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Memorandum

Date: 7 July 2022

To: Jeffery Haferd and Trevor Nickerson, Marathon Pipe Line, LLC

From: Daniel Woeste, P.E.(IL) and Logan Brant, Ph.D., P.E.(TX), Geosyntec Consultants, Inc.

Cc: Bailey Theriault P.G.(NH), David Vance, P.G.(GA) and Rodolfo B. Sancio, Ph.D., P.E.(TX), D.GE., Geosyntec Consultants, Inc.

Subject: Memorandum Addressing Cause of Ground Movement
Edwardsville, Illinois
Geosyntec Memorandum: TXG0258-0700-MM-001 (Rev. 1)

INTRODUCTION

Geosyntec Consultants, Inc. (Geosyntec) has prepared this memorandum at the request of Marathon Pipe Line, LLC (MPL) to present our findings regarding the geotechnical and hydrotechnical factors that contributed to ground movement in the vicinity of the Wood River-to-Patoka (WoodPat) 22-inch pipeline (Pipeline) and Cahokia Creek in Edwardsville, Illinois (Site). The rupture location is within MPL right-of-way (ROW) Number (No.) 15 adjacent to the intersection of Edwardsville Road (IL-143) and Cahokia Creek (Creek). The Site is located on the southeast terrace of the Creek and the Pipeline traverses roughly parallel to the Creek in a southwest to northeast orientation.

Geosyntec's team of geotechnical and hydrotechnical engineers has assisted MPL with the following activities related to the Site:

- On 17 March 2022, Geosyntec's engineers conducted a visual inspection of the ground conditions at the Site to inform the development of recommendations for temporary stabilization and geohazard monitoring.
- On 21 March 2022, Geosyntec submitted a technical memorandum summarizing the field observations, recommendations for temporary stabilization and requesting data needed to advance the geohazard mitigation design.
- On 4 April 2022, Geosyntec submitted a memorandum summarizing our preliminary geohazard assessment for the Site.
- On 11 to 13 April 2022, Geosyntec oversaw the drilling and sampling of two geotechnical boreholes at the Site. Inclinometer casing and a vibrating wire piezometer were installed in each of the two boreholes. Subsequently, Geosyntec also installed two ShapeArray

inclinometers, and five sets of primary and redundant strain gauges at the Site, three sets on the WoodPat pipeline and two sets on the adjacent RoxPat pipeline.
- On 13 May 2022, Geosyntec submitted a geotechnical report for the Site, which included interpretations of the subsurface condition and geotechnical design parameter recommendations for stability analysis and mitigation design.
- On 27 May 2022, Geosyntec submitted a slope stability assessment calculation package (dated 26 May 2022) and presented the results of our hydrotechnical analysis (dated 20 May 2022) which was submitted following a call with MPL.

This memorandum builds on Geosyntec's prior activities related to the Site and offers our assessment of the cause of the ground movement.

FIELD OBSERVATIONS

Geosyntec conducted a visual inspection of the Site on 17 March 2022, and our observations are summarized in the *Geohazard Assessment of Edwardsville Site, Illinois* memorandum, dated 21 March 2022.

A few key observations from the site visit include the following:

- Water in the Creek, as it passes underneath the bridge north of the Site, flows directly toward the south stream bank (left bank looking downstream) near the southwestern extent of the ground movement, as shown in Figure 1.
- Sandy flood deposits were observed along the streambank more than 15-feet above the observed water elevation, suggesting episodic high-flow and associated erosional events occur within the Creek.
- Streambank deposits along the Creek are alluvial deposits which are susceptible to scour.

Figure 1 - View Looking Southwest from Edwardsville Road Bridge (Photo Taken 17 March 2022)

DOCUMENT REVIEW

In addition to field observations made during the site visit, the following documents were reviewed and considered in our findings presented herein:

- 2014 slope repair documents, including: (i) Submar Design-Build Proposal dated 9 January 2014; and (ii) Land & Pipe Management Report dated 8 August 2014.
- 2015, 2016, and 2017 slope repair documents, including: (i) MPL documentation checklist dated 13 May 2015; (ii) MPL erosion control – assessment sheet dated 2 June 2016; and (iii) Land & Pipe Management Report dated 17 April 2017.
- Bedrock and surficial geology maps from the Illinois State Geological Survey.
- Nearby water well logs from the Illinois State Geological Survey.

