TEXAS EASTERN TRANSMISSION, LP

MAY 4, 2020 FLEMING COUNTY INCIDENT GEOTECHNICAL CAUSATION REPORT

FINAL

PROJECT NO.:	1607024	DATE:	April 26, 2021
DOCUMENT NO.:	Rev A		

EXECUTIVE SUMMARY

This report presents the results of BGC Engineering USA Inc.'s (BGC's) geotechnical causation investigation of the Enbridge Line 10 gas pipeline rupture in Fleming County, Kentucky. This event is herein referred to as the Fleming County Incident (FCI).

On May 4, 2020 at approximately 4:36 PM, Line 10 of the Texas Eastern Transmission, LP (TETLP) natural gas pipeline system ruptured, which resulted in an explosion and fire. The event created a 60 by 25-foot blast crater. The incident site (the Site) was approximately 14 miles northeast of Owingsville, Kentucky in southern Fleming County at latitude and longitude [redacted].

Line 10 and the adjacent Lines 15 and 25 were temporarily shut-in to allow for a site assessment, cut-out and replacement of damaged pipeline, and the installation of mitigative measures.

At TETLP's request, BGC responded to the incident and mobilized to the Site with the objective of performing the geotechnical aspects of the pipeline failure causation study. BGC's investigation included field-based and desktop studies that involved:

- Post-incident field investigation including detailed geomorphic mapping of landslide features, installation of survey monitoring hubs to track ground movement, and logging of excavations and boreholes
- A literature review of the site geology and regional landslide processes
- Bending strain analysis of Inertial Measurement Unit (IMU) data from past In-Line Inspection (ILI) tool runs on Lines 10, 15 and 25
- Lidar change detection assessment using publicly available and proprietary lidar data obtained before and immediately after the FCI
- Review of historical air photos spanning the timeframe from 1959 (shortly after the construction of Lines 10 and 15) to 2018
- Review of historical precipitation data
- Review of past documented TETLP construction activities at the Site.

The Site was first identified by BGC as a geohazard in October 2018. Between then and the May 4, 2020 FCI, the Site had been assessed using lidar imagery and IMU bending strain data and inspected in the field. Based on these assessments, it was evident that landslide movement had impacted both Lines 10 and 15 causing elevated strain particularly on Line 10. Based on this work, TETLP had planned to mitigate the Site in 2020 with measures including visual and X-ray assessment of Line 10, strain gauge installation and the installation of subsurface drainage measures.

The Site is located in northeast Kentucky, within the unglaciated Appalachian Plateau. Many studies over the past 50 years have shown that landslide susceptibility and rates of landslide occurrence in this region are characterized as "high" due to multiple factors including: weak bedrock, steep slopes, high annual amounts of precipitation, and thick clay-rich colluvial soils.

Based on multiple lines of evidence observed during this investigation, BGC concludes that acceleration of the landslide feature that Line 10 was installed within was a key contributing factor to the rupture of Line 10. On-going slope movement producing a gradual accumulation of strain had been occurring likely over much of the life of the pipeline, but significant acceleration of movement in recent years, and particularly the large acceleration over the winter preceding the rupture would have caused a rapid change in pipe strain leading to the rupture. The key points supporting accelerating slope movement as a key contributing factor to the pipeline rupture include:

- An active and well-defined landslide was observed on and downslope of the TETLP corridor intersecting approximately 165 ft of Line 10 and 160 ft of Line 15. Clay colluvium and clear slip planes were observed within the excavation for the cut outs of Lines 10 and 15. Instrumentation installed following the FCI confirmed active ground movement along the former Line 10 alignment and within the landslide downslope of the rupture site.
- Bending strain consistent with downslope ground movement was measured across a length of 250 ft of Line 10, the majority of that within the landslide, in the June 2007, April 2018, and June 2019 IMU data. Definite strain change had occurred between each of the time intervals in the IMU data. Strain was observed increasing at the failed girth weld (GW11330) between April 2018 and June 2019. While this girth weld did not have the highest girth weld bending strain in June 2019, high rates of ground movement between November 2019 and May 2020 likely led to strains that caused the rupture. Tensile strains would also have been present at the rupture location associated with the axial component of movement which are not measurable in the IMU data alone.
- Ground displacement estimates were inferred from the IMU data but also from OOS estimation following the FCI and the lidar change detection assessment in the landslide mass downslope of the TETLP corridor. Based on these assessments, three distinct periods of ground movement have been identified:
    1. 1952 to June 2007: 0.7 inches/yr (3.3 ft of ground movement, 15% of total ground movement) – Overall long-term average movement rate. Ground movement may have been natural, related to a pre-existing landslide, or impacted by TETLP pipeline construction.
    2. June 2007 to November 2019: 10 inches/yr (10.1 additional ft of ground movement, 45% of total ground movement) – More than a ten-fold increase in slope movement rate compared to pre-2007 levels. Elevated rate is sustained for 12 years, until November 2019. This significant increase in rate is likely related to the combined influence of timber harvesting, construction activities on the TETLP corridor, and long-term increases in regional precipitation between 2008 and 2019.
    3. November 2019 to May 2020 FCI: 17.9 ft/yr (8.9 additional ft of ground movement, 40% of total ground movement) – A more than twenty-fold increase in slope movement rate compared to the June 2007 to November 2019 period. This large change in rate is considered to be related to the combined influence of TETLP grading activities in the summer of 2019, high precipitation between October 2019 and April 2020 and the fact that the high precipitation occurred when the site was

vulnerable with existing open ground cracks, and preferential groundwater flow paths related to the existing backfilled pipeline trenches.

The landslide impacting Line 10 was a pre-existing feature that would likely have been in a marginal state of equilibrium and sensitive to changes in slope geometry and groundwater conditions. Various construction activities have occurred at this site prior to the May 2020 FCI, including the construction of Lines 10 and 15 in the 1950’s, Line 25 in the 1965, and TETLP corridor maintenance (excavations, grading and equipment vibrations). These activities would have involved the excavation of pipe trenches and long-term redirection of seepage flows into the landslide feature, changes to surface drainage, and importantly different levels of disturbance and grading on the slope which likely led to increased fill placed over Line 10 at the head of the slide mass.

Beginning in June 2007, ground movement rates increased significantly from the low rate of movement over the past five decades, and remained elevated until 2019, due to both natural and man-made events. Timber harvesting at the Site between 2006 and 2010 may have initiated the increased movement rate though various construction activities on the TETLP corridor and a prolonged period of above average annual precipitation beginning in 2008 maintained the higher ground movement rate. The decade between 2010 and 2020 was the wettest on record since the installation of Line 10 in 1952, and 2018 was the wettest year over this same time period. This prolonged period of above average precipitation would have increased pore water pressures, driving further movement at the Site. Additionally, TETLP had completed an erosion repair at the site in June and July of 2019, shifting an unknown amount of soil from the south (upslope) side of the corridor over Line 10. This would have increased traction loads on Line 10 and driven continued movement of the landslide.

The acceleration between November 2019 and May 2020 was dramatic. The acceleration corresponded to an abnormally wet fall and winter. While 2018 overall had greater precipitation, October 2019 to April 2020 had greater precipitation than similar time periods in the two previous years. Lower evaporation rates due to less sunlight and minimal evapotranspiration increases the impact of elevated precipitation during these winter months on slope stability as more surface water infiltrates the soil. However, the elevated precipitation alone does not account for the rapid increase in slope movement.

A 20-fold increase in ground movement was unique to the Site and was not observed at neighboring landslides on similar aspect slopes. This is suspected to be due to the unstable state of the landslide prior to November 2019 and its heightened vulnerability to being destabilized by precipitation. Grading activities over the summer of 2019 had placed additional load at the head of the slide and while ground cracks were repaired on the TETLP corridor, field inspections confirmed they were still present downslope and off the corridor. These cracks would serve as conduits to intercept surface water flows that would have otherwise been shed off the slope, conveying the water directly into the slide mass, driving further movement. As additional movement occurred, existing cracks would widen and new cracks would form, allowing additional infiltration and driving further acceleration of movement. Another key difference between the Site and neighboring landslides is that three backfilled pipeline trenches were directing water into the moving landslide feature at the Site. This additional source of water would not be present in landslides off the TETLP corridor. It is suspected this combination of the high levels of winter precipitation, pre-existing cracks, additional ground water conveyance along the pipeline trenches and loading associated with the summer 2019 grading activities drove the large acceleration between November 2019 and May 2020. This rapid acceleration likely led to strain great enough to fail GW 11330.

While Line 15 was also within and impacted by the landslide feature, overall strains on the line were lower than Line 10 likely due to a combination of lower ground displacement rates as Line 15 was likely in a less active part of the landslide along the upslope periphery of movement, and lower amounts of soil cover reducing the soil loading on the pipeline that would cause out-of-straight deformation and associated pipe strain. Line 25 was found to not be impacted by the landslide as it was predominantly trenched within bedrock along the upslope margin of the slide.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
3D	Three-dimensional
ALS	Aerial Lidar Survey
BGC	BGC Engineering Inc.
DNV	Det Norske Veritas
DOC	Depth of cover
Enbridge	Enbridge Gas Transmission
FCI	Fleming County Incident
ft	Feet
ft/yr	Feet per year
GW	Girth weld
ILI	In-line Inspection
IMU	Inertial Measurement Unit
in.	Inch
LCD	Lidar change detection
Lidar	Light Detection and Ranging
MDR	Multi-disciplinary review
NOAA	National Oceanic and Atmospheric Administration
OOS	Out-of-straight
ROW	Right-of-way
RTR	Run-to-run, in reference to IMU data comparisons
SAA	Shape accel arrays
TETLP	Texas Eastern Transmission, LP
USDA	United States Department of Agriculture

LIMITATIONS

BGC Engineering USA Inc. (BGC) prepared this document for the account of Texas Eastern Transmission, LP; the United States Department of Transportation Pipeline and Hazardous Materials Safety Administration; and the National Transportation Safety Board (Clients). BGC prepared this document based on relevant information available to BGC at the time of document preparation. BGC accepts no duty to any third party (i.e., any person or entity other than Clients) related to this document. Third parties use or rely on this document at their own risk. BGC will not be responsible or liable for any injury, loss, or damages suffered by any third party due to such third party's use of or reliance upon this document or its content. A record copy of this document is on file at BGC. That copy is the record document, which takes precedence over any other copy or reproduction of this document.

1.0 INTRODUCTION

1.1. Purpose and Scope

This report presents the results of BGC Engineering USA Inc.'s (BGC's) geotechnical causation investigation of the Texas Eastern Transmission, LP (TETLP) Line 10 gas pipeline rupture in Fleming County, Kentucky. This event is herein referred to as the Fleming County Incident (FCI).

On May 4, 2020, Line 10 of the TETLP system ruptured, which resulted in an explosion and fire. The rupture occurred on a northwest facing slope in forested terrain near Hillsboro, Kentucky. All three of the TETLP pipelines that occupy the corridor traversing the slope (Lines 10, 15 and 25) were temporarily shut-in to allow the Site to be assessed, mitigation measures put into place, and to cut-out and replace damaged pipeline.

At TETLP's request, BGC responded to the incident and mobilized to the Site with the objective of performing the geotechnical aspects of the pipeline failure causation study.

Other parties retained by TETLP for the causation investigation included:

- Det Norske Veritas (DNV): Responsible for the metallurgical and strain assessment of the failed pipeline segment.
- Otis Eastern Service LLC (Otis Eastern): Responsible for initial construction response, removal of failed pipeline segment and geotechnical test pitting.
- SGC Engineering LLC (SGC): Responsible for surveying following the incident, including recording the centerlines of Lines 10, 15 and 25; surveying landslide features (scarps, cracks, seeps); installing and taking regular readings of ground monitoring hubs within the slide mass and along Line 25.
- WSP USA (WSP): Responsible for monitoring environmental impacts of FCI, designing and monitoring erosion control measures and measuring daily precipitation amounts.

The purpose of this report is to present the findings from BGC's geotechnical investigation of the FCI, and specifically to summarize the geotechnical causation assessment. BGC was also involved with the design of mitigation and long-term monitoring measures for the Site, which will be reported under separate cover.

BGC's investigation was completed under TETLP's Purchase Order Number 3500026748 dated May 11, 2020. The services provided under this assignment were governed by the Spectra Energy Services, LLC Master Services Agreement with BGC, dated March 1, 2016, and associated addendums (Contract ID CW2227833).

1.2. Report Structure

This report presents information using the following framework:

- Section 2.0 provides background information about the location and past work completed at the Site of the FCI.
- Section 3.0 describes the various data sources and methods used in the FCI causation assessment and provides the key findings of each component of the assessment. These

observations include a post-FCI site description; geologic and geotechnical conditions as observed in the crater and excavations; review of past inertial measurement unit (IMU) bending strain data on Lines 10, 15, and 25; results of airborne light detection and ranging (lidar) change detection analysis of pre- and post-incident topography; a review of historic aerial imagery; a description of historic rainfall data; and a review of past construction activities at the Site.

- Section 4.0 discusses what the findings of the assessment indicate about the landslide mechanism at the Site, the vulnerability of Line 10 to ground movement and triggering factors and recent activity changes that may have led to the FCI.
- Section 5.0 presents the conclusions of the study and the key factors supporting those conclusions.

2.0 BACKGROUND

2.1. Fleming County Incident

On May 4, 2020 at 4:36 pm, Line 10 of the TETLP system ruptured. The event created a 60 by 25 ft blast crater. The FCI site (the Site) was approximately 14 miles northeast of Owingsville, Kentucky in southern Fleming County at latitude and longitude [redacted] (Figure 2-1).

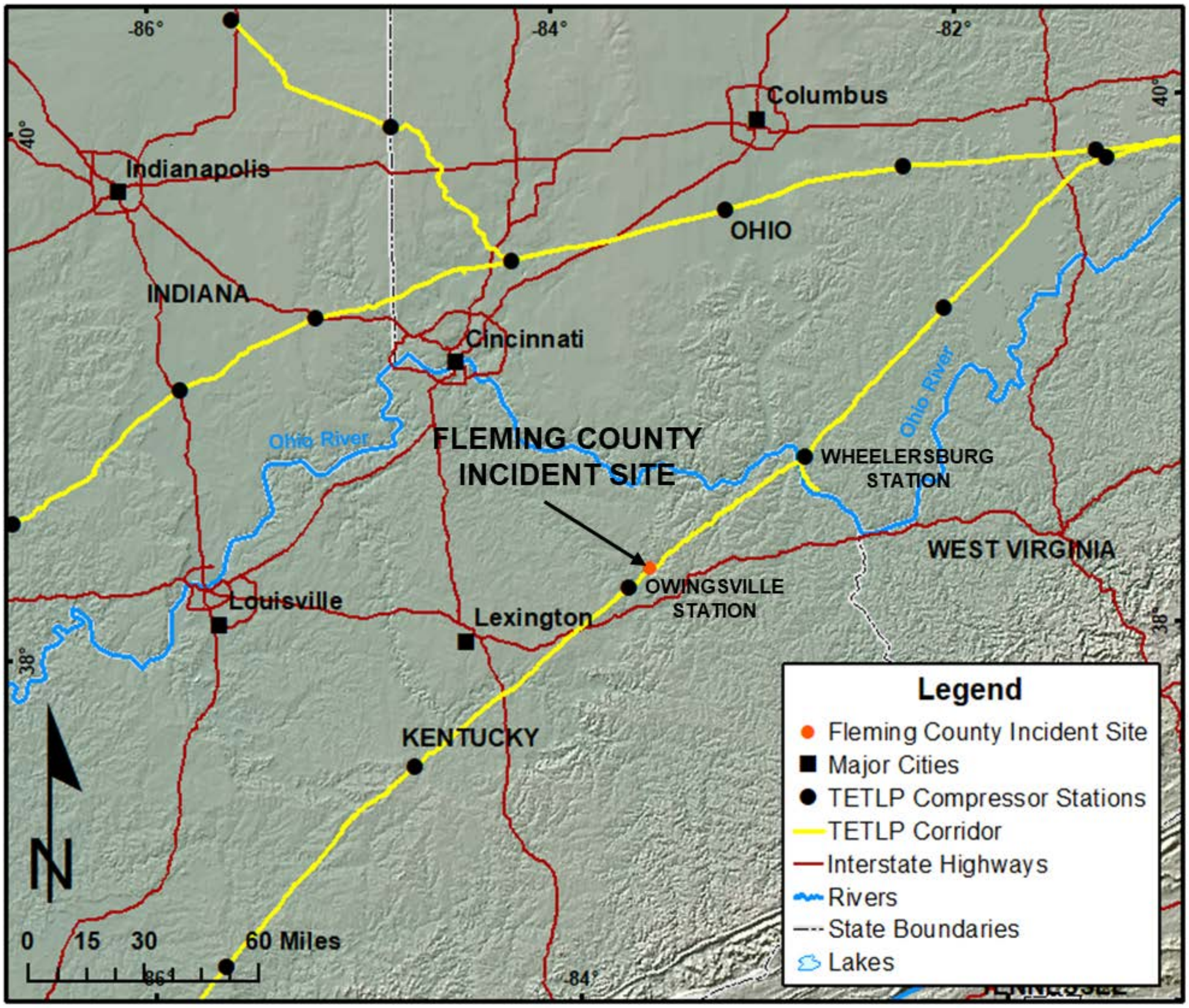


Figure 2-1. FCI site location map. Yellow lines are TETLP Gas pipeline corridors; Black circles are compressor stations, and the Owingsville and Wheelersburg stations are labeled. The Site is denoted by the orange circle. TETLP corridor and compressor stations provided by TETLP; base map imagery from USGS (2017); interstates, rivers, lakes, cities, and state boundaries from ArcGIS Online (Esri, 2020).

