readily available. Instead, Geosyntec estimated degradation associated with observed natural geomorphic processes associated with natural degradation described below. Long-term degradation was conservatively estimated to be 2 feet.

General Scour (z_{gs})

General scour is the lowering of the stream bed across the channel over relatively short time periods and is associated with the passing of a single flood. The Lacey Regime Equation (ASCE 2005), Zeller equation (USACE, 2021), U.S. Bureau of Reclamation (USBR) Envelope Curve (USACE, 2021), and the Neill competent velocity equation was used to calculate general scour for this study. The average value of all four equations was used to estimate general scour depth. Calculated general scour (averaged from applicable equations) was 4.8 feet.

Bend Scour (z_{bs})

Bend scour is associated with meandering channels that can induce transverse or secondary currents. It is the scour associated with the outside of a bend. The US Bureau of Reclamation equation for gravel bed rivers (USBR, 2019), which summarizes the charts for scour prediction contained in Plate B41 of Engineer Manual 1110-2-1601 (USACE, 1994), was used to calculate bend scour for this study. The Thorne (Thorne, 1988), Maynord (Maynord, 1996), and Zeller (USACE, 2021) equations were also calculated and considered in this study. The average value of all four equations was used to estimate general scour depth. Calculated bend scour (averaged from applicable equations) was 9.8 feet.

Local Scour (z_{ls})

Local scour is the scour that results from an obstruction and abrupt change in the direction of flow. It is caused by an acceleration of flow and resulting vortices induced by the obstruction. The component of local scour considered in this analysis is large woody debris (LWD). Local scour from LWD was applied for each stream crossing to consider the potential for accumulation of LWD at or near the crossing that could lead to scour and pipeline exposure.

Large woody debris was considered as part of this analysis due to the prevalence of forested land cover throughout the pipeline alignment and in vicinity of the crossings and its associated watersheds. An equation for pier scour, based on Hydrologic Engineering Circular No. 18 (FHWA, 2012), was used as a basis for estimating scour associated with in-stream LWD. Calculated local scour from LWD was 3.1 feet.

Contraction Scour (z_{cs})

Contraction scour is the scour that results when the flow area of a stream is reduced by a natural contraction or a bridge constricting the flow. An equation for contraction scour, based on Hydrologic Engineering Circular No. 18 (FHWA, 2012), was used as a basis for estimating contraction scour. Calculated contraction scour was 0.2 feet.

Total Scour **(z_{ts})**

Geosyntec calculated total scour depth by averaging the average scour value for each component. Total scour results are presented in **Table 1** below.

Table 1. Summary of Calculated Scour Components and Total Scour

Scour Component	Calculated Scour Depth (ft)
Long-term Scour	2.0
General scour	4.8
Bend Scour	9.8
Local Scour	3.1
Contraction Scour	0.2
Bedform Scour	0.0
Total Scour	**19.9**

Lateral Migration Analysis

Geosyntec completed a lateral migration analysis of the crossing to assess potential lateral migration hazards relative to the proposed lateral setback locations. Using aerial recent and historical imagery, Geosyntec observed less than 15 feet of lateral bank migration on both the east and west banks of the Missouri River over the observation period of aerial imagery (**Figure 1**). Further, Geosyntec observed minimal potential for channel avulsion on the east or west bank floodplains due to the presence of high terraces. It should be noted that the east bank, located on the inside bend, is depositional in nature and features a floodplain approximately 900+ feet wide before reaching a high terrace. The west bank is characterized by the presence of previously installed river training structures adjacent to the high terrace. These structures are presently providing lateral stability along the west bank. It was beyond Geosyntec's scope to identify who installed these structures and who is responsible for maintenance. It should be noted that these structures need to be maintained to continue to provide bank stability and protection.