HYDROTECHNICAL ANALYSIS

Geosyntec reviewed historical aerial images, evaluated historical stream gage data, and performed hydraulic analyses for the purpose of assessing the contributions from bank and bed scour on ground stability at the Site.

Historical Aerial Image Review

Review of aerial images from 1991 through 2022 obtained from Google Earth^{TM} and NearMap show riverine behavior at the Site is influenced by historical straightening and natural attempt to re-establish a meander pattern. In the area where scour has resulted in lateral migration of the south streambank, there is evidence of scarp progression and ground instability dating back at least several decades.

Previous repair attempts in 2014 and 2017 using erosion control devices appear to have had little to no impact on preventing scour of the streambank and thus preventing or slowing ground movement.

Figures 2 through 5 present a series of historical aerial images showing changes that occurred at the Site since 2011.

- The image from September 2011 (Figure 2) shows the absence of deep-rooted forest canopy along the streambank, a defined scarp at the head of the ground instability, presence of large woody debris (LWD), and a point bar on the opposite side of the creek that is re-directing the flow hydraulics toward the Site.
- The image from April 2016 (Figure 3) shows the bank conditions without vegetive cover along the streambank, presence of LWD along downstream end of left bank at Site, the development of hydraulic expansion pool created by increased flow velocities downstream from the bridge floodway constriction and grade drop downstream of the bridge, and splay deposits indicative of flooding and outer bend hydraulics. The photo also shows articulated concrete mats that were installed for erosion control above a section of the Pipeline in 2014, but which generally do not appear to be protecting the bank from scour or contributing to the stability of the slope.
- The image from July 2020 (Figure 4) shows an additional area of LWD accumulation at the upstream end of the left bank at the Site. The existence and proximity of LWD to the left bank complicate scour hydraulics creating local scour conditions resulting for localized velocity accelerations and multidirectional flow patterns.
- The image from 1 March 2022 (Figure 5) shows flow through the Illinois Department of Transportation (IDOT) installed scour mitigation riprap directed towards the left bank and accumulations of LWD.