2.2. Texas Eastern Pipelines (Lines 10, 15, and 25)

Line 10 is one of three gas pipelines constructed within a corridor that transects the Site from southwest to northeast. Originally, flow on TETLP had been from the southwest to the northeast, but flow on the Owingsville to Wheelersburg segment at the time of the FCI was in the opposite direction, flowing from the northeast to the southwest. At the Site, the pipelines are (from north to south): Line 10, Line 15, and Line 25 (Figure 2-2). Figure 2-3 shows the girth welds for the three pipelines at the Site with the In-Line-Inspection (ILI) tool vendor assigned girth weld numbers and Figure 2-4 shows a representative cross section of the pipelines within the corridor at the Site. Tables 2-1 through 2-3 correlate the girth weld numbers with the TETLP stationing for the three pipelines. The installation date, pipe diameter, and other relevant details provided by TETLP include:

- Line 10 was installed in 1952. The pipeline diameter is 30 in. and has a nominal wall thickness of 0.375 in. The typical joint spacing is 40 ft.
- Line 15 was installed in 1957. The pipeline diameter is 30 in. and has a nominal wall thickness of 0.375 in. The typical joint spacing is 40 ft.
- Line 25 was installed in 1965. The pipeline diameter is 36 in. and has a nominal wall thickness of 0.39 in. The typical joint spacing is 40 ft.

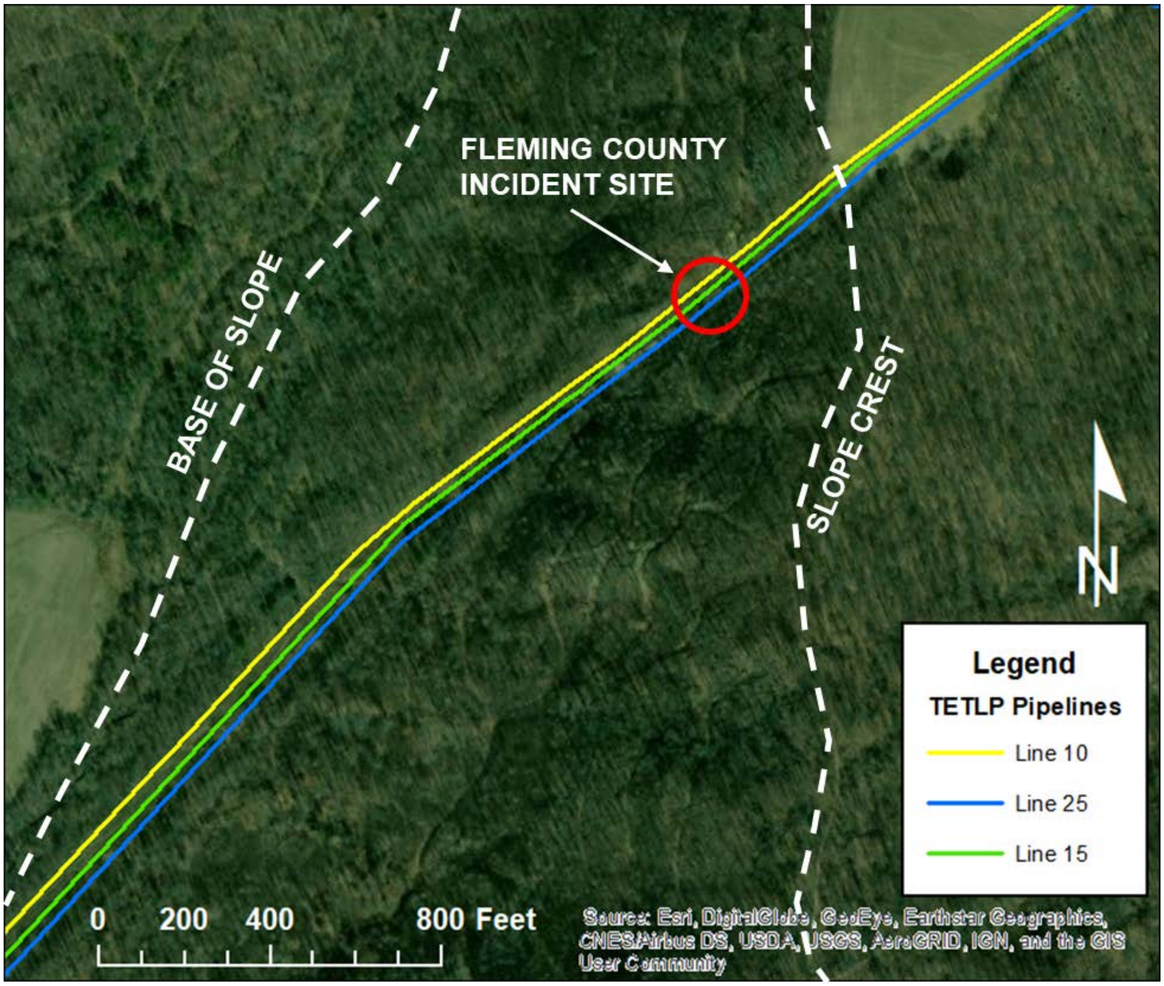


Figure 2-2. Detailed location of the FCI site. Gas pipeline centerlines provided by TETLP; Imagery from ArcGIS Online (Esri, 2020).

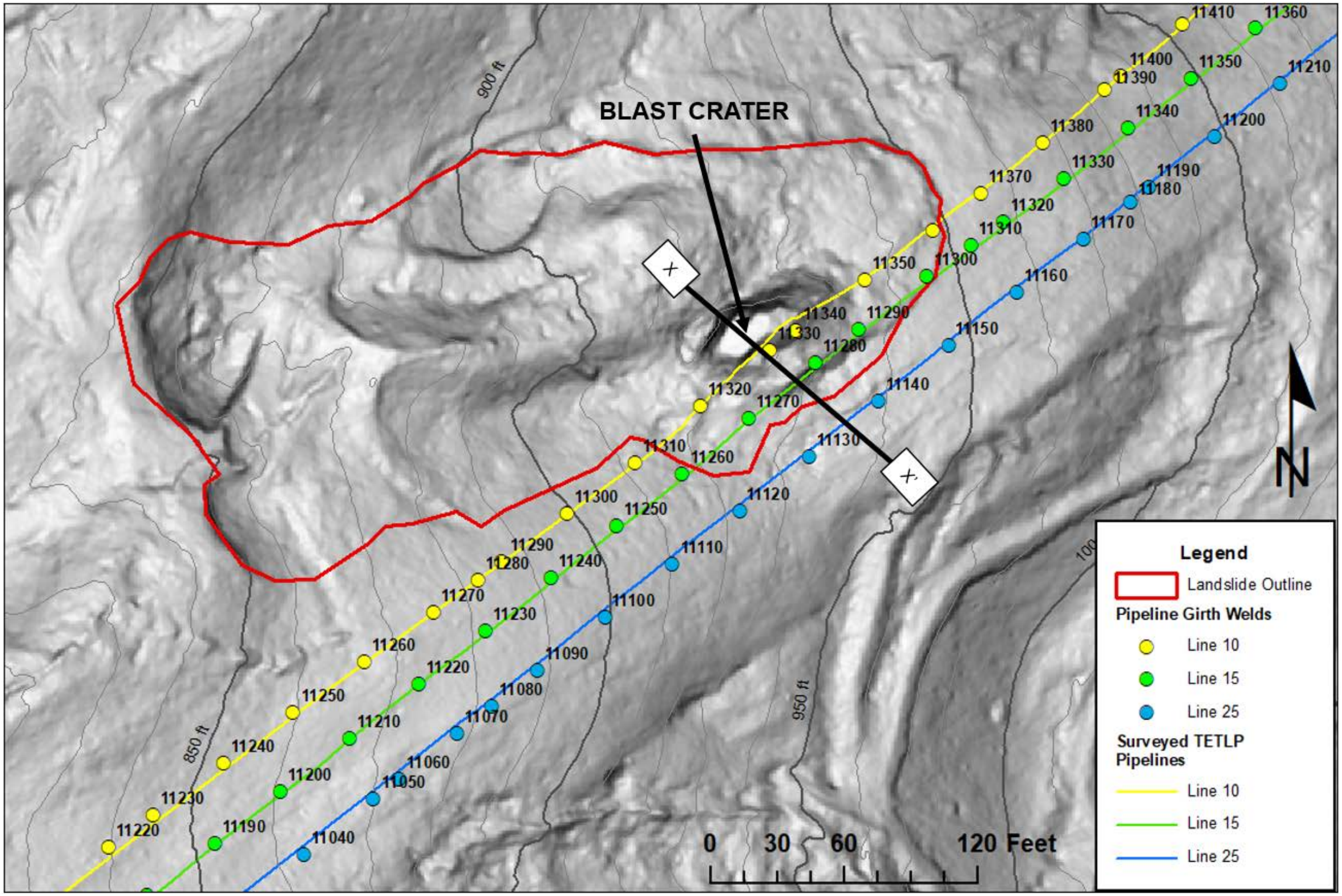
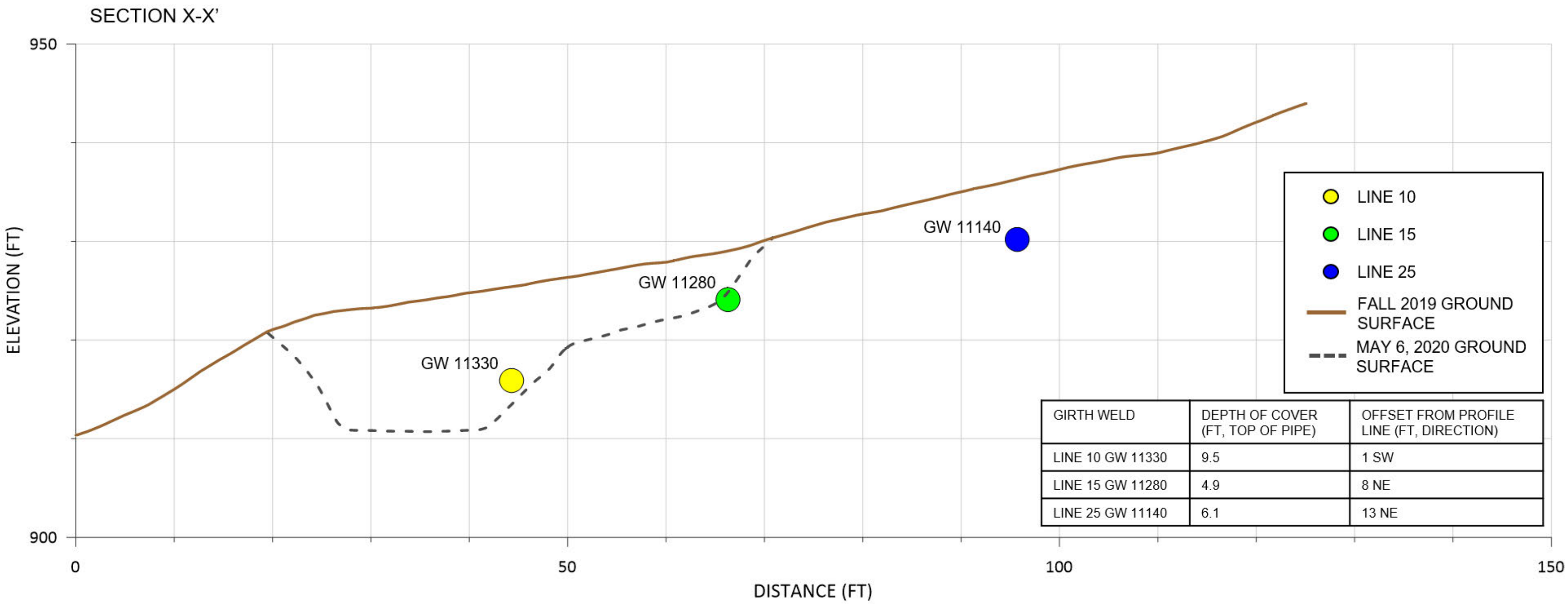


Figure 2-3. Plan-view of the FCI showing the Baker Hughes (ILI vendor) Girth Weld numbers referred to throughout the report. Lidar imagery was provided by TETLP (flown May 6, 2020) and girth weld locations are based on pre-FCI IMU data provided by Baker Hughes (July 2014, Line 10; May 2017, Line 15; and April 2014, Line 25). The cross-section X-X' is provided in Figure 2-4.



GIRTH WELD	DEPTH OF COVER (FT, TOP OF PIPE)	OFFSET FROM PROFILE LINE (FT, DIRECTION)
LINE 10 GW 11330	9.5	1 SW
LINE 15 GW 11280	4.9	8 NE
LINE 25 GW 11140	6.1	13 NE

Figure 2-4. Representative cross-section showing the configuration of all three pipelines at the FCI site. The plan-view location of the cross section is shown on Figure 2-3. The grade prior to the rupture (extracted from lidar data provided by TETLP, flown November 2019) and the blast crater (extracted from lidar data provided by TETLP, flown May 6, 2020) are shown for reference. The approximate depth of cover to the top of the pipelines prior to the rupture are summarized in the table at the bottom right of the figure.

Table 2-1. Line 10 girth weld and stationing correlation.

GW Number	Latitude	Longitude	Stationing
11050	[redacted]	[redacted]	2691294
11100	[redacted]	[redacted]	2691499
11150	[redacted]	[redacted]	2691651
11200	[redacted]	[redacted]	2691819
11250	[redacted]	[redacted]	2691995
11300	[redacted]	[redacted]	2692146
11330	[redacted]	[redacted]	2692265
11350	[redacted]	[redacted]	2692319
11400	[redacted]	[redacted]	2692469
11450	[redacted]	[redacted]	2692607
11500	[redacted]	[redacted]	2692749
11550	[redacted]	[redacted]	2692900
11600	[redacted]	[redacted]	2693065

Note: Girth weld numbers from the July 2014 IMU data, provided by Baker Hughes. Stationing provided by TETLP.

Table 2-2. Line 15 girth weld and stationing correlation.

GW Number	Latitude	Longitude	Stationing
11050	[redacted]	[redacted]	2693963
11100	[redacted]	[redacted]	2694140
11150	[redacted]	[redacted]	2694338
11200	[redacted]	[redacted]	2694495
11250	[redacted]	[redacted]	2694692
11300	[redacted]	[redacted]	2694884
11350	[redacted]	[redacted]	2695059
11400	[redacted]	[redacted]	2695191
11450	[redacted]	[redacted]	2695359

Note: Girth weld numbers from the May 2017 IMU data, provided by Baker Hughes. Stationing provided by TETLP.

Table 2-3. Line 25 girth weld and stationing correlation.

GW Number	Latitude	Longitude	Stationing
10850	[redacted]	[redacted]	2693756
10900	[redacted]	[redacted]	2693967
10950	[redacted]	[redacted]	2694162
11000	[redacted]	[redacted]	2694350
11050	[redacted]	[redacted]	2694547
11100	[redacted]	[redacted]	2694681
11150	[redacted]	[redacted]	2694881
11200	[redacted]	[redacted]	2695037
11250	[redacted]	[redacted]	2695226
11300	[redacted]	[redacted]	2695419
11350	[redacted]	[redacted]	2695619
11400	[redacted]	[redacted]	2695811
11450	[redacted]	[redacted]	2695981

Note: Girth weld numbers from the April 2014 IMU data, provided by Baker Hughes. Stationing provided by TETLP.

2.3. FCI Site Geohazard Management History

Since Fall 2018, TETLP has been in the process of implementing a system-wide geohazard management program. As part of this program, the Site had been identified, assessed using lidar imagery and IMU data, and inspected in the field. Based on the findings of these actions, the Site was recommended for monitoring and mitigation in 2020. The following is a timeline of the Site up until the FCI:

- October 9, 2018: The Site is identified as part of the initial desktop geohazard screening for the program using publicly available 2017 lidar imagery (Slope 8800, 8801 and 8802). The screening inspection is provided in Appendix A. The screening inspection recorded in Enbridge Gas Transmission's (Enbridge's) geohazard database describes landslide morphology present over the TETLP corridor and recommended the Site be field inspected on the ground within one year, by October 9, 2019.
- January 28, 2019: The site is inspected by TETLP and BGC during a helicopter patrol as part of the initial evaluation of landslide hazards to the TETLP system. During the flyover, bare soil and surface water erosion was noted, but no evidence of ground movement was observed from the helicopter. The photo inspection is included in Appendix A. No immediate follow-up action was recommended by BGC.
- June 27, 2019: A bending strain anomaly (0.93% bending strain in the pipe body) and bending strain growth are identified at the Site by ILI Vendor, Baker Hughes, during preparation of the Line 10 OWSV-WHEE Bending Strain report, documenting the April 17, 2018 ILI tool run. Baker Hughes provides run-to-run (RTR) plots showing the 2018 and 2007 IMU data to Enbridge ahead of the rest of the report, which is delivered on July 19, 2019. The RTR bending strain plots are assessed by BGC and it is concluded that the

bending strain pattern and change is likely from ground movement. An approximate out-of-straight (OOS) of 4 ft is estimated from the 2018 IMU data and appears to have occurred between the 2007 and 2018 ILI tool run. The strain assessment is documented in a July 5, 2019 screening inspection included in Appendix A.