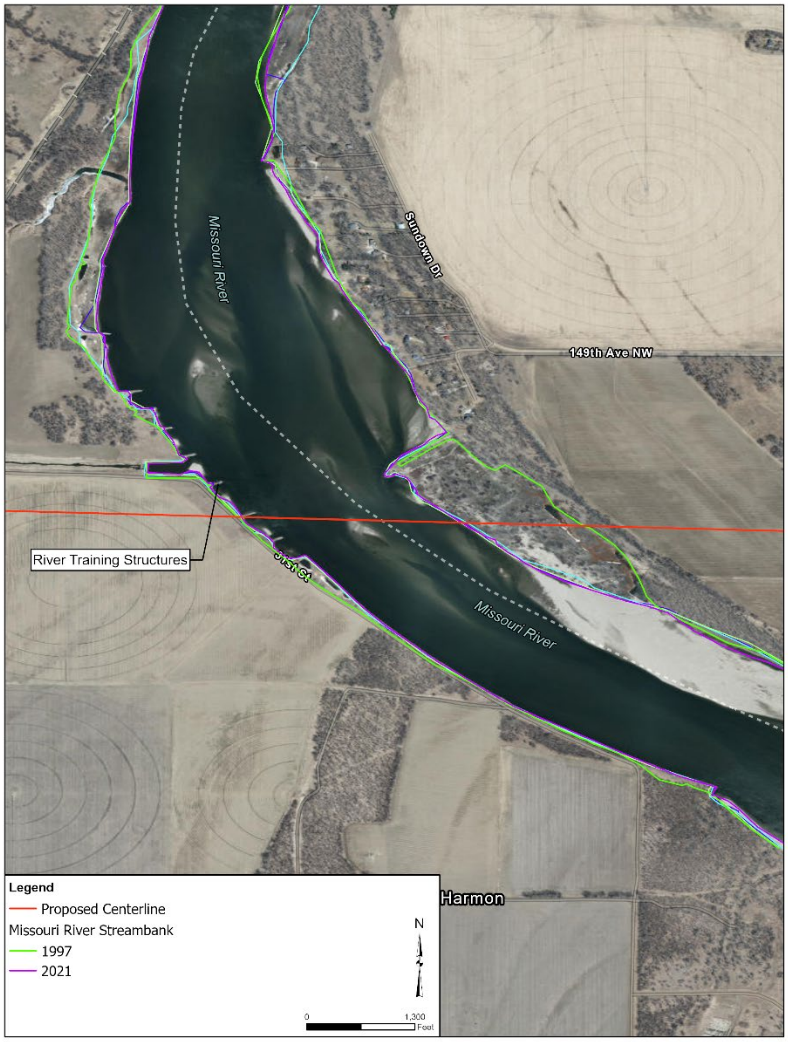

Figure 1. Missouri River Lateral Historic Streambank Delineation

RECOMMENDATIONS

Total scour depth was calculated to be 19.9’. Based on the current bathymetric data (supplied by TRC), the channel bottom elevation is 1,605.82’ NAVD88 and the proposed HDD burial elevation is 1,584.79’ NAVD88. A scour depth of 19.9’ below the existing bed would result in only 1.13 ft of cover over the proposed HDD burial elevation. Given the estimated minimal amount of cover at the proposed HDD elevation, Geosyntec recommends lowering the HDD elevation by approximately 10 ft to provide for a minimum factor of safety of 1.5.

The east bank point of inflection (PI) at station 7338+47.1 for HDD burial depth elevation is located greater than 900 ft beyond the ordinary high-water mark (OHWM) of the Missouri River and the HDD exit at station 7333+32 is located atop a high terrace greater than 1,000 feet from the

OHWM. The west bank PI at station 7368+11.6 is located approximately 200 feet from the top of bank (TOB) and OHWM and the HDD entry point at station 7373+46 is approximately 700 feet from the TOB and OHWM. Based on the lateral migration analysis, the proposed east and west bank PIs for the HDD are sufficient to mitigate lateral migration, assuming the river training structures are maintained and functional over the service life of the pipeline.

CLOSING

We greatly appreciate the opportunity to support Gulf Interstate on this project. Should you have any questions or need additional information, please do not hesitate to contact David at Dvance@Geosyntec.com or (678) 361-4801 or Jeremy at JYeglin@Geosyntec.com or (832) 455-3684.

Sincerely,

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August 26, 2022

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