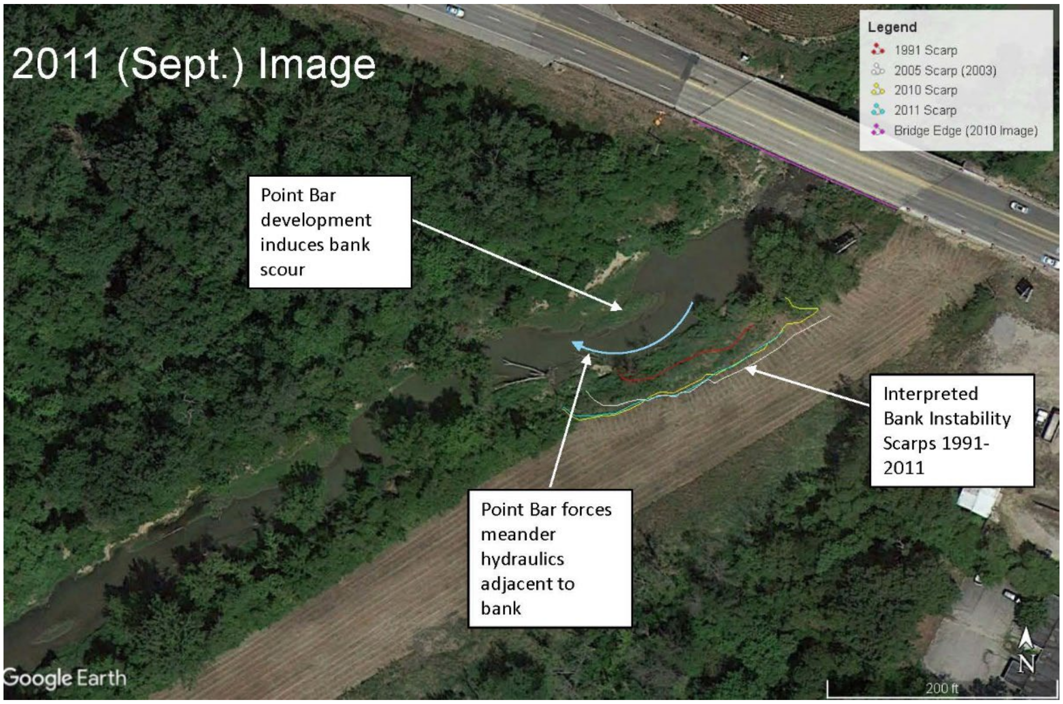

Figure 2 - Aerial Image Dated September 2011 (from Google Earth™)

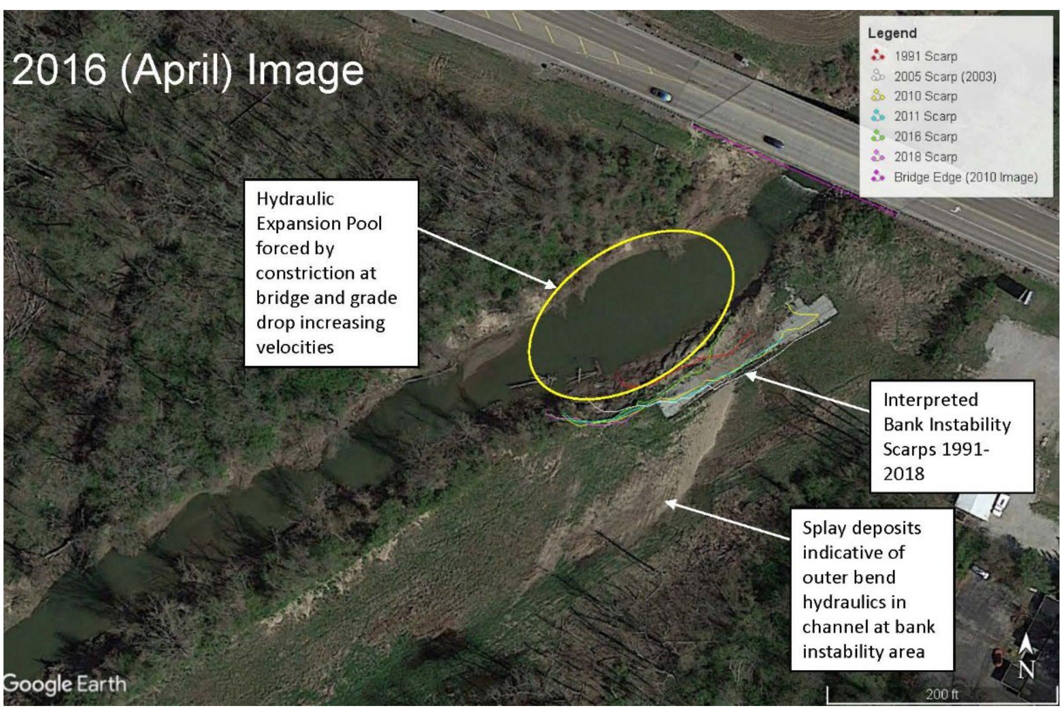

Figure 3 - Aerial Image Dated April 2016 (from Google Earth™)

Figure 4 - Aerial Image Dated July 2020 (from Google Earth™)