- July 8, 2019: BGC completes a ground inspection at the Site. The ground inspection observations are included in Appendix A. As part of the inspection, Lines 10, 15, and 25 are staked and the OOS of each pipeline are measured: 4.3 ft of downslope OOS over a 180 ft length is observed on Line 10; 2 to 3 feet of downslope OOS is observed over approximately 180 ft on Line 15; and no deflection is observed on Line 25. The measured OOS on Line 10 is similar to the 2018 IMU data. The Site appeared to have been the location of recent right-of-way (ROW) maintenance activity and erosion control matting had been placed over the majority of the TETLP corridor at the Site. According to TETLP staff, the maintenance activities were completed by TETLP Operations to repair erosion that had occurred along the corridor. An arcuate scarp was observed crossing Line 10 at the upslope end of the Line 10 OOS. The erosion control matting obscured most of the scarp. Seepage was noted over Lines 15 and 25 at an elevation similar to the scarp. An incised gully was observed downslope of the corridor, but inspectors did not observe evidence of ground movement into the gully. BGC recommended Enbridge assess the strain demand on Lines 10 and 15 based on the OOS measurements made during the ground inspection and consider mitigation, including a strain relief and drainage installation.
- September 23, 2019: Based on analysis of the June 7, 2019 Line 10 IMU run, Baker Hughes identifies further bending strain growth at the Site since the 2018 IMU run. In addition, RTR IMU data for Line 15 between 2019 and 2011 (delivered September 6, 2019) also showed bending strain growth. BGC reviewed the new IMU datasets together. The assessment is included as an October 30, 2019 Geotechnical Inspection (Appendix A). BGC compared 2019 IMU data and 2018 IMU data on Line 10 and found that the deflection had increased from approximately 4 feet to 4.5 feet and that the maximum bending strain in the pipe body had increased by 0.13% (0.926% in 2018 to 1.050% in 2019). The maximum bending strain on a girth weld was 0.414%, at GW 11310[1]. BGC recommends the Site for review by Enbridge Pipeline Integrity.
- October 30, 2019: Enbridge Pipeline Integrity reviews the Site. Enbridge estimates that the maximum strain (bending and estimated axial) on a girth weld is 0.6%. Based on this and the rate of strain growth between 2018 and 2019, Enbridge decides that additional monitoring and ground condition improvements are required at the Site, and that further consideration will be given to potentially conducting a stress relief on Line 10.
- February 18, 2020: Enbridge Pipeline Integrity and BGC complete a multi-disciplinary review meeting (MDR) to review the scope for the 2020 monitoring and mitigation program at the Site. Based on the strain demand discussed in October 2019, and the rate of strain

[1] The 2019 Line 10 bending strain report girth weld IDs were consistently offset by 10 from the correct value. For consistency, girth welds discussed in this report always utilize the corrected ID numbers, revised by Baker Hughes on May 7, 2020.

growth up to the 2019 IMU run, Enbridge plans to conduct monitoring and mitigation activities in the summer of 2020 during more favorable construction conditions to minimize potential negative impacts of construction disturbance on the slope and pipelines. Enbridge requests BGC prepare a scope of work to install strain gauges on Lines 10 and 15 and provide guidance on the installation of a drainage system to improve slope stability at the Site. Enbridge discusses x-raying girth welds at the Site during the program to evaluate whether a stress relief would be sufficient, or if a pipe cutout may be warranted on Line 10.

- March 24, 2020: BGC submits a proposal for strain gauge installation and drainage measures to Enbridge for the Site. This proposal is included in Appendix B. Within the scope, BGC proposes installing five strain gauge sets on Line 10 and three on Line 15 at high bending strain locations and at key locations within the suspected landslide mass.
- April 20, 2020: High-resolution lidar data commissioned by Enbridge and flown along the TETLP corridor in the fall of 2019 is delivered to BGC.

2.4. Immediate Actions Following the Fleming County Incident

Following the FCI, and the isolation of the impacted valve segment, TETLP mobilized multiple parties to respond and gather data and observations to aid in the causation assessment and emergency response. The data from these initial actions were used through the causation assessment to characterize the Site. Key actions that contributed to the causation assessment and responsible parties can be found in Table 2-4.

Table 2-4. Timeline of actions related to the causation assessment following the FCI.

Action	Date	Responsible Party
Initial mapping and geotechnical observations	May 6, 2020	BGC, TETLP
Locating, staking and surveying Lines 10, 15, and 25 upslope and downslope of the FCI site	May 6, 2020	SGC
Aerial lidar acquisition	May 6, 2020	Quantum Spatial
Three-dimensional (3D) lidar scan of the blast crater and failed pipeline segment	May 6, 2020	DNV
Survey of landslide features and extent	May 7 and 8, 2020	SGC with guidance from BGC
Installation of monitoring hubs downslope of the TETLP corridor within and outside of the surveyed landslide extents	May 11, 2020	SGC with guidance from BGC
Excavation, geologic logging and surveying of Line 10 between GW 11310 and 11350	May 11 to May 14, 2020	Otis Eastern, BGC, and SGC with guidance from DNV
Removal of Line 10 between GW 11310 and 11350	May 13 to May 14, 2020	Otis Eastern
Initial test pitting along the removed section of Line 10	May 15, 2020	Otis Eastern with guidance from BGC

Action	Date	Responsible Party
Additional test pitting along the removed section of Line 10	May 30 to June 2, 2020	Otis Eastern with guidance from BGC
Excavation and removal of Line 15 between GW 11210 and GW 11340	June 3 to June 8, 2020	Otis Eastern
Test pitting along the removed section of Line 15	June 8 to June 9, 2020	Otis with guidance from BGC
Geotechnical drilling between Lines 10 and 15 to confirm depth to bedrock	June 11 to June 13, 2020	BGC
Drilling and installation of Shape Accel Arrays (SAAs) and Inclinometers	July 23 to September 4, 2020	BGC
Long-term Mitigation Construction	September 8 to November 9, 2020	Otis Eastern with guidance from BGC and TETLP
Final Site Restoration	November 10 to November 21, 2020	Otis Eastern with guidance from WSP and TETLP

3.0 METHODS AND DATA RESULTS FOR ASSESSMENT OF GEOTECHNICAL CAUSATION

BGC's geotechnical assessment of the FCI Causation began with an initial field reconnaissance trip on the morning of May 6, 2020. Since then, BGC has continued to evaluate the Site through field-based and desktop analysis methods. Field-based analysis included:

- Geomorphic mapping
- Geologic logging of natural and excavated exposures and boreholes
- Survey and staking of pipeline centerlines
- Logging the excavations related to the removal of Lines 10 and 15.

To supplement the field investigation, desktop evaluation included analysis of the following:

- Bending strain analysis of Line 10 performed using IMU data collected in 2007, 2018 and 2019. IMU data from Lines 15 and 25 were also assessed to further delineate landslide extent and changes in movement rates.
- Aerial imagery, spanning from 1959 to 2018
- Review of published geologic maps and literature pertaining to regional landslide processes
- Review of pre- and post-incident lidar data including pre- and post-incident lidar topographic change detection
- Review of precipitation data from the years preceding the event (1952 to April 2020)
- Review of past TETLP corridor construction activities.

The following subsections present overviews of the assessment methods and present the key results provided by each.

3.1. Post-Incident Field Investigation

BGC arrived on site on May 6, 2020, two days following the FCI. Once on site, BGC began the process of documenting the extent of the landslide, the surficial soil and bedrock characteristics, and assessing the out-of-straight (OOS) on Lines 15 and 25. Other activities included the installation of monitoring pins within the active landslide downslope of the TETLP corridor to document movement within the landslide mass in the months immediately following the FCI and eventually test pitting, drilling and logging the pipeline trench along Line 10 and Line 15. Photographs from the Site are included in Appendix C.

3.1.1. General Site Observations

At the FCI site, the TETLP corridor obliquely crosses a 350 ft high, west-facing slope. The overall slope angle, along the fall line, is 22 degrees and there is a lower angle, 16-degree bench at midslope, where the FCI occurred (see Photo C-1 and Figure 3-1). At the location of the FCI, the rupture of Line 10 created a 60 ft by 25 ft blast crater with the longer dimension oriented subparallel to the alignment of Line 10 (see Photo C-2 and Figures 3-1 and 3-2). The crater walls were unstable and continually sloughed in, precluding safe access to the crater (See Photo C-2). Sloughing on the upslope wall of the crater led to the exposure of Line 15. Seepage was observed flowing into the blast crater from the upslope wall and along the upslope Line 10 trench backfill (see Photo C-2).

On the TETLP corridor, a main scarp (ground cracking with vertical offset) was observed crossing Lines 10 and 15 (see Photo C-3 and Figure 3-2). Tension cracks (ground cracking with horizontal offset) were observed further upslope and over Line 25. The scarp extended off the downslope (north) side of the corridor and a distinct active toe bulge was observed 300 ft downslope of the Site. A detailed description of the landslide is provided in the following section. An additional landslide was observed upslope of the corridor, south of the FCI site. The toe of this landslide was upslope but not over any of the TETLP pipelines (see Figure 3-1).

Outside of the crater, seepage was observed flowing from multiple locations at the ground surface upslope of the FCI site. These areas are shown in Photo C-4 and Figure 3-1. Two distinct seeps were observed over Lines 15 and 25, suggesting that the backfilled pipeline trench may serve as a conduit for seepage. A major seep was observed upslope of Line 25 immediately upslope (southeast) of the Site in an area where shale bedrock was observed at surface along the cut for the TETLP corridor. Free flowing water was observed at this seep.

In-place shale bedrock was only observed at surface on the upslope (southern) side of the TETLP corridor, paralleling Line 25 and on the upper portion of the slope. Sandstone cobbles and boulders were observed at surface throughout the slide mass and on the slopes above. In-place sandstone was observed near the slope crest, overlying in-place shale. Surficial soil at the Site and within the landslide mass was predominantly clay and silt with gravel to boulder-sized clasts of shale and sandstone.

Multiple logging roads were observed on both sides of the corridor, suspected to be from past timber harvest activities (see Section 3.5 for further detail). These roads crisscrossed the Site and were observed going through the main landslide mass downslope of the TETLP corridor (see Figure 3-1).

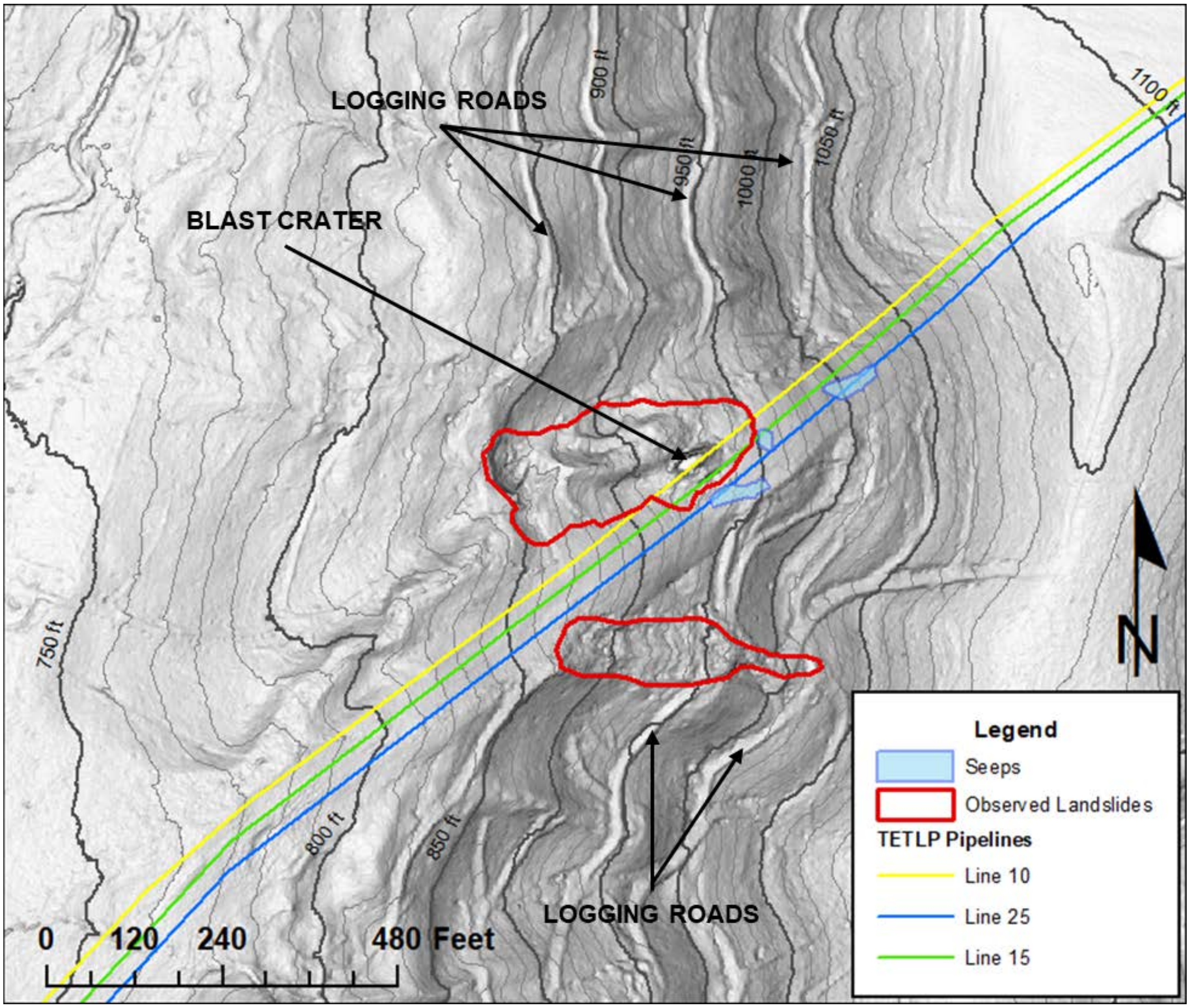


Figure 3-1. Map showing the slope at the FCI site. The blast crater (visible in the lidar imagery) and former logging roads can be seen. Observed landslides and seeps are also shown. Centerline and May 6, 2020 lidar imagery provided by TETLP.

3.1.2. Detailed Landslide Mapping

BGC completed detailed mapping of the landslide at the FCI site by documenting and surveying ground cracks, scarps and toe bulges on and downslope of the TETLP corridor on May 7 and 8, 2020. The FCI had burned away the forest and underbrush on the landslide and the neighboring slope which aided in the direct observation of landslide features (see Photo C-1). Figure 3-2 shows the mapped visible extent of the active landslide. Overall, the landslide length was approximately 370 ft, and the width was approximately 140 ft. The majority of the landslide was downslope of the TETLP corridor, with only the upper 100 ft on the corridor. The landslide was oriented obliquely to the TETLP corridor, at an angle between 20 and 25 degrees to Line 10. As the main scarp was observed crossing Lines 10 and 15 and ground cracks were observed over top of (and parallel to) Line 25, OOS measurements were completed to estimate the additional

OOS on the pipelines that may have occurred since the previous May (Line 15) and June (Line 10) 2019 IMU data and July 2019 ground inspection.

A 3D lidar scan of the Line 10 blast crater was completed on May 6, 2020, prior to the use of heavy equipment and immediate construction activities on the site, and provided by DNV to assess OOS measurements along Line 10 immediately after the FCI. The actual OOS at the exact time of the FCI is suspected to have been slightly less, as caving of the blast crater further deflected Line 10; however, the instability of the ground around the crater prohibited any earlier or more accurate measurements (see Photo C-2). SGC took survey points along the top of Line 10 during the cutout of the failed section of pipeline and using the combination of the DNV 3D scan and the SGC surveyed centerline, the OOS of Line 10 was approximated to be 7.4 ft at the time of the FCI, approximately 3 ft more than the July 2019 field measurement and the June 2019 IMU measurement. See Section 3.1.1 for further discussion on the Line 10 OOS measurements.

The unstable ground conditions caused by the blast crater limited direct access to the highest displaced section of Line 15, though rudimentary OOS measurements indicated that approximately 205 ft of Line 15 was deflected with a maximum OOS of 3.75 ft through the slide mass. This was in a similar range as the pre-incident OOS measurements on Line 15 (up to 3 ft), indicating that Line 15 did not experience nearly the same amount of movement as Line 10. Ground staking completed along Line 25 indicated two sections of line that had a marginal downslope OOS along a 200 ft length upslope of the landslide extents. The OOS were 0.7 ft over 85 ft and 1 ft over a 95-foot length of pipeline. Given the small magnitude of the OOS and that they were separate and not continuous, these OOS trends were more consistent with OOS related to construction rather than downslope movement of Line 25.

Downslope and off the TETLP corridor, lateral cracks were observed along the landslide flank east and west of a prominent gully feature. Stretched tree roots were observed in the cracks, and unburned soil was also observed (see Photo C-5). The uncharred soil indicated that additional movement had occurred within the three days following the FCI. At the base of the landslide two distinct toe bulges were observed. The toe bulges were observed overriding living trees and the soil was saturated (Photo C-6).