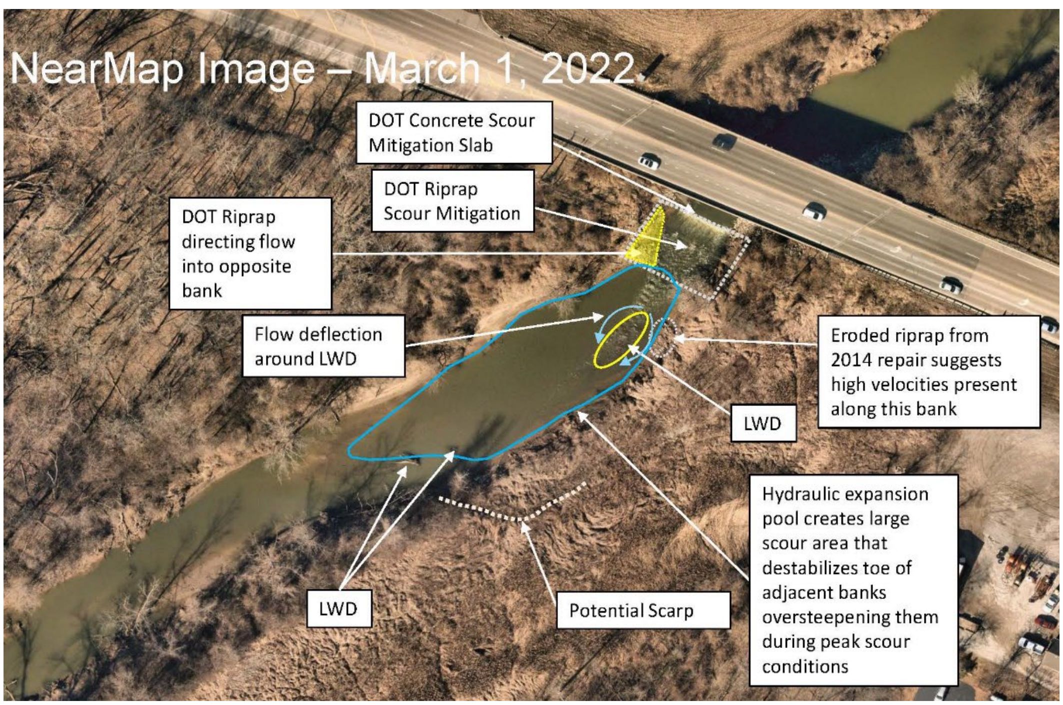

Figure 5 - Aerial Image Dated 1 March 2022 (from NearMap)

Creek Bathymetry and Bank Topography

The creek bathymetry and bank topography collected by DoC Mapping LLC after the 11 March 2022 ground movement is shown in Figure 6. These contours, along with the cross sections in Figure 8, illustrate topographically the impact of scour and ground movement on the left bank relative to the forested upstream and downstream streambanks. The instabilities along the left bank are coincident with deeper creek bed depths (i.e., resulting from bed scour), lateral bank position, and altered bank slope inclination. As shown in Figure 8, in the area of the ground instability, the creek bed depth is about five feet deeper and the bank is recessed laterally about 15 feet, compared to the upstream and downstream streambanks.