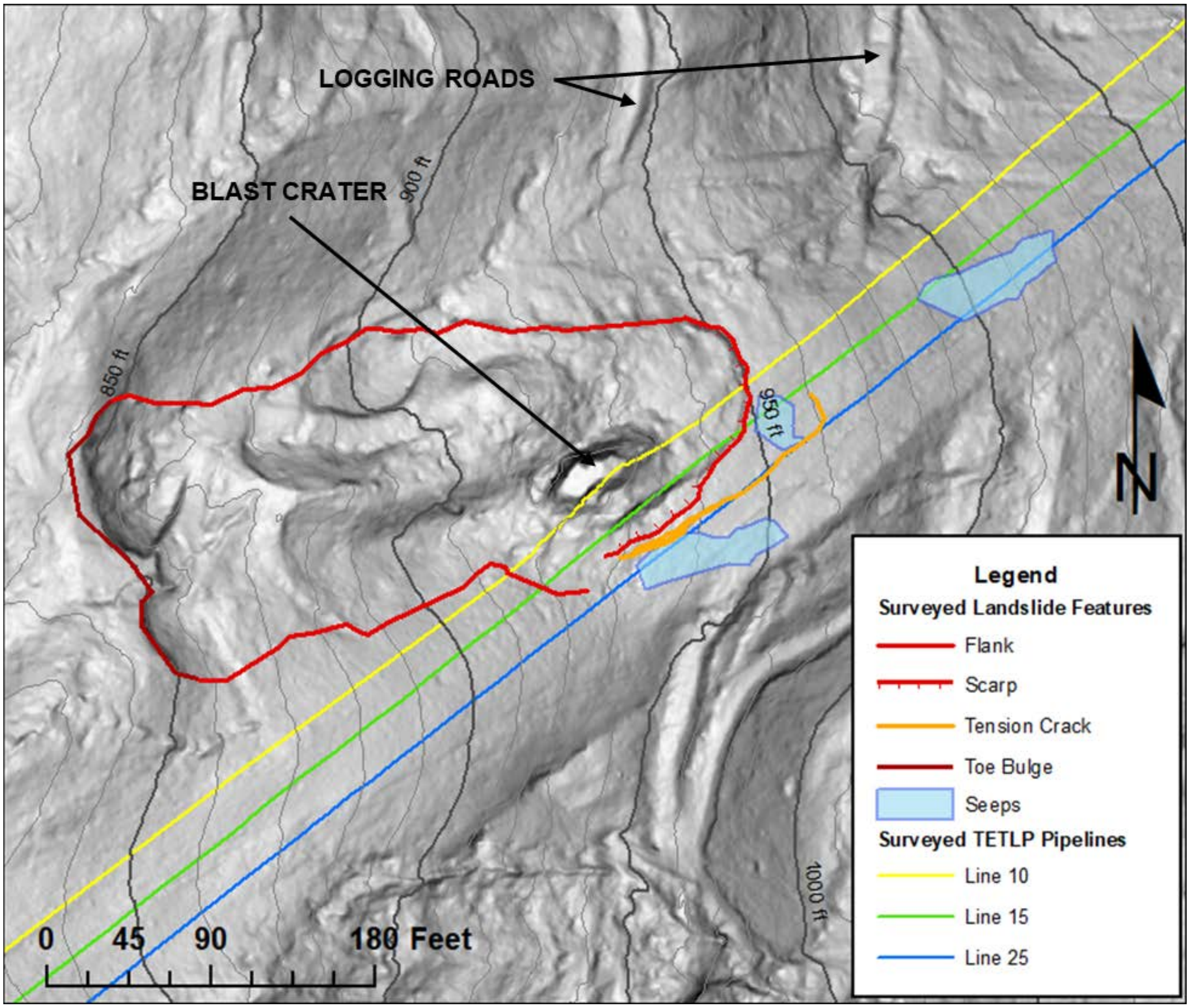


Figure 3-2. Map showing the surveyed landslide features at the FCI site, the blast crater (visible in the lidar imagery) and former logging roads. Surveyed centerlines, landslide extents and seepage extents provided by SGC. May 6, 2020 lidar imagery provided by TETLP.

3.1.3. Landslide Monitoring Hubs

Nine survey monitoring hubs were installed downslope of the TETLP corridor by SGC on May 11, 2020 to monitor ground movement within the landslide mass. The monitoring hubs consisted of 2-ft lengths of rebar driven into the ground. Seven hubs were installed within the landslide mass while two hubs were installed in what was assumed to be stable ground based on the detailed landslide mapping (see Figure 3-3). SGC surveyed the position of the hubs daily except when no construction activity was occurring on the Site. This was done to evaluate the rate of ground movement and observe the impact of rainfall and construction activities (see Figure 3-4). Appendix D contains a table with the baseline coordinates and the cumulative displacement of the monitoring hubs up until hub removal for slope mitigation construction (September 8, 2020) (Figures D-1). Appendix D also contains plan views of the monitoring hubs (Figure D-2) and the movement vectors (Figure D-3). The monitoring hubs within the landslide mass moved between

1.95 and 4.03 ft between May 12 and September 8, 2020. This movement occurred in distinct episodes, with the greatest movement of approximately 0.8 ft occurring within two days following a precipitation event when 4 inches of rain fell within a 48-hour period (see Figure 3-4).

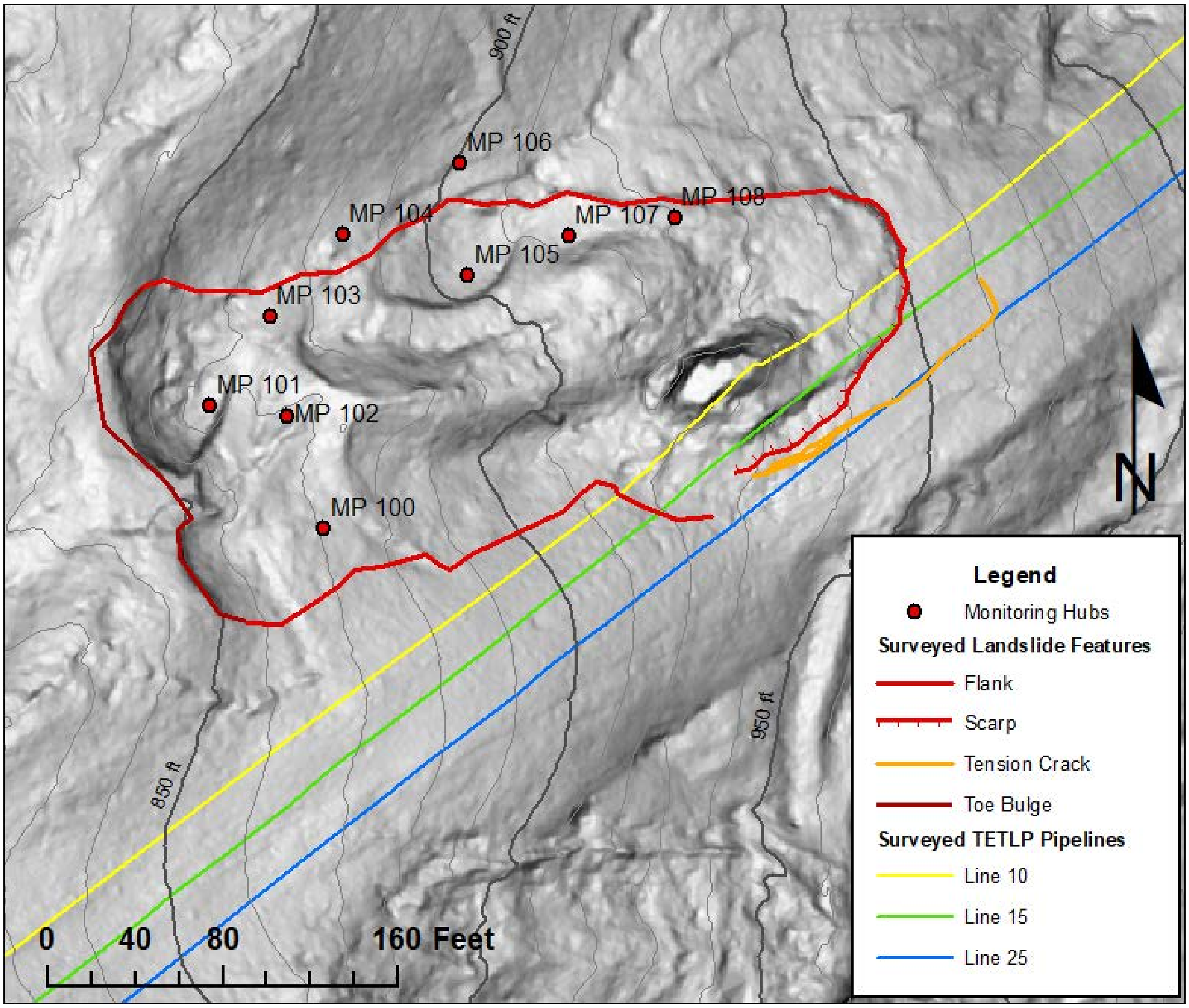


Figure 3-3. Map showing the landslide monitoring hubs installed downslope of the TETLP corridor at the FCI site on May 11, 2020. Surveyed centerlines, landslide extents and monitoring hubs provided by SGC. May 6, 2020 lidar imagery provided by TETLP.

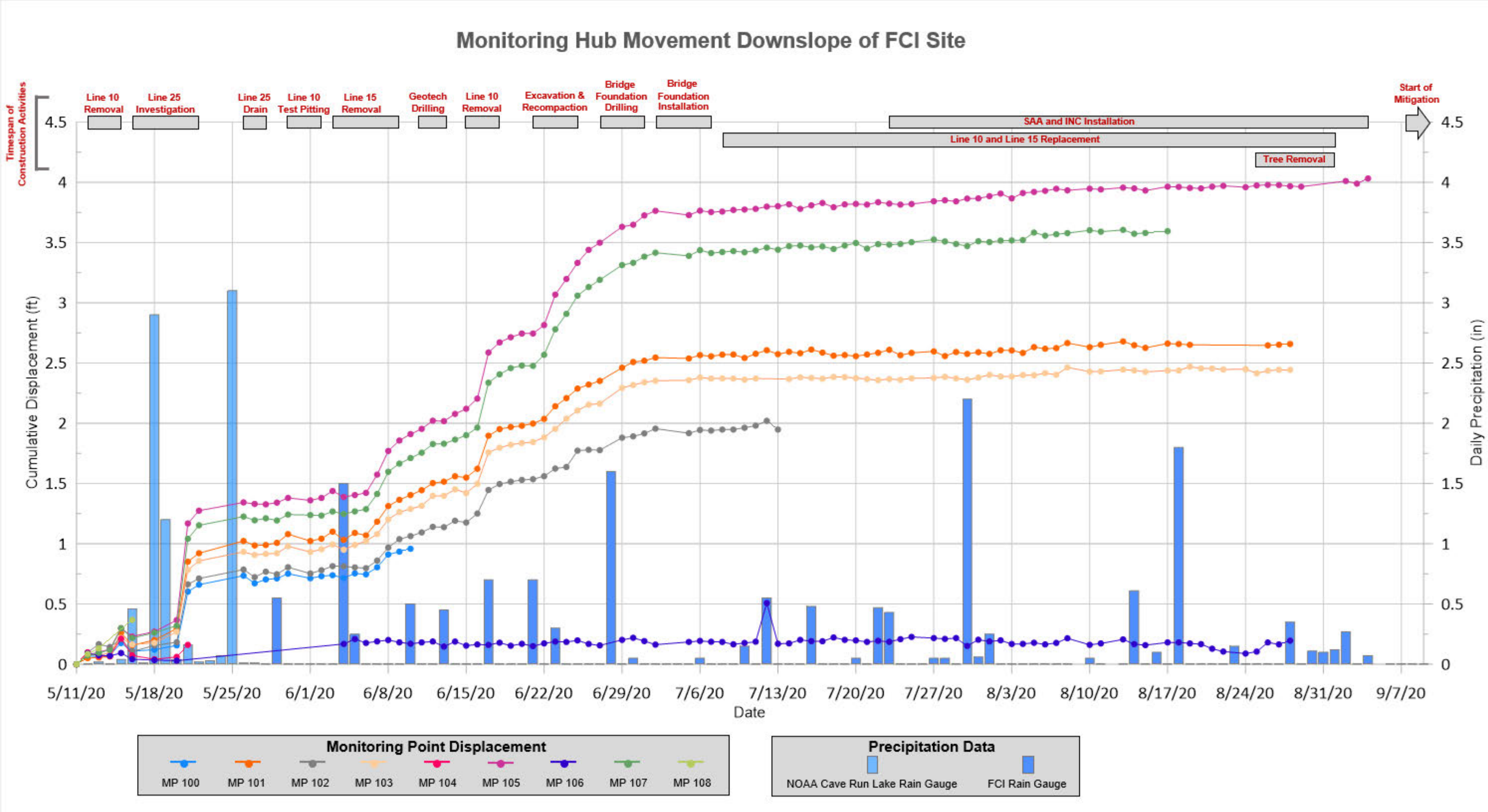


Figure 3-4. Cumulative displacement plot of downslope landslide monitoring hubs at FCI site between installation on May 11, 2020 and September 8, 2020. 24-hour period rainfall amounts and construction activities are also shown. Survey data provide by SGC. Rainfall data obtained from the Cave Run rain gauge (National Oceanic and Atmospheric Administration, 2020A) and FCI rain gauge data provided by WSP.

3.1.4. Subsurface Investigation

A subsurface investigation was completed to document the soil and rock, observe the material Line 10 was installed within and evaluate the depth of the slide plane on the TETLP corridor. The investigation included documenting the excavations for the removal of Lines 10 and 15, logging test pits completed across the corridor and logging geotechnical boreholes in the locations where the depth of the slide plane was too great for typical excavation. Appendix E contains photo logs of the test pits, Appendix F contains the borehole logs and notes from the drilling program and Appendix G contains results of the soil testing program. A timeline of the investigation is in Table 3-1, below. Cross sections showing the interpreted bedrock surface at the Site are provided in Appendix H.

Table 3-1. Timeline of subsurface investigation.

Date	Activity	Key Finding
May 11 through May 14, 2020	Excavation and removal of Line 10 between GW 11310 and 11350.	Established that Line 10 transitions from bedrock to colluvium 10 ft downstream of GW 11310. Directly observed slip plane at transition from bedrock to colluvium in Line 10 trench.
May 15, 2020	Test Pits 05 through 09 completed along and downslope of the removed section of Line10	Provided an initial bedrock profile beneath Line 10 created.
May 30 to June 2, 2020	Test Pits 10 through 20 are completed along the removed segment of Line 10	Clarified the bedrock profile beneath Line 10.
June 3 to 8, 2020	Excavation and removal of Line 15 between GW 11210 and GW 11340	Established the length of Line 15 buried within colluvium.
June 8 to 9, 2020	Test Pits 21 through 24 completed along the removed segment of Line 15	Initial bedrock profile beneath Line 15, indication that sandstone bedrock observed in test pits may not be in place.
June 11 to 13, 2020	Drilling completed in areas of suspected sandstone boulders and areas where bedrock was too deep to expose during test pitting.	Proved out that sandstone encountered in test pits was not in place, but was rather large, tabular boulders. Further established depth to bedrock through the middle section of the slide mass.
June 15 to June 16, 2020	Removal of remaining length of Line 10 between GW 11260 and 11380,	Confirmed upslope location where Line 10 transitions to a bedrock trench.
July 23 to September 4, 2020	Drilling and installation of Shape Accel Arrays (SAAs) and Inclinometers	Established depth to bedrock within the slide mass and downslope of the landslide toe. Determined the depth of movement within the landslide mass.

Observed Soil and Bedrock

Line 10 is situated in colluvium (past landslide deposits) for a length of approximately 165 ft, between 10 ft upslope of GW 11310 to 5 ft upslope of GW 11360, and in weathered bedrock for an additional 80 ft upslope, just upslope of GW 11380. Line 15 is situated in colluvium for a length of approximately 160 ft between GW 11260 and GW 11310 (see Appendix H). The colluvium both Lines 10 and 15 are buried within at the Site appears to infill an older gully feature within the underlying shale bedrock that roughly parallels and likely controls the extents of the landslide. Colluvium was low to high plasticity clay, with gravel to boulder sized clasts. Large tabular fine-grained sandstone boulders were common within the material. These boulders are likely from the sandstone formation near the crest of the slope. A gray, high plastic clay was observed within the colluvium either just above the contact with weathered bedrock or above the sandstone boulders. Data from the SAAs indicate the slip surface of the landslide was confined to the colluvium and did not extend into the underlying bedrock.

Fifteen soil samples were collected for geotechnical analysis. Sample numbers, locations, and sample material are summarized in Table G-1 in Appendix G. Samples were analyzed for Atterberg Limits, Grain Size and Moisture Content and results are included in Appendix G.

In-place bedrock consisted of laminated to thinly bedded shale. Typically, there was a 1 to 3-foot-thick weathered zone of shale overlying lightly weathered, black shale. This weathered zone had the overall structure and undisturbed bedding of the less-weathered underlying shale but was soft, easily excavated and soil-like. In general, the depth to bedrock increased through the middle of the slide mass, with bedrock up to 30 ft below ground surface in the center of slide mass along Line 10 and shallowing to be within 5 ft to 10 ft of ground surface upslope and downslope of the visibly active slide mass. The bedrock surface drops off steeply from the upslope (Line 25) side of the TETLP Corridor, downslope of Line 10 (see Figures H-5 through H-9 in Appendix H).

Groundwater Conditions

Seepage was observed from three distinct locations during the subsurface investigation: the pipeline trench backfill, the bedrock colluvium contact, and fractured beds within the in-place shale, with the dominant source being the fractured shale beds. During test pitting, the excavation of Lines 10 and 15 upslope of the Site, and during later excavation and re-compaction efforts, distinct hard and highly fractured beds within the shale were saturated and free water was often observed.

Soil within the excavations for Lines 10 and 15 was generally wet, particularly in fill immediately adjacent to pipelines. This indicated that groundwater was preferentially following the backfilled pipeline trenches at the Site, likely sourced from where Lines 10 and 15 are trenched within the shale upslope of the Site. Any seepage intercepted by the pipeline trenches upslope of the landslide appeared to be preferentially flowing along the backfilled trenches downslope into the active slide mass.

In test pits and along excavations for installation of interim drainage measures, seepage was also observed at the contact between the colluvium and underlying shale. This seepage was likely sourced from both surface water and the groundwater-bearing beds within the underlying shale. Surface water would feed this seepage source through typical infiltration but also via the observed tension cracks within the landslide mass. Tension cracks associated with episodic and rapid movement can intercept surface water that would otherwise have been shed off the slope and serve as conduits, allowing surface water to quickly infiltrate and reach this contact or the landslide slip surface.

3.2. Site Geology

BGC reviewed publicly available geologic maps and geohazard publications to identify whether the Site was in known landslide-prone soils or bedrock. The Site is located within the Eastern Hills of Fleming County on the western edge of the Appalachian Plateau physiographic province. To the northwest is the Interior Lowlands province, and to the southeast is the Ridge and Valley province (Fenneman, 1938). The Unglaciated Appalachian Plateau covers eastern Ohio, most of eastern Kentucky, West Virginia, eastern Tennessee and western Pennsylvania. The topography of the Fleming County Eastern Hills consists of flat-topped hills bisected by narrow to broad valleys, and steep to very steep slopes. These conditions characterize the physiographic province and are the result of incision of a dendritic drainage system into relatively erodible sedimentary bedrock. The local relief ranges from about 300 ft to 450 ft (McDowell et al., 1971).