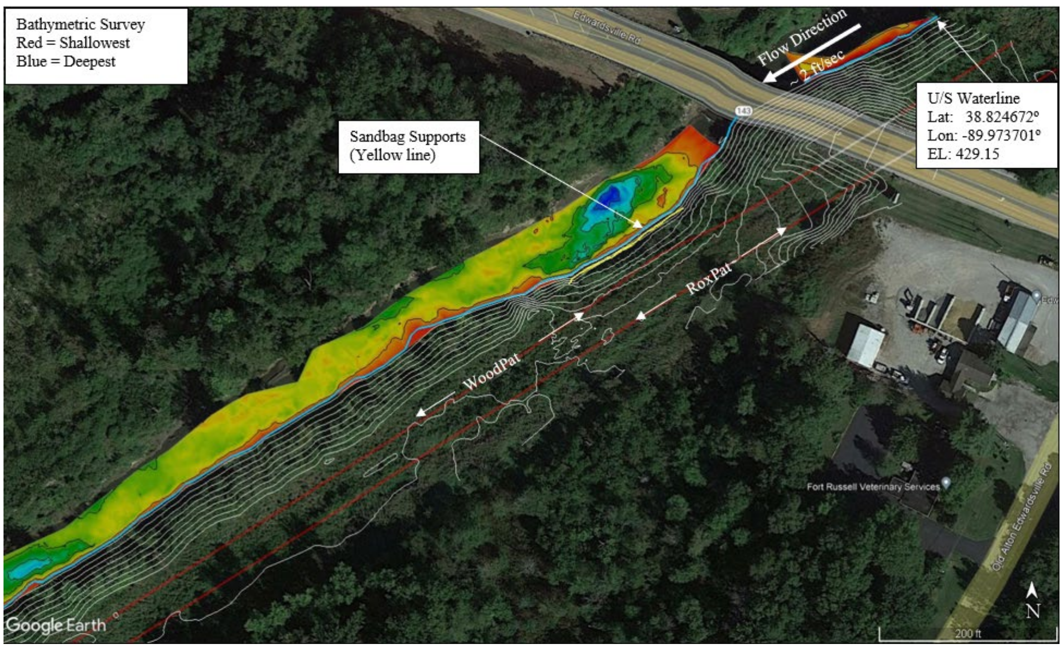

Figure 6 - Site Plan with Bathymetric and Ground Contours Obtained April 2022 (from DoC Mapping LLC)

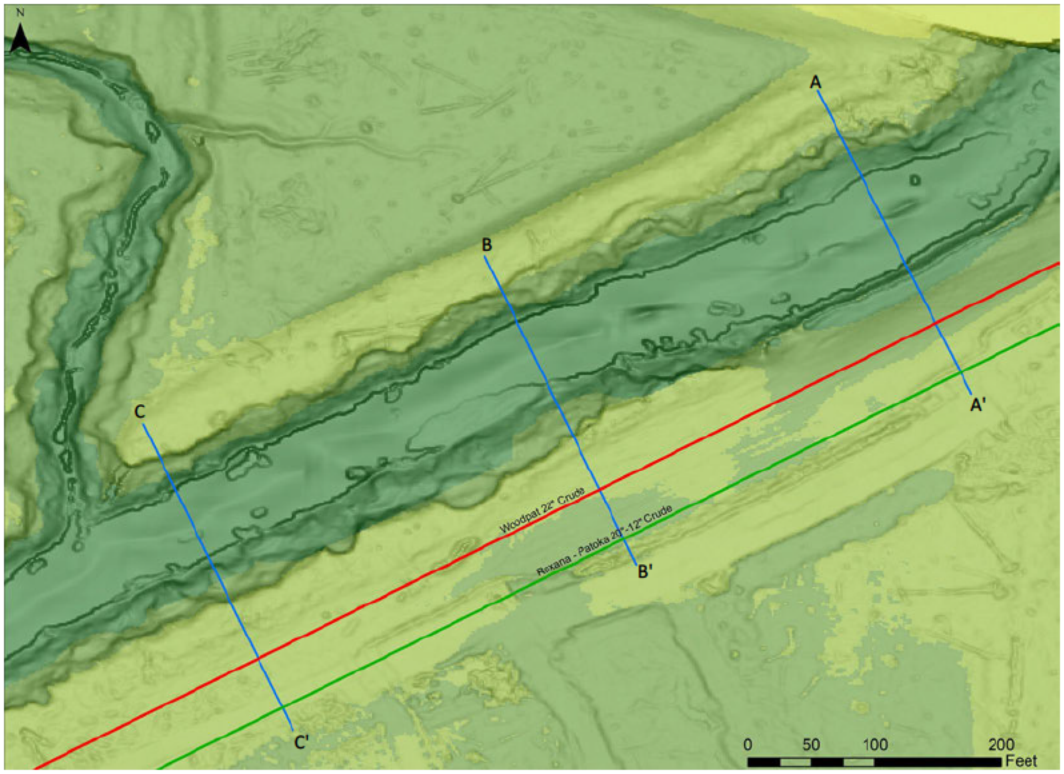

Figure 7 - Plan Showing Locations of Cross Sections

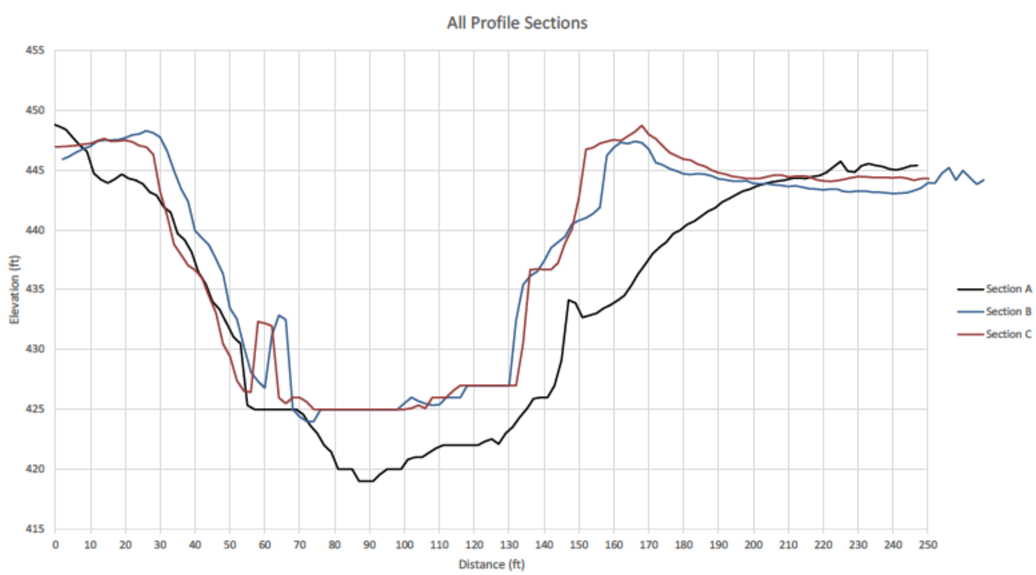

Figure 8 - Cross Section Profiles

Flood Event on 7 March 2022

The flood event which occurred on 7 March 2022, preceding the Pipeline rupture by several days, is reported to have had a stream flow magnitude of 4,070 cubic feet per second (cfs), which corresponds to approximately a 1.5-year return period event. This is equivalent to a "bankfull" event responsible for the dominant sediment transport annually. It is suspected that a single flood event is not responsible for the scour which led to the conditions at the Site, but rather a series of multiple smaller events, such as the 7 March 2022 flood event. Figure 9 contains a hydrograph with stream flow data for the Creek showing the relatively frequency of flood events with stream flows in the range of 4,000 cfs from May 2021 to April 2022.