The bedrock geology of the Eastern Hills consists of Silurian and Devonian shales forming the lower and main portions of slopes and Mississippian sandstone and shale at the crest of the flat-topped hills. Figure 3-5 shows the bedrock geology from McDowell et al. (1971) overlain on aerial lidar imagery at the FCI Site. Mapping by McDowell et al. (1971) shows the lower portion of the slope at the Site to be within the Silurian Crab Orchard formation, the main steep portion of the hill to be within the Devonian Ohio Shale and the upper portion of the slope to be within the Mississippian Bedford and Sunbury Shales. The crest of the slope is within the Borden Formation which consists of the Farmers Member Sandstone capped by the Nancy Member Shale. The landslide occurred within colluvium overlying the Ohio Shale.

The Ohio Shale is a dark gray to black fissile shale that often has a hydrocarbon odor and is mapped as 150 ft to 220 ft thick in the vicinity of the Site. The shale weathers to a gray to light brown clay soil. The unit is noted for forming steep slopes and is often well exposed (McDowell et al., 1971). The Ohio Shale is the rock unit in which the FCI site is located and was observed during the subsurface investigation at the Site. The upper contact is marked by a slope break with the overlying Bedford shale which forms lower angle benches on slopes in the region.

The Bedford Shale is a greenish-gray shale with numerous thin siltstone beds. It weathers to reddish or yellowish-brown clay and is typically covered with colluvium. Locally, the unit is 10 to 40 ft thick. The upper contact is marked by a change of slope as the overlying Sunbury Formation forms steeper slopes, similar to the Ohio Shale. Like the Ohio Shale, the Sunbury Formation is dark gray to black and also has a hydrocarbon odor. The Sunbury tends to be 15 to 20 ft thick in the area. The upper contact is marked by a shift to the fine-grained sandstone of the overlying Farmers Member of the Borden Formation (McDowell et al., 1971).

At the Site, the crest of the slope is marked by the Farmers Member. The rock is typically a very fine-grained sandstone, with beds up to 4 ft thick near the base. Shale content increases in the upper portion of the unit, eventually transitioning to the interbedded shale, siltstone and sandstone of the Nancy Member, which forms the bedrock on the flat top of the hills in the area. The Farmers Member is noted as 33 to 95 ft thick in the area (McDowell et al., 1971).

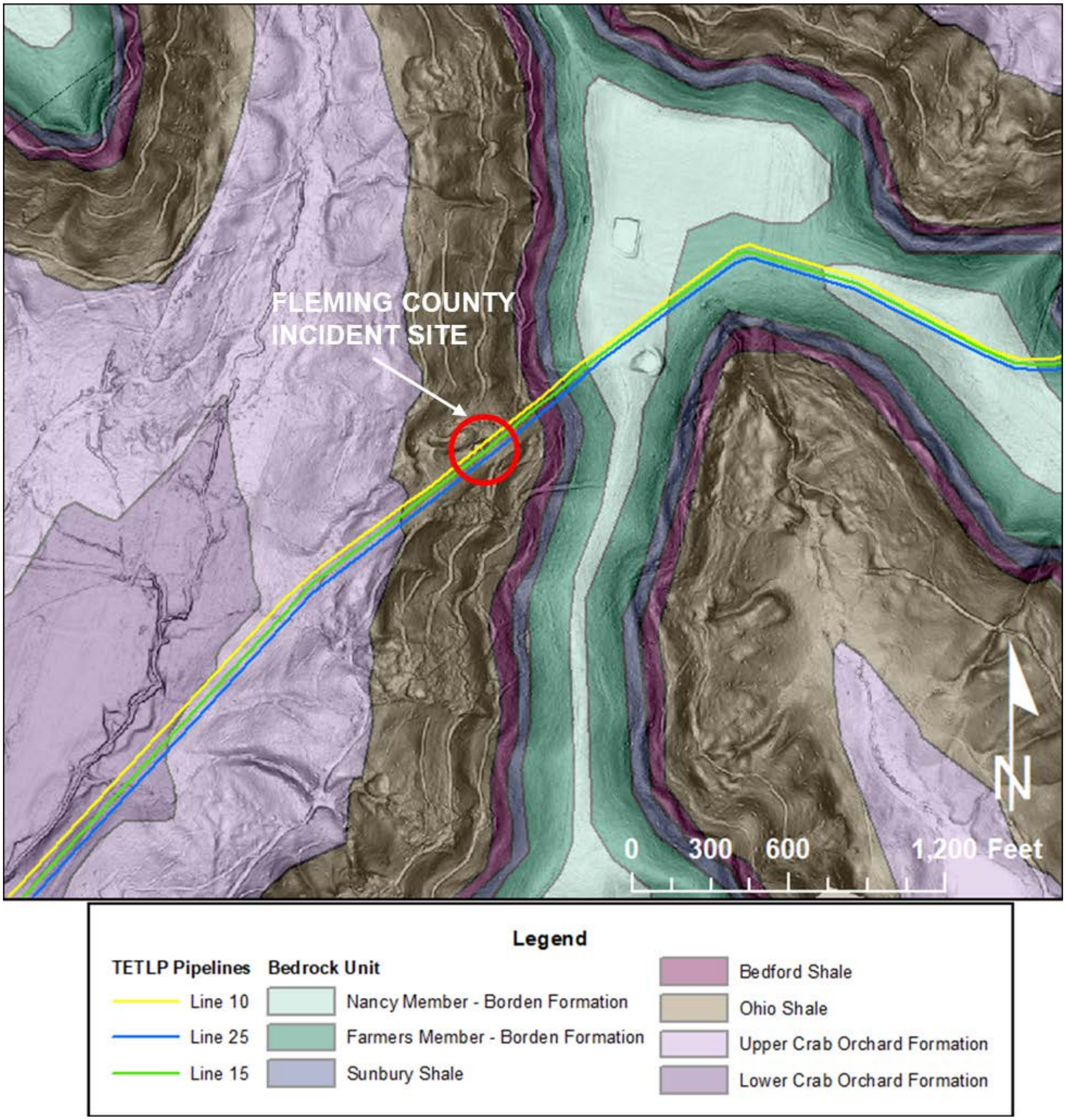


Figure 3-5. Geologic map of the Site. Geology modified from McDowell et al. (1971). Centerlines and lidar base image provided by TETLP.

Throughout the unglaciated Appalachian Plateau, abundant moisture, relatively weak bedrock, thick colluvium, and steep slopes create high landslide susceptibility and high rates of landslide occurrence (Radbruch-Hall et al., 1982). These characteristics describe the conditions in Eastern Kentucky around the Site. Carey and Buckles (2008) specifically note weathered shale and colluvium on slopes composed of the Ohio, Bedford, and Sunbury Shales are prone to slope movement, due to the low strength of the clays derived from the shale and the destabilizing impacts of elevated pore-water pressure from seepage within fractured beds in the shales. Slope composed of the underlying Crab Orchard Formation are also prone to slope movement due to similar characteristics.

Using the terminology of Varnes (1978), slope failures in the Appalachian Plateau include: slides (earth and rock slumps, debris slides), flows (debris flows, earth flow, debris avalanche, and soil creep), complex movement, and falls (rockfall). Many failures occur in the high clay-content colluvial soil (D'Appolonia et al., 1967; Gray et al., 1979) as rotational slumps or earthflows (Gray et al., 2008).

3.3. Inertial Measurement Unit Assessment

Data from past ILI tool runs for Lines 10, 15 and 25 were assessed to evaluate bending strains at the FCI site and on the overall slope to assess which strains were induced by ground movement rather than construction practices as well as investigate changes in the bending strain over time. The OOS measurements derived from the IMU data were also used to estimate an approximate equivalent ground displacement which could be used to calculate ground movement rates and changes in ground movement rate over time. This comparison of the IMU datasets over time for each pipeline also indicates that the bending strains on Line 10 and 15 were related to ground movement and that ground movement rates differed over the two pipelines and accelerated over time. Section 3.3.1 discusses the changes in bending strain and OOS observed in the IMU data, while Section 3.3.2 discusses the inferred ground movement of the landslide mass calculated from the OOS measurements.

3.3.1. Bending Strain and Out-of-Straight Assessment

As part of the FCI causation assessment, BGC reviewed IMU data from past runs on all three pipelines within the TETLP corridor. IMU plots and raw IMU data was provided by Baker Hughes. These plots are provided in Appendices I, J, and K for Lines 10, 15 and 25, respectively. The OOS plots for each plot along Lines 10, 15 and 25 are shown in Figure 3-6. From this figure alone, it is apparent that the IMU datasets for Lines 10 and 15 show increasing horizontal OOS through time, while Line 25 does not. The positions of maximum horizontal OOS on Lines 10 and 15 are located within the landslide extent and the affected lengths of pipeline extend outside the landslide margins. Further insight was gained by reviewing the changes in strain and OOS within the IMU data between time intervals.

BGC reviewed Line 10 IMU-derived bending strains from June 2007, April 2018, and June 2019. The three Line 10 datasets showed that the magnitude of bending strains at the Site grew through time. The strain signatures, when oriented as if the measurement tool was travelling from downslope to upslope (southwest to northeast), showed a ‘W-shape’ sequence of left bending, right bending, and left bending. This ‘W-shape’ within the horizontal strain signatures was approximately 250 ft long, began near girth weld (GW) 11310, and ceased near GW 11380. The vertical strains also showed a ‘W-shape’ pattern of overbending, sagbending, and overbending across a similar interval. This ‘W-shape’ pattern in the downslope direction over multiple pipe joints is completely consistent with being caused by ground movement patterns at the Site. The 250 ft length impacted in the IMU data is greater than the 165 ft of Line 10 within the landslide as the pipeline trench does not transition to competent bedrock immediately on the upslope side of the landslide, but rather is trenched within weathered bedrock past GW11380. This would allow for some of the deformation and bending strain from ground movement to be accommodated outside of the landslide mass.

Even in the baseline June 2007 IMU data for Line 10, it is evident that slope movement at the FCI site had already affected Line 10 and created some degree of downslope pipeline translation. This can be seen in the formed horizontal bend between GW11320 and GW11330 showing reversal in the horizontal bending strain plot (see Figure I-1 in Appendix I). Based on an assessment of the pipeline orientation upstream and downstream of this bend, BGC was able to estimate that 1.3 ft of OOS had occurred on Line 10 prior to the baseline June 2007 ILI tool run, where the pipeline originally had an uphill side bend that was inverted by slope movements up to that point (Figure 3-7). Given that the failed section of Line 10 was not originally straight, but OOS measurements are made assuming a straight pipeline segment, this additional OOS of 1.3 ft was added to OOS measurements made from later IMU data and field OOS measurements (originally estimated to be 7.4 ft as described in Section 3.1.2).

The bending strains for each IMU dataset along Line 10 and the bending strains at girth welds 11310, 11320 and 11330, discussed below, are provided in Table 3-2. The June 2019 IMU data for Line 10 indicated that GW 11330, the weld that later ruptured, had 0.364% bending strain. The overlaid IMU datasets showed approximately 0.19% growth at GW 11330 between June 2007 and April 2018 (average annual growth rate of 0.017%), then approximately 0.011% growth between April 2018 and June 2019. Nearby GW 11310 had a higher reported bending strain of 0.445% in June 2019, with approximately 0.20% growth between June 2007 and April 2018 (average annual rate of 0.017%). The strain growth between April 2018 and June 2019 was approximately 0.009%, similar to the rate at GW 11330. The June 2007 and June 2019 IMU showed approximately an additional 4 ft of horizontal OOS growth in the downslope direction for a total OOS on Line 10 of approximately 5.1 ft by June 2019. The increase in the peak total bending strain over time and the increase in OOS in the downslope direction make it clear that slope movement was impacting Line 10; however, the rate of change of OOS and strain was relatively constant (i.e., not accelerating) between June 2007 and June 2019.

Table 3-2. Line 10 girth weld and pipe body bending strains from IMU data.

IMU Run Date	Peak Total Bending Strain[1]	Change	Girth Weld Total Bending Strain (%)					
			GW11310	Change	GW11320	Change	GW11330 (Rupture)	Change
June 2007[2]	0.352	-	0.241	-	0.212	-	0.165	-
April 2018[3]	0.926	0.574	0.436	0.195	0.243	0.031	0.353	0.188
June 2019[4]	1.050	0.124	0.445	0.009	0.253	0.01	0.364	0.011

Notes:

1. Peak total bending strain is the peak bending strain outside of formed bends. At the Site, these all occurred within the pipe body, not on girth welds.
2. 2007 strain values are determined by assessing raw data because no vendor-provided metrics have been provided for the 2007 run alone.
3. Baker Hughes GE (July 19a, 2019).
4. Baker Hughes GE (September 23, 2019).

The bending strains for each IMU dataset along Line 15 and the bending strains at girth welds 11260, 11280 and 11310, discussed below, are provided in Table 3-3. Four IMU datasets were available for Line 15: April 2011, May 2017, May 2019, and October 2019. The four datasets showed increasing bending strain magnitudes over approximately 250 ft. The horizontal strains in each dataset made a similar ‘W-shape’ pattern as the Line 10 data (left bending, right bending, left bending), but with smaller total magnitudes. The maximum bending strain on a girth weld in October 2019 was approximately 0.19% at both GWs 11260 and 11310. GW 11260 showed approximately 0.08% growth between October 2019 and April 2011 (average annual growth rate of 0.01%). Line 15 GW 11310 had a ‘hat’ signature, characteristic of girth weld misalignments. The October 2019 bending strains showed an apparent decrease of 0.03% since 2011; slight changes at girth weld misalignments are commonly observed in repeat bending strain assessments received as part of the TETLP IMU catalogue. The strain differences between May and October 2019 did not show consistent patterns that indicate increasing ground movement impact. The April 2011 and October 2019 IMU showed approximately an additional 2.6 ft of horizontal OOS growth in the downslope direction for a total OOS on Line 15 of approximately 3 ft. Similar to Line 10, the IMU data indicates that the Line 15 bending strain was also induced by slope movement, although not to the same magnitude as Line 10.

Table 3-3. Line 15 girth weld and pipe body bending strains from IMU data.

IMU Date	Peak Total Bending Strain	Change	Girth Weld Total Bending Strain (%)					
			GW11260	Change	GW11280	Change	GW11310	Change
April 2011[1]	0.287	-	0.111	-	0.12	-	0.227	-
May 2017[1]	0.312	0.025	0.22	0.109	0.107	-0.013	0.171	-0.056
May 2019[2]	0.331	0.019	0.177	-0.043	0.142	0.035	0.212	0.041
October 2019[2]	0.31	-0.021	0.188	0.011	0.148	0.006	0.196	-0.016

1. Baker Hughes GE (July 19b, 2019).
2. Baker Hughes GE (September 6, 2019).
3. Baker Hughes GE (July 24, 2020).

Only two IMU bending strain reports were available for Line 25 at the Site, from April 2014 and January 2020 (Baker Hughes GE, April 13, 2020). While an IMU was run in July 2007 on Line 25, a full bending strain report was not issued due to data quality issues elsewhere on the segment. Due to the lack of report, no discrete bending strain features were reported from the July 2007 data. The raw July 2007 data was considered during the Site assessment and can be seen in Appendix K. The April 2014 and January 2020 Line 25 strains did not have vendor-reported strain features that were co-located with the Line 10 and 15 strains. The maximum January 2020 bending strain on a girth weld in the vicinity of the strains on adjacent lines was 0.196% at Line 25 GW 11200 and the bending strain pattern did not show downslope OOS. This indicates that Line 25 was likely not impacted by slope movement.

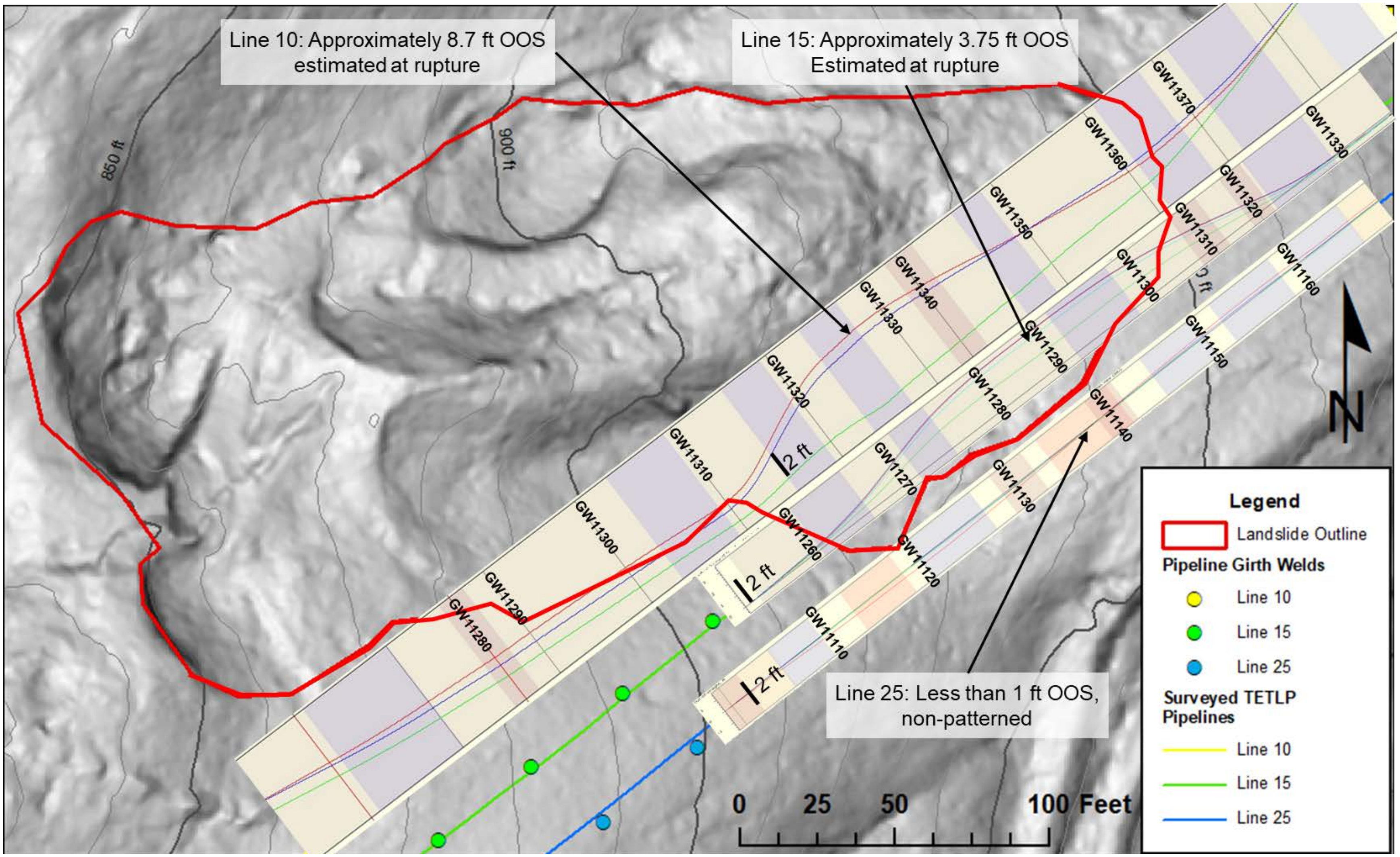


Figure 3-6. Plan view showing Baker Hughes IMU plots shown at a shared, exaggerated scale and aligned to the girth weld positions on the slope. Note the relationship to the surveyed landslide extent and the OOS sections on the IMU plots. Full size IMU plots can be found in Appendices I, J, and K. November 2019 lidar imagery provide by TETLP. Girth weld locations and IMU plots provided by Baker Hughes.

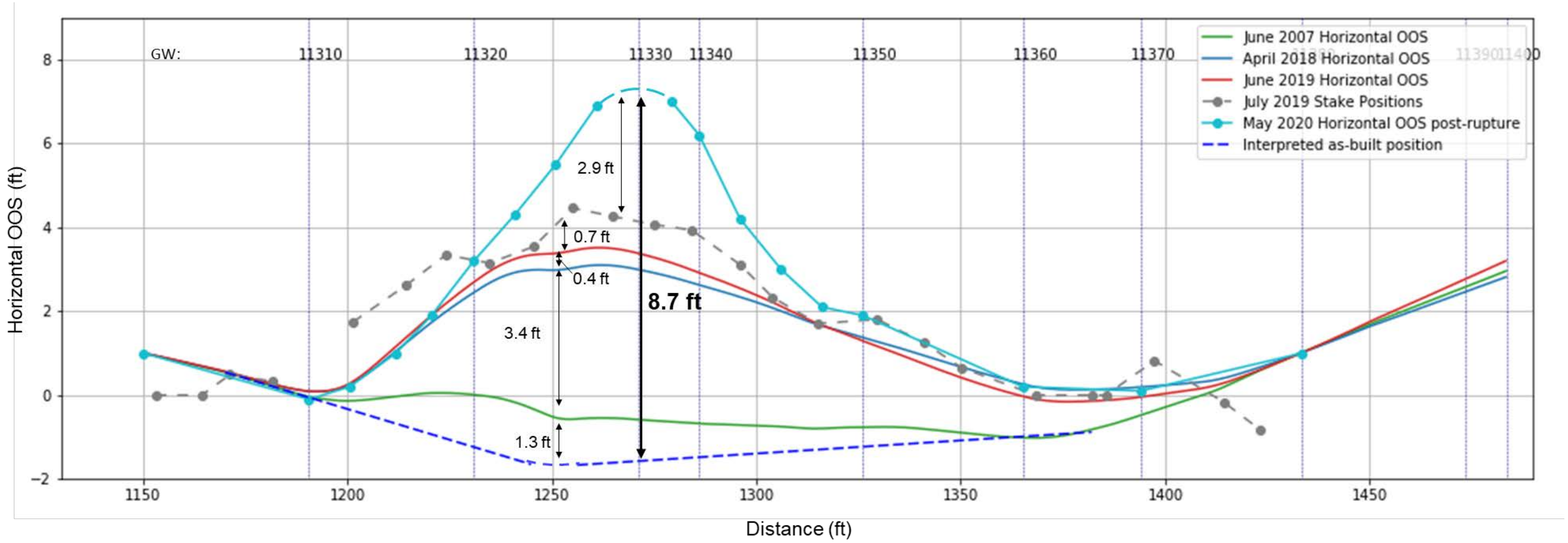


Figure 3-7. Overlaid horizontal OOS datasets from IMU, focused to the affected length of Line 10. The as-built position was interpolated by considering the 2007 pipeline position and rolled bends. A total of 5.1 ft OOS is estimated as of June 2019.

3.3.2. Inferred Ground Movement Calculations

If the vector of slope movement is known or can be estimated, the OOS measurement of the pipeline can be used to calculate the equivalent ground movement needed to produce that OOS. The estimation is calculated using trigonometry and is based on the assumption the OOS dimension can approximate the perpendicular component of slope movement to the pipeline. This is because as the soil moves obliquely to the pipeline the axial component of movement will tend to slide along the pipeline and induce some degree of axial strain (not measurable by OOS measurements), while the lateral component of movement will displace the pipeline laterally. Figure 3-8 illustrates this concept. This assumption is not completely true based on the rigidity of the pipelines; however, it does provide a lower bound on the amount of ground movement that has impacted the pipelines for a scenario where the pipelines started with a straight or near straight orientation.

At the Site, the OOS measurement was divided by the Sine of 23° (based on the orientation of the landslide being between 20 and 25° to the orientation of the TETLP pipelines). Based on this calculation, the OOS measurements have been used to calculate the equivalent ground movement displacement necessary to produce the OOS measurements for both Lines 10 and 15. The various OOS measurements from the IMU assessments and measurements made following the FCI as well as the equivalent ground displacements can be found in Table 3-4 for Line 10 and Table 3-5 for Line 15. The ground movement rates, calculated by dividing the equivalent ground movement by time have also been provided in these tables. As can be seen in these tables, the equivalent ground displacement for Line 10 at the time of the FCI was approximately 23 ft, while the ground displacement for Line 15, approximately 25 feet upslope of Line 10, was only 10 ft. This indicates that Line 10 was within a much more active portion of the landslide than Line 15 and may explain how Line 15 survived the slope movement while Line 10 failed. It is also notable that ground movement accelerations are evident based on these movement rates particularly between April 2018 and the FCI on Line 10 and October 2019 and the FCI on Line 15. The accelerations were nearly four times greater on Line 10 than Line 15, further indicating that Line 10 was in a more vulnerable position than Line 15.

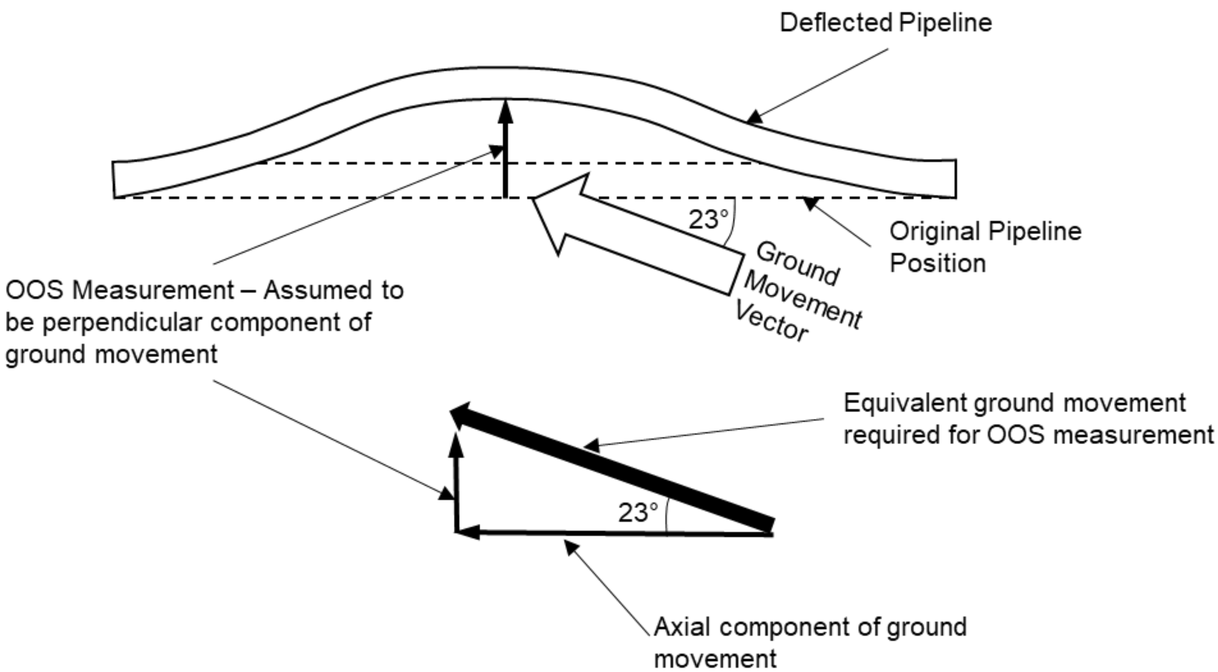


Figure 3-8. Simplified schematic of how equivalent ground movements were calculated from OOS measurements.

Table 3-4. Line 10 OOS measurements and equivalent ground movement.

	June 2007[1,2]	April 2018	June 2019	May 2020 (FCI)[4,5]
OOS Measurement[3] (ft)	1.3	4.7	5.1	8.7
Equivalent Ground Movement (ft)	3.3	12.0	13.1	22.3
Ground Movement Rate (ft/yr)	0.064	0.8	0.9	10.05

Notes:

1. OOS measurement estimated based on reversal of formed bends and trajectory of the pipeline upstream and downstream of the bend.
2. The ground movement rate up to the baseline OOS reading is calculated by dividing the baseline OOS measurement by the total time between the date of the baseline and the installation of Line 10.
3. OOS measurements have an additional 1.3 ft added, based on the estimated pre-2007 OOS.
4. OOS measurements estimated from the DNV 3D lidar scan as 7.4 ft, with 1.3 ft added to account for the pre-2007 OOS. See Section 3.1.2 for further details.
5. May 2020 ground movement rate is for the time period between the June 2019 IMU data and May 2020, due to level of error within the ground staking measurements (+/- 1 foot) completed during the July 2019 ground inspection. Given the short time period between the June 2019 IMU and July 2019 field OOS measurements, the error bounds of the staking could provide a broad range of potential ground movement rates.

Table 3-5. Line 15 OOS measurements and equivalent ground movement.

	April 2011[1]	May 2017	May 2019	October 2019	May 2020 (FCI)[2]
OOS Measurement (ft)	1.4	2.6	2.9	3	3.75
Equivalent Ground Movement (ft)	3.6	6.7	7.4	7.7	9.6
Ground Movement Rate (ft/yr)	0.062	0.5	0.4	0.6	2.1

Notes:

1. The ground movement rate up to the baseline OOS reading is calculated by dividing the baseline OOS measurement by the total time between the date of the baseline and the installation of Line 15.
2. OOS measurement measured during BGC field investigation. See Section 3.1.2 for further details.

3.4. Lidar Change Detection

Airborne lidar scanning (ALS) data were collected at the Site in 2017 (no month provided), November 2019, and May 6, 2020. Summary details on each dataset are outlined in Table 3-6. It is important to note that the post-incident lidar data (May 6, 2020) was collected prior to any heavy equipment disturbing the Site and is considered representative of the topography immediately following the incident. Other than the blast crater and associated debris, the rupture and fire are not anticipated to have caused measurable ground movement downslope of the TETLP corridor compared to the days prior to the FCI. The ALS data were used to analyze topographical changes at the Site by evaluating the 3D spatial change through time, referred to as lidar change detection (LCD), as well as through examination of profiles cut through the data at key locations.

Table 3-6. Airborne lidar scanning technical specifications.

Date	Source	Bare earth resolution
2017 (No month provided)	Kentucky state repository	2 points per square meter
November 2019	Quantum Spatial	4 points per square meter
May 6, 2020	Quantum Spatial	10 points per square meter

With the three sets of ALS data, six LCD analyses were conducted at various scales. Key findings from the LCD analysis and examination of profiles are reported in Table 3-7, Figure 3-9 and Figure 3-10. Figure 3-9 illustrates the change detection results in the vicinity of the blast crater for 2017 versus November 2019 and November 2019 versus May 2020 alongside three profiles, positioned at key locations, through the 2017, 2019 and 2020 ALS datasets. Analysis of the profiles illustrate the direction of movement across the landslide mass as well as an acceleration in movement between November 2019 and May 2020 compared to 2017 vs November 2019. The upper portion of the slide mass was dropping vertically (Section A-A'), the mid slope was translating horizontally (Section B-B') and the toe was up-thrusting (Section C-C'). As can be seen in Sections B-B’ and C-C’, lateral movement rates within the slide mass are estimated to have increased between 6 and 20 times between the 2017 to November 2019 and the November 2019 to May 2020 time periods. Figure 3-10 shows that while local landslides had similar amounts of ground movement between 2017 and 2019, the landslide at the Site was the only slide that had appreciable movement between November 2019 and May 2020. The full suite of results from the LCD assessment can be found in Appendix L.

Table 3-7. Findings from the lidar change detection analysis (key observations bolded).

Date Range	Figures for reference	Observations
2017 to Nov. 2019	Figure L-1	• Four active landslides on western facing slopes. • All landslide scarps are near elevation 948 ft. • Two landslides with visible toe bulges are near elevation 848 ft.
2017 to Nov. 2019	Figure L-4 and L-7	• Headscarp and toe bulge of the landslide at the Site are visible. • Differential change along the headscarp at the Site approximately 1.5 to 2.0 ft. • Differential change at the toe at the Site approximately 1.0 to 2.0 ft. • Moderate activity observed in the landslide on the southern side of the TETLP corridor.
Nov. 2019 to May 2020	Figure L-3, L-6 and L-9	• **Significant landslide activity (>1 ft of vertical change) at the Site.** • **Minimal to no identifiable activity at other landslides in the immediate region.**
2017, Nov. 2019, and May 2020	Figure L-11	• **Acceleration of displacement at the Site visible at the toe and mid slope between Nov. 2019 and May 2020 compared with activity between 2017 and Nov. 2019.** • Approximately 2 ft of horizontal displacement at a road cut mid-slope between 2017 and Nov. 2019. • Approximately 4 ft of horizontal displacement at the same road cut between Nov. 2019 and May 2020.
2017, Nov. 2019, and May 2020	Figure L-12 and L-14	• **Acceleration of displacement at the Site visible at the toe between Nov. 2019 and May 2020 compared with activity between 2017 and Nov. 2019.** • Approximately 1 foot of vertical displacement between 2017 and Nov. 2019. • Approximately 1 foot of vertical displacement between Nov. 2019 and May 2020.
2017, Nov. 2019, and May 2020	Figure L-13	• **Acceleration of displacement at the Site visible at the headscarp between Nov. 2019 and May 2020 compared with activity between 2017 and Nov. 2019.** • Approximately 1 foot of vertical displacement between 2017 and Nov. 2019. • Approximately 1 foot of vertical displacement between Nov. 2019 and May 2020.

Date Range	Figures for reference	Observations
2017, Nov. 2019, and May 2020	Figure L-14	• **Acceleration of displacement at the Site visible at the toe between Nov. 2019 and May 2020 compared with activity between 2017 and Nov. 2019.** • Approximately 0.5 ft of horizontal displacement at the toe between 2017 and Nov. 2019. • Approximately 2 ft of horizontal displacement at the toe between Nov. 2019 and May 2020.
2017, Nov. 2019, and May 2020	Figure L-15	• **Acceleration of displacement at the Site visible at mid slope between Nov. 2019 and May 2020 compared with activity between 2017 and Nov. 2019.** • 1.5 ft of erosion (incising) of a gully with no measurable horizontal deformation between 2017 and Nov. 2019. • Approximately 4 ft of horizontal displacement between Nov. 2019 and May 2020.
2017, Nov. 2019, and May 2020	Figure L-17, L-18, L-21	• Profiles through landslide formations in the near vicinity of the Site with head scarps and toe bulges at similar elevations as the Site. • No detectable deformation in the 2017 to May 2020 time period.
2017, Nov. 2019, and May 2020	Figure L-19, and L-20	• Profiles through landslide formations in the near vicinity of the Site with head scarps and toe bulges at similar elevations as the Site. • **Activity at the toe between 2017 and Nov. 2019 is a similar magnitude (approximately 2 ft) at the Site.** • **Near zero activity between Nov. 2019 and May 2020.**
2017, Nov. 2019, and May 2020	Figure L-22	• Profile through a shallow landslide in the near vicinity of the Site. Depletion and deposition of material between 2017 and Nov. 2019. Depth of landslide was approximately 3 ft. • Near zero activity between Nov. 2019 and May 2020.

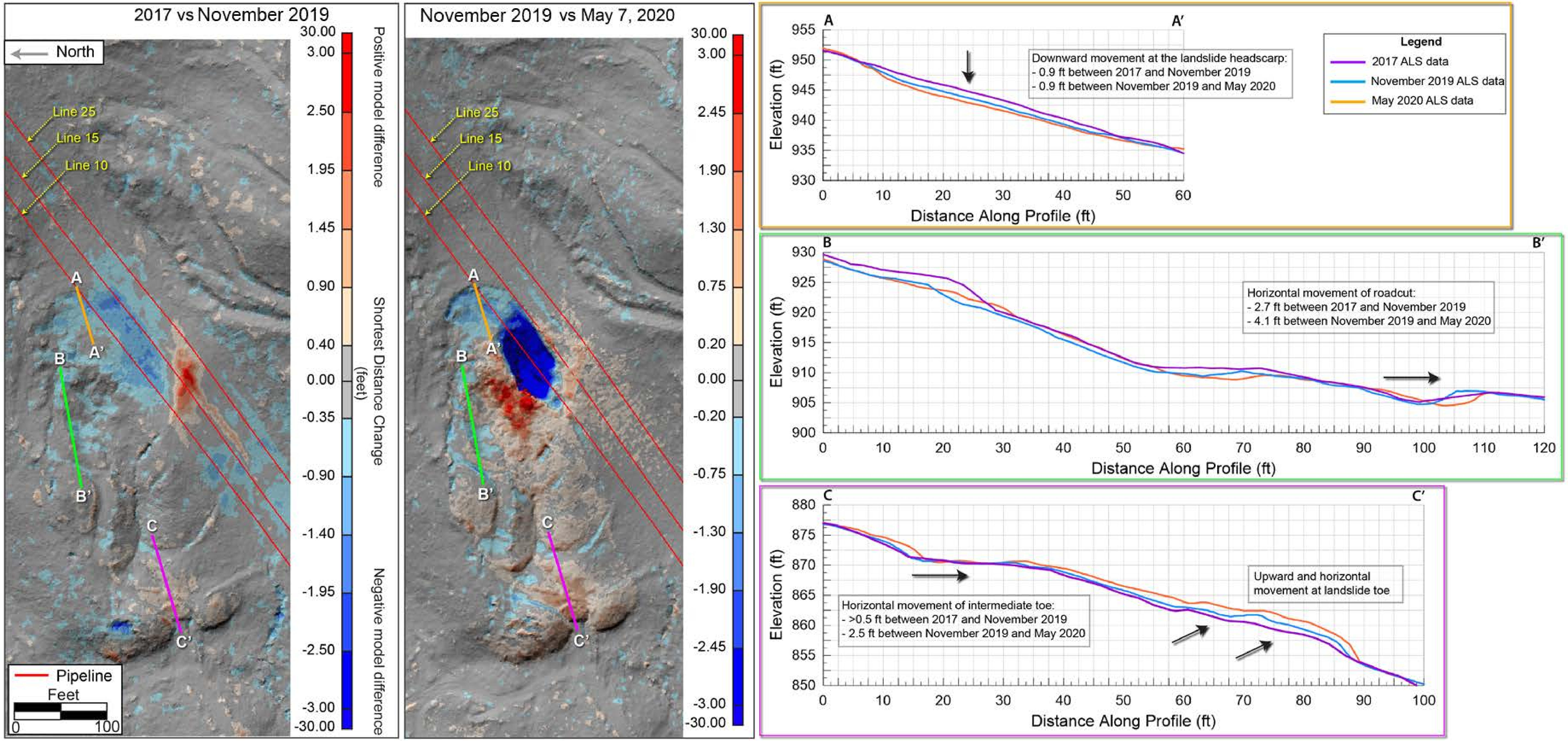
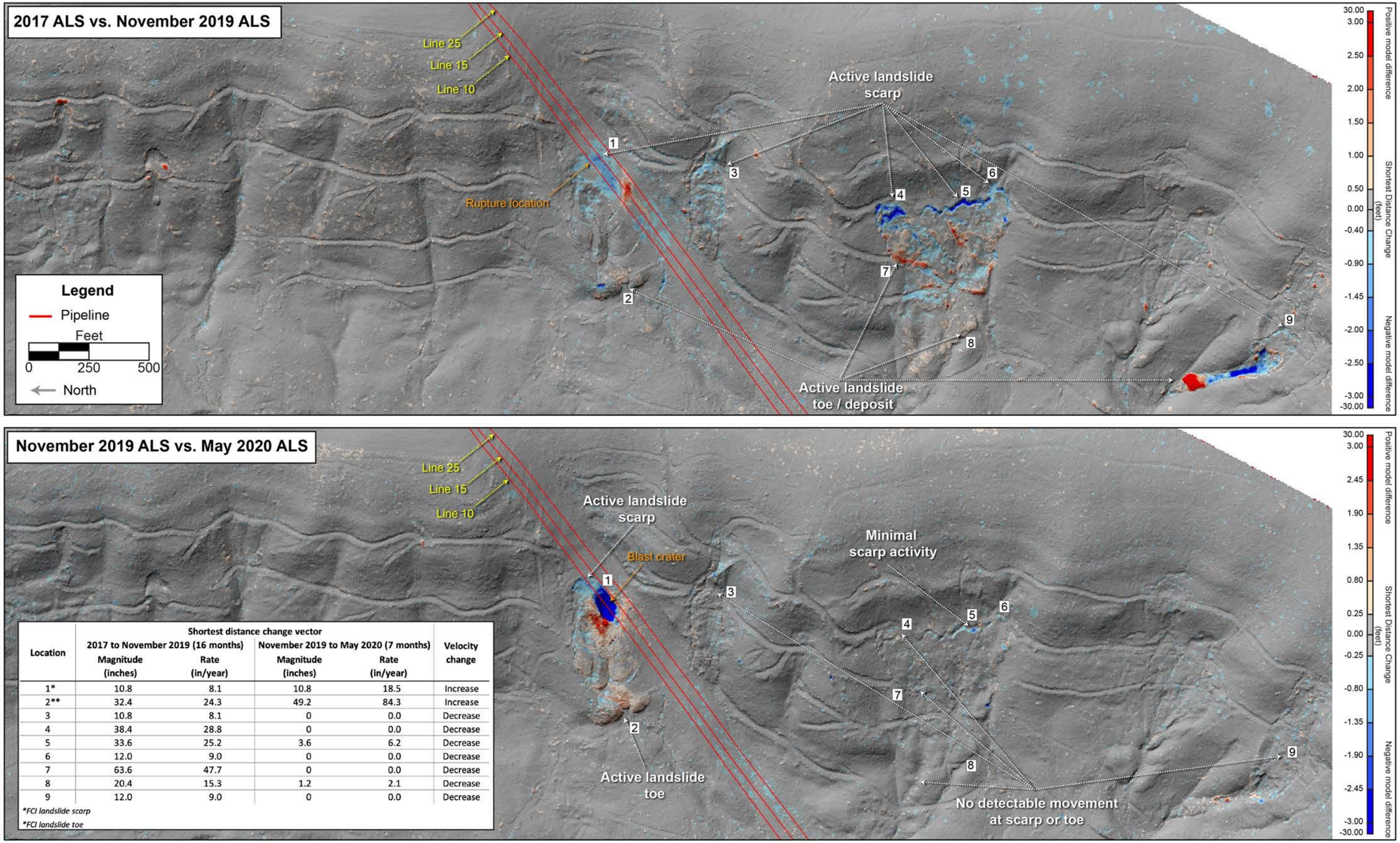


Figure 3-9. Assessment of LCD between 2017 vs November 2019 and November 2019 vs May 2020 in the vicinity of the blast crater. Profiles through key locations all indicate an acceleration in the velocity of the landslide movement between November 2019 and May 2020 compared to previous years at the Site.



Location	Shortest distance change vector: 2017 to November 2019 (16 months) Magnitude (inches)	Rate (in/year)	November 2019 to May 2020 (7 months) Magnitude (inches)	Rate (in/year)	Velocity change
1*	10.8	8.1	10.8	18.5	Increase
2**	32.4	24.3	49.2	84.3	Increase
3	10.8	8.1	0	0.0	Decrease
4	38.4	28.8	0	0.0	Decrease
5	33.6	25.2	3.6	6.2	Decrease
6	12.0	9.0	0	0.0	Decrease
7	63.6	47.7	0	0.0	Decrease
8	20.4	15.3	1.2	2.1	Decrease
9	12.0	9.0	0	0.0	Decrease

**FCI landslide scarp*
**FCI landslide toe*

Figure 3-10. Assessment of landslide velocity between 2017 vs November 2019 (upper image) and November 2019 vs May 2020 (lower image) in the vicinity of the Site.

3.5. Air Photo Review

As part of the causation assessment, BGC acquired and reviewed aerial imagery of the Site spanning from 1959 to 2018. This was done to review past activities at the Site including construction and timber harvesting. Images were procured from the United States Department of Agriculture (USDA). Imagery dates and key findings are summarized in Table 3-8, below. Images and image details can be found in Appendix M.

Based on the review of the air photo record, the following key findings were made:

- Bare soil, indicative of erosion was apparent over multiple timeframes at the Site, first observed in the September 1959 air photo (Figures M-1 and M-2) and as recently as the October 2018 air photo (Figure M-24). Particularly in the April 2016 photo (Figures M-21 and M-22), rilling and wet spots can be seen on the TETLP corridor in the location of the bare soil, indicating persistent seepage may be a contributor to the bare soil. Persistent seepage indicates groundwater pressures at or above the current surface elevation of the slope, which would be evidence of elevated porewater pressures at the Site. This would be a contributing factor to slope instability.
- Recent construction on the TETLP corridor was observed in the October 1965 (related to Line 25 construction), March 1988 (likely related to a 1986 pipe segment replacement on Line 10) and July 2012 (related to anomaly digs on Lines 10 and 15) air photos. Construction activities can cause or worsen slope instabilities by de-buttressing slopes during excavation, changing driving and resisting forces through grading, and changing the surface and ground water flow paths. The various construction activities documented at the Site are discussed in further detail in Section 3.7.
- Timber harvesting occurred on the slope between the July 2006 and July 2010 air photos, which involved the construction of temporary logging roads and the removal of mature trees. Timber harvesting operations can initiate or worsen slope instability through the removal of mature vegetation. This has two impacts: the first is the immediate pause of evapotranspiration, the process in which trees and other vegetation remove groundwater through photosynthesis, and the second being the longer-term impact of root strength loss as the roots decay, potentially leading to shallow instabilities if vegetation has not been reestablished. Another impact of timber harvesting is the destabilization caused by logging roads as the roads typically have sidehill cuts and fills, as well as redirecting surface water into unstable areas on the slope. The July 2008 air photo (Figures M-15 and M-16) show the extensive number of roads that crisscross the slope and landslide area downslope of the Site.

Table 3-8. Aerial imagery details and findings.

Year	Month and Day	Figures for reference	Observations
1959	Sept 12	M-1 and M-2	Extensive bare soil can be observed on the TETLP corridor in the location of seepage mapped following the 2020 FCI. Evidence of recent construction, likely related to Line 15 (installed in 1958), can be seen on the upland and along the base of the slope. Bare soil may be related to erosion from surface water derived from seepage and/or recent construction activity.
1965	October 25	M-3	A stock pond has been constructed on the south side of the TETLP corridor at the slope crest. Evidence of recent pipeline construction is visible. New water diversion berms have been constructed on the steep upper section of the slope upslope of the Site. Construction appears to have fixed the bare soil area observed in 1959.
1972	Sept 20	M-4 and M-5	Extensive bare soil is again visible on the TETLP corridor in the same location as 1959. Bare soil is suspected to be related to erosion caused by seepage.
1981	May 22	M-6	Bare soil continues to be observed at the Site. No major changes from 1972.
1983	March 15	M-7	Bare soil continues to be observed at the Site. No major changes from 1972.
1983	June 9	M-8	Bare soil continues to be observed at the Site. No major changes from 1972.
1985	April 17	M-9	Bare soil continues to be observed at the Site. No major changes from 1972.
1988	March 11	M-10 and M-11	New water diversion berms have been constructed on the steep upper slope above the Site. Bare soil erosion area appears to have been repaired. This is likely related to a documented replacement of 60 feet of Line 10 completed in 1986. A new stock pond has been constructed in the agricultural field on the upland. This stock pond may have been constructed to supply fill in support of the 1986 pipe replacement.
1995	February 18	M-12	No major changes from 1988.
2004	Sept 21	M-13	Timber harvesting activities first observed to the north and south of the TETLP corridor. Trees have been cleared and numerous small roads have been graded. Activity still more than 700 ft from the corridor. Bare soil reappears in similar location to past observations.
2006	July 27	M-14	Timber harvesting activities within 50 ft north of the TETLP corridor. Trees have been cleared and numerous small roads have been graded.
2008	July 11	M-15 and M-16	Timber harvesting activities have extended over the TETLP corridor. Trees have been cleared and numerous small roads

Year	Month and Day	Figures for reference	Observations
			have been graded across the corridor. Timber harvesting is occurring both adjacent and upslope of the corridor. Bare soil area increases in the same location as in the past.
2010	July 11	M-17	Timber harvesting activities have stopped. Area of bare soil on TETLP corridor has decreased in size, but still present.
2012	July 5	M-18 and M-19	Ground disturbance observed in the TETLP corridor on the slope. This is likely related to 2012 anomaly digs to recoat sections of Lines 10 and 15.
2014	June 15	M-20	Bare soil continues to be observed at the Site. No major changes from 2012.
2016	April 4	M-21 and M-22	Bare soil continues to be observed at the Site. Wet soil and rilling related to seepage can be observed within the bare area. A potential scarp is observed adjacent (north) of the corridor. The feature correlates with the mapped landslide in 2020. A landslide has developed upslope (south) of the Site.
2016	June 9	M-23	Bare soil continues to be observed at the Site. Vegetation obscures landslide features visible in April 2016.
2018	October 22	M-24	Bare soil continues to be observed at the Site. Vegetation obscures landslide features visible in April 2016.

3.6. Historic Rainfall Review

Precipitation records from the National Oceanic and Atmospheric Administration (NOAA) over the lifespan of Line 10 (1952 to April 2020) were reviewed to evaluate whether changes in precipitation could play a role in the increased movement of the landslide at the Site (NOAA, 2020). Gray et al. (1979) reports that landslides within colluvium are often initiated during periods of above-average precipitation. For the site, the Cave Run Lake weather station, located 13 miles to the south, was chosen as a representative weather station as it is near the Site and in similar hilly terrain that could influence precipitation amounts. Annual recorded precipitation from 1952 to 2019 and deviation from average precipitation are shown in Figure 3-11. A similar plot specifically focused over the time period for which IMU records exist for the pipelines within the TETLP corridor is shown in Figure 3-12. From Figure 3-11, it is evident that between 2010 and 2020, precipitation in the area has increased, with the decade between 2010 and 2020 having 15% more precipitation than the long-term average. Focusing in on this decade in particular (Figure 3-12), it is evident that annual precipitation amounts have been above average in the area since 2013, with a notable increase in precipitation since 2018, with 2018 and 2019 having 58% and 33% more rainfall than the long-term average, respectively.

To further assess the potential impacts of the above average precipitation during these years, monthly data from January 2017 through April 2020 was reviewed. Monthly precipitation records from this time period for the Cave Run Lake weather station (NOAA, 2020) are shown in Figure 3-13. Figure 3-13 shows that since January 2017, 29 out of 40 months have posted precipitation totals that exceed the long-term monthly average (1905 to 2019) for the Cave Run

Lake weather station. This includes above-average precipitation totals for nine months in the year leading up to the FCI. The annual precipitation total for the 12-month period preceding the FCI was 63.8 in., exceeding the long-term average by 35%. Much of this precipitation occurred between October 2019 and May 2020. Figure 3-14 shows the cumulative precipitation and the percentage deviation from the long-term average monthly rainfall for the fall through spring months (October through April). October 2019 to April 2020 was 46% above the long-term average rainfall, while the similar time frame in 2018 to 2019 was 17% above the average and for 2017 to 2018 it was 22% above the average (see Figure 3-14). Homing in directly on the winter months is important as there is less daylight and temperatures are lower, reducing rates of evaporation. Plants, both deciduous and coniferous, are also not removing nearly as much water from the soil through evapotranspiration during this time (Weaver and Mogensen, 1919). The cooler temperatures decrease in sunlight and decrease in evapotranspiration mean precipitation that falls during these months will not evaporate or be pulled from the ground as readily as the summer months and will be more likely to infiltrate and increase porewater pressures which can accelerate ground movement.

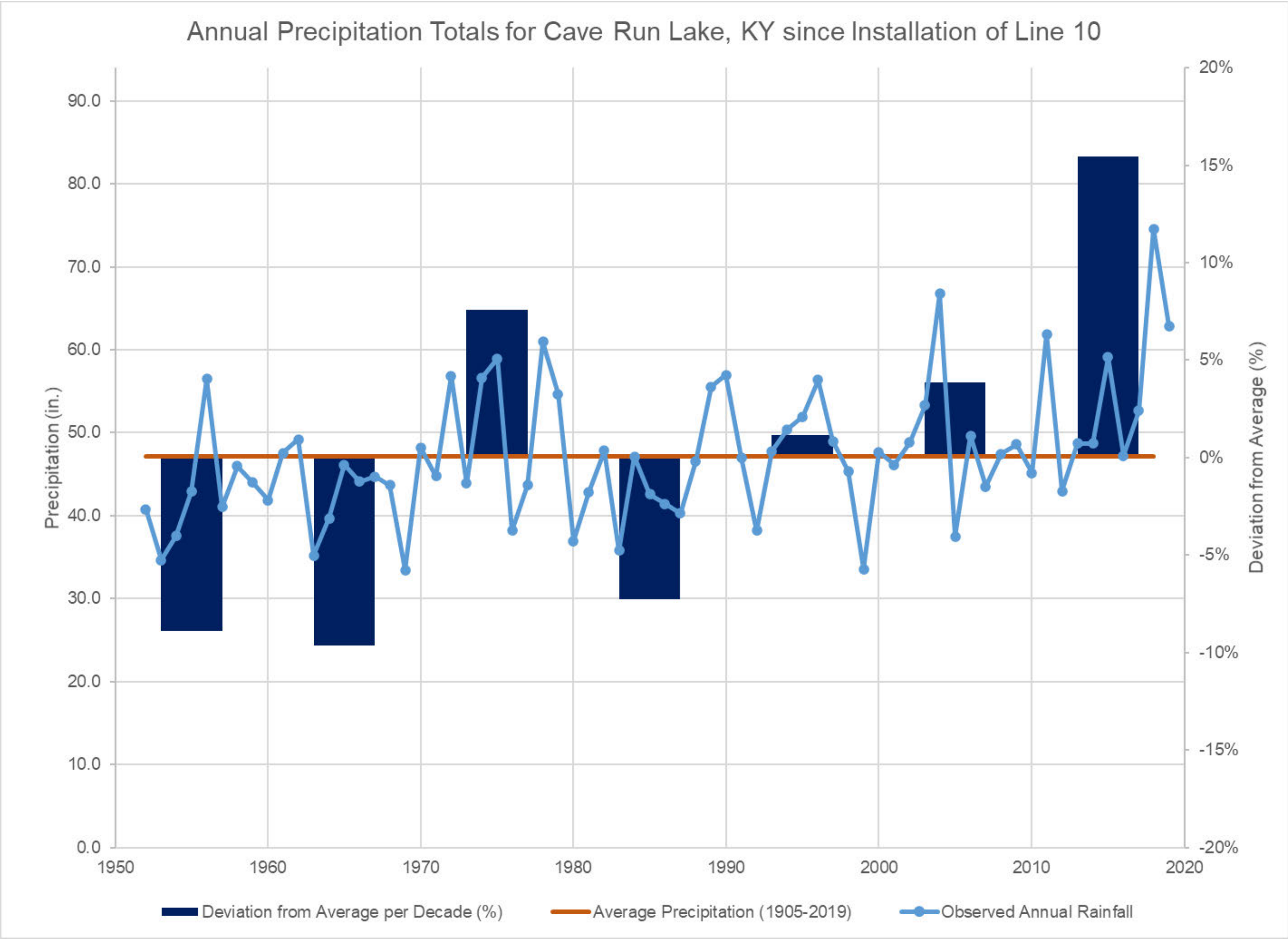


Figure 3-11. Observed annual precipitation data over the lifespan of Line 10 (1952 to 2019) from the Cave Run Lake Weather Station. The percentage deviation from the average precipitation over each decade is shown by the dark blue bars. Data obtained from NOAA (2020).

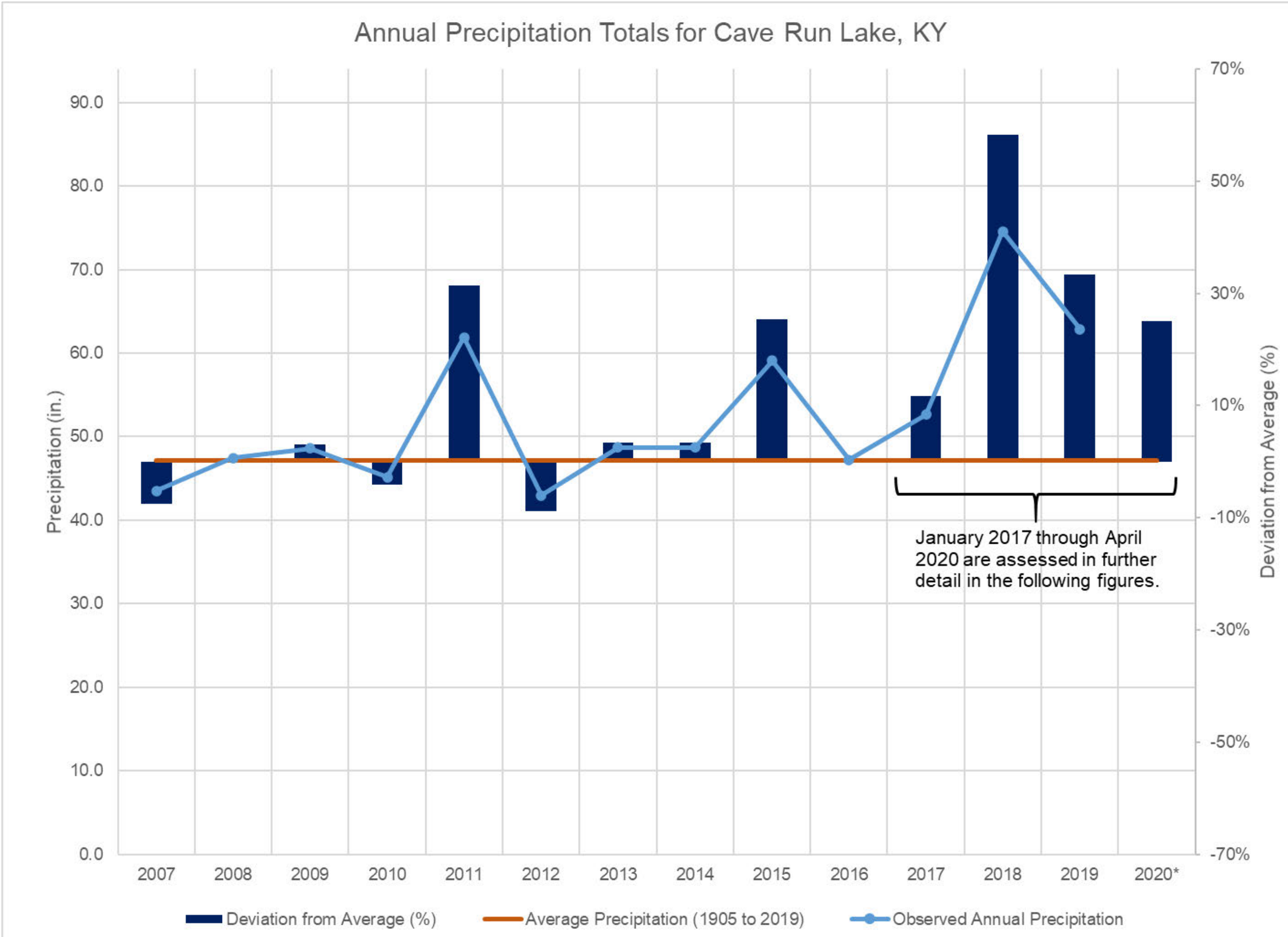


Figure 3-12. Observed annual precipitation data for 2007 to 2019 from the Cave Run Lake Weather Station. The percentage deviation from the long-term average annual precipitation is shown by the dark blue bars. The deviation for 2020 is based on the observed precipitation from January to April 2020 in relation to the average precipitation over the same months. Data obtained from NOAA (2020).

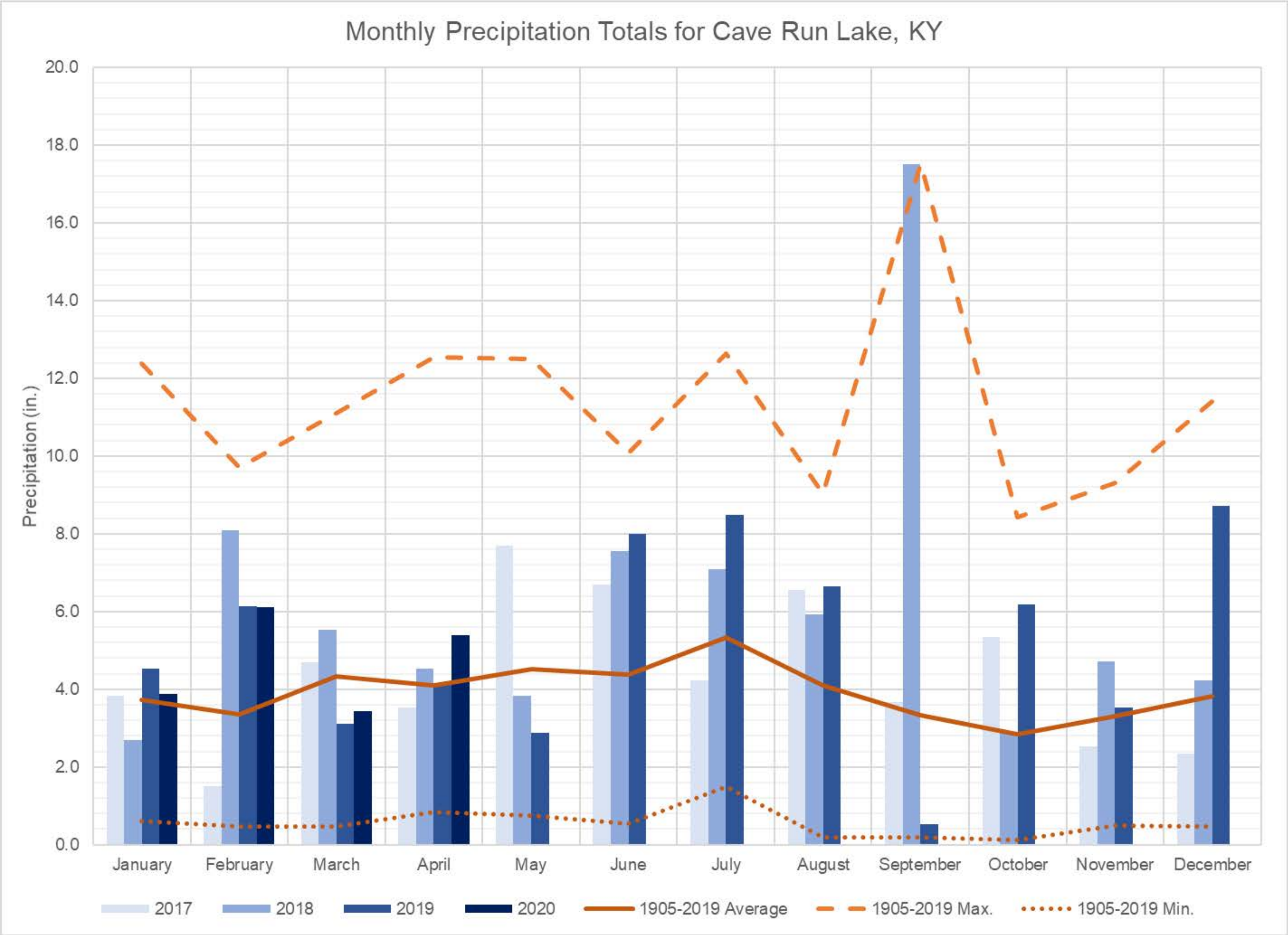


Figure 3-13. Long-term average precipitation and recorded precipitation data from the Cave Run Lake Weather Station. Data obtained from NOAA (2020).

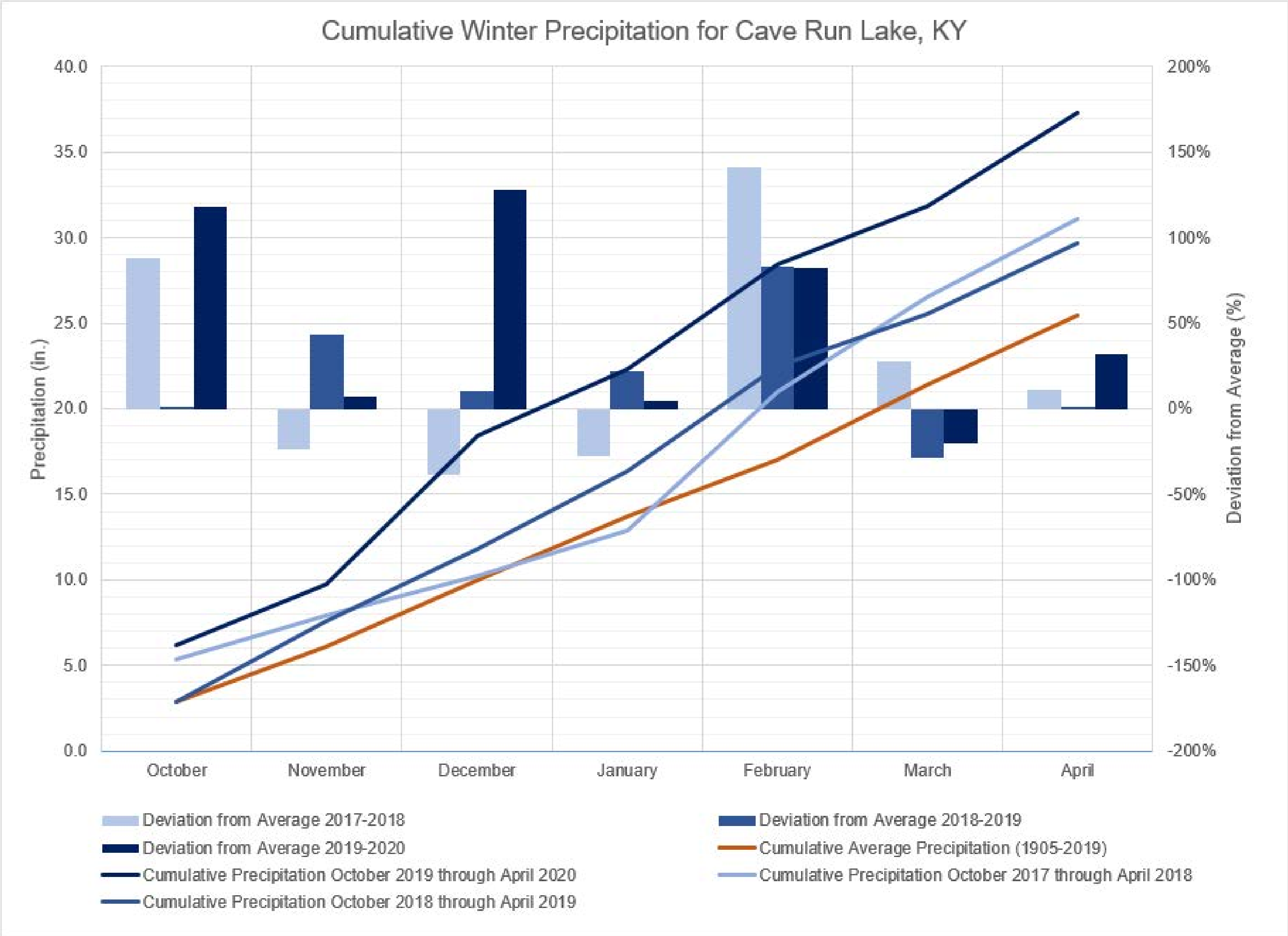


Figure 3-14. Cumulative precipitation data from the Cave Run Lake Weather Station for October to April preceding the FCI and similar timeframes in 2017 and 2018. Data obtained from NOAA (2020).

3.7. Review of Past Construction Activities

TETLP provided BGC with the locations of past documented construction activities along the TETLP corridor at the Site. The location of each of the various activities is illustrated on Figure 3-15, and the information obtained for each project is summarized in Table 3-9. The most complete information covers the 10 years preceding the FCI. Formally documented information at TETLP for past corridor activities mainly relates to integrity digs involving exposure of one of the pipelines, as opposed to work on the slope that did not involve pipeline exposure, such as the grading and erosion control work done in 2019 discussed below. Other than the June and July 2019 erosion repair work, only the year of past construction work was provided.

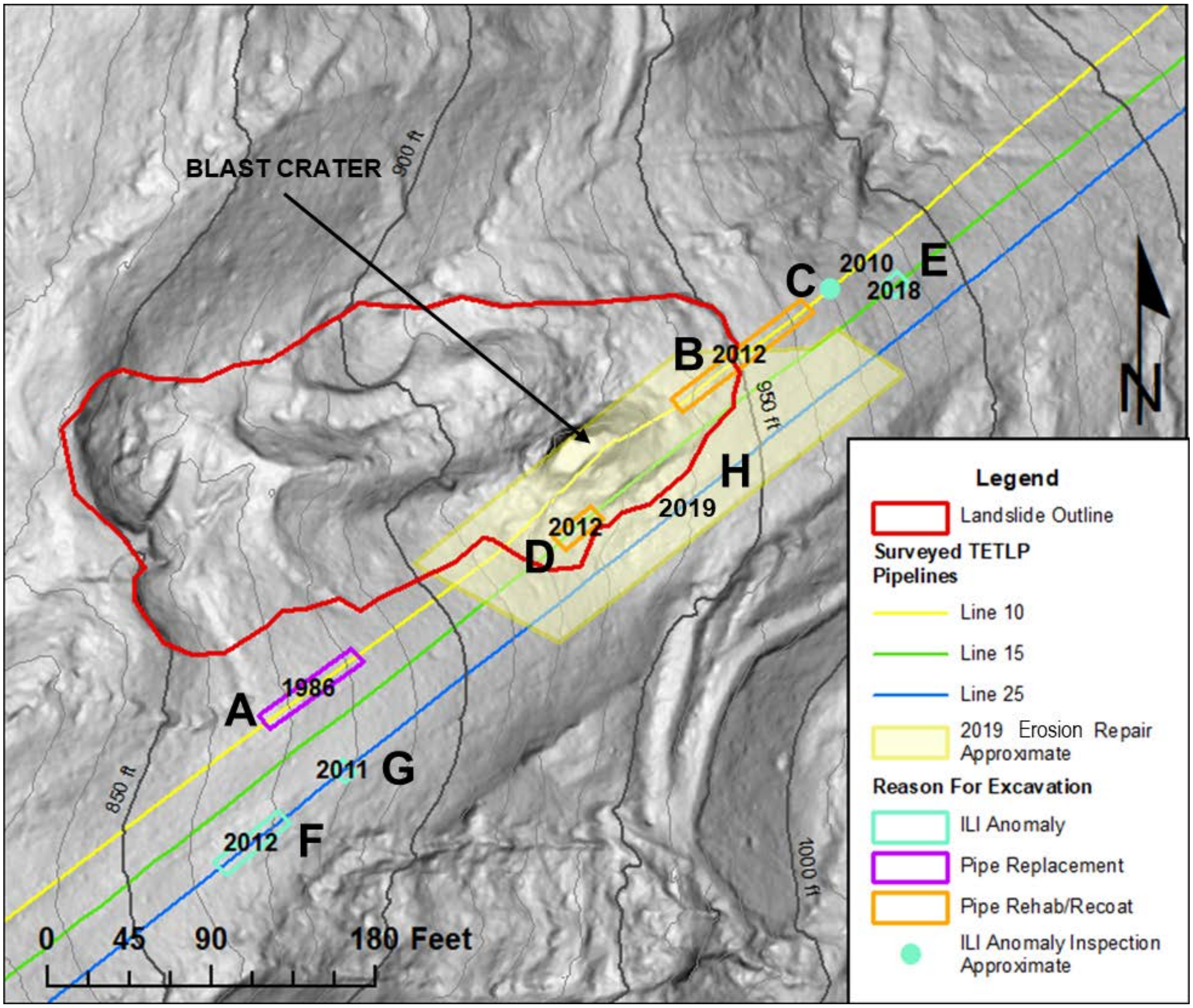


Figure 3-15. **Map showing the locations, extents and dates of documented past excavations and repairs at the FCI site. Excavations and repairs have been labeled A