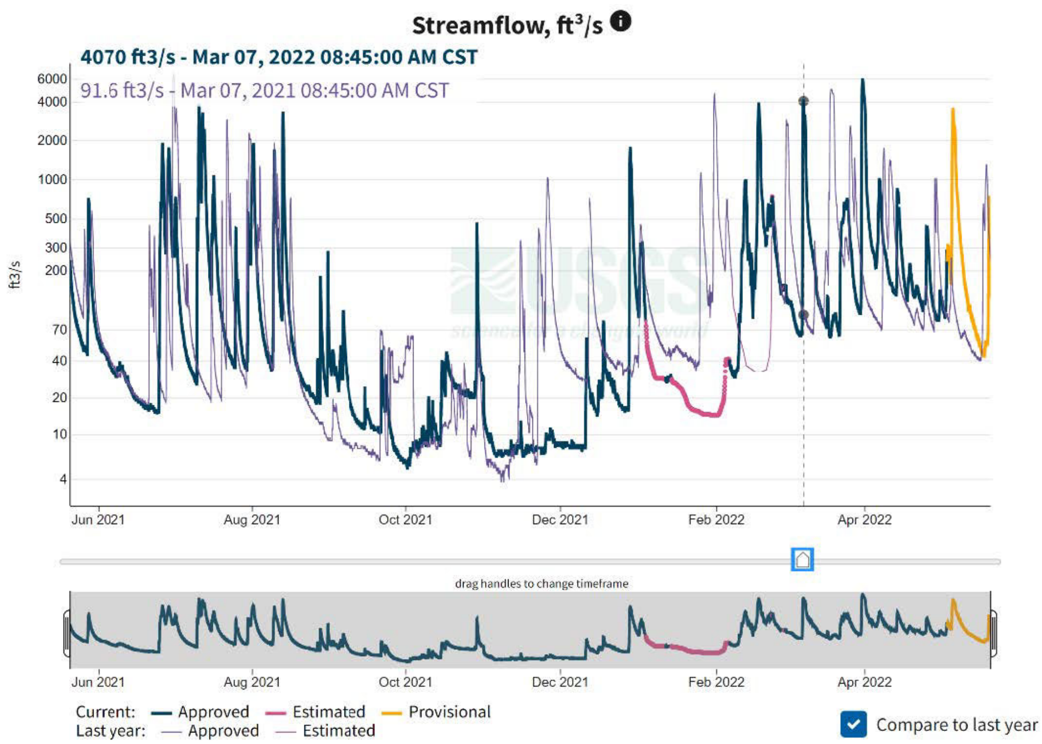

Figure 9 - 1-yr Cahokia Creek Hydrograph (from USGS)

Hydraulic Analyses

The hydraulic analyses were performed using HEC-RAS 2D to model existing hydraulic conditions and one stabilization concept (i.e., an anchored sheet pile wall). The modeling used the bathymetric data collected by DoC Mapping LLC in April 2022 and data from the nearby United States Geological Survey (USGS) stream gage. Geosyntec modeled existing conditions at 2-, 5-, 10-, 25-, 50-, and 100-year flood return interval discharges using the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) hydrology for initial set up and approximation of the model. Follow-on scour modeling using HEC-RAS 2D was conducted for the 50- and 100-year flood return intervals. The scour modeling analyses confirmed the potential for deep bed scour at the Site, with maximum bed scour depths of 7 to 9 feet (below current bed depths) predicted for large 50- and 100-year return period flood events, enough to scour the creek bed down to the top of the underlying bedrock.

Streambank Instability Root Cause Hypothesis

The hydrotechnical analysis results indicate the following mechanics are the root cause of the streambank instability at the Site:

- Scour mitigation placed to protect the bridge has been preferentially eroded by the Creek, such that the scour mitigation directs flow toward the affected streambank.
- Hydraulic expansion conditions downstream of bridge create a scour pool that destabilizes toe of adjacent streambanks oversteepening them during peak scour conditions.
- Outer bend flow hydraulics force outer bank toe scour. Toe scour over-steepens the streambank setting up conditions for streambank instability.
- Fluctuating water levels in the Creek, especially after extensive high water and/or wet periods is a contributing factor in furthering bank failures of varying magnitudes (see Geosyntec *Slope Stability Assessment* calculation package dated 26 May 2022).
- LWD is prevalent in this system and regularly deposits or is impinged on the affected streambank. The presence of LWD creates local hydraulics inducing scour (i.e., local scour).

Conclusions

The hydraulic and scour conditions noted above and described further in Geosyntec's *Hydrotechnical Analysis (TXG0258-0600)* dated 20 May 2022, are expected to continue at the Site. The streambank instability was caused by ground movement resulting from riverine scour and LWD which influenced local scour along the left bank (looking downstream). Mitigation of future streambank instabilities will need to accommodate the observed scour patterns, occurrence of LWD, and scour depths illustrated in the *Hydrotechnical Analysis (TXG0258-0600).* Mitigation measures should be designed to minimize destabilizing adjacent streambanks parallel to the Pipeline downstream.

GEOTECHNICAL STABILITY ANALYSIS

Geosyntec performed two-dimensional (2D) limit equilibrium slope stability analyses for the Site using the Slide2 software by Rocscience and a geotechnical model developed following the geotechnical investigation. The analysis is summarized in Geosyntec's *Slope Stability Assessment* calculation package, dated 26 May 2022. The analysis was performed to assess the present condition of the Site and to assess potential causes for the 11 March 2022 ground movement. The analysis included evaluating the slope for changing hydraulic conditions (i.e., fluctuating groundwater table and rapid drawdown) resulting from flooding and rainfall events, and instability caused by riverine scour along the streambank.

The slope stability analysis results for Section A-A' under the assumed conditions at the time of instability are shown in Figure 10. This scenario considers a streambank slope of approximately 1.2H to 1V with material removed at the slope toe from riverine scour. Groundwater is modeled as a rapid drawdown condition with initial and final water elevations changing from EL. 440 feet[1] to EL. 425 feet within the model to match flooding conditions observed prior to the event on 11 March 2022. The undrained shear strength of the alluvial clay (Unit 2A) below EL. 430 feet was adjusted until a factor of safety equal to 1.0 was achieved. The resulting undrained shear strength is 400 pounds per square foot (lbs/ft^2), a value that is consistent with the range of shear strengths for this material measured from laboratory testing.

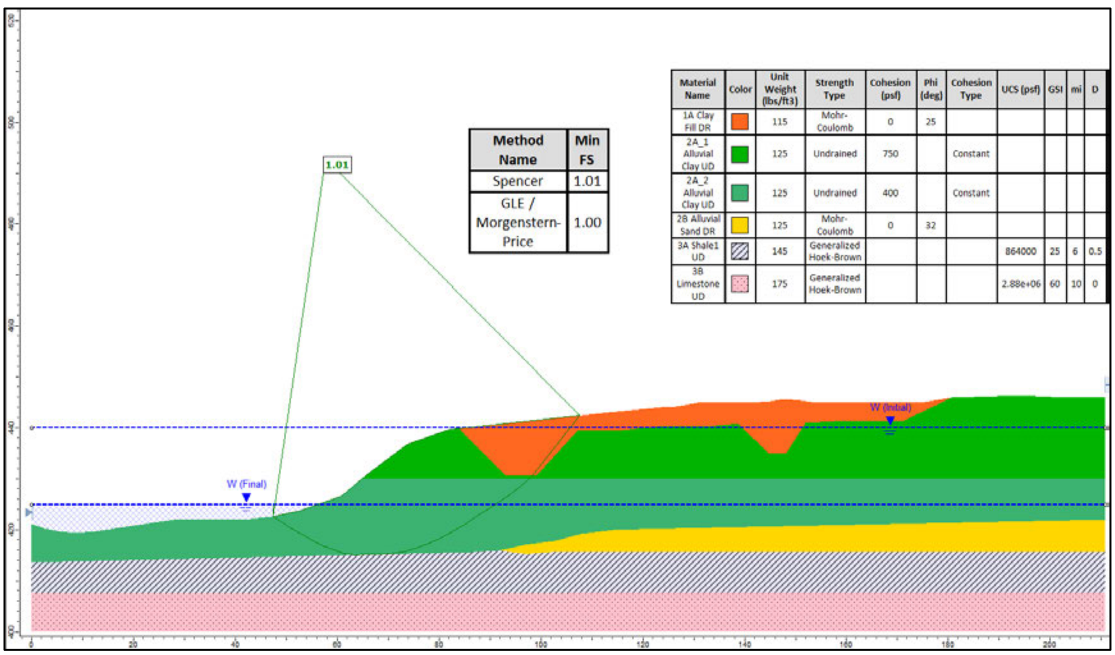

Figure 10 - Limit Equilibrium Slope Stability Analysis at Section A-A'

Conclusions

The slope stability analyses indicate that a combination of streambank scour in the Creek and a reduction of undrained shear strength in the subsurface soil is the plausible cause of instability which led to ground movement. The slope stability sensitivity analysis results presented in Geosyntec's *Slope Stability Assessment* calculation package, dated 26 May 2022, which generally utilize the material parameters provided in the Geosyntec's *Geotechnical Report,* dated 13 May

[1] Elevations (EL) provided herein are in North American Vertical Datum of 1988 (NAVD88)

2022, closely simulate the conditions that are suspected to have led to the 11 March 2022 instability at the Site. The analyzed cross sections indicate a deep-seated sliding surface with entrance/exit locations generally consistent with field observations. As such, mitigation should be designed to address the apparent deep-seated or global instability at the Site.

SUMMARY

The inferred cause of ground movement at the Site is a combination of scour and a reduction of shear strength in the alluvial soils due to softening and repeated shearing. These two mechanisms combined to induce progressive ground movement of upslope soils into the Creek when sediment from the toe of the streambank was removed by scour during subsequent episodic high-flow events. The progressive ground movement over the past decade or more deflected the Pipeline horizontally and vertically downslope toward the Creek.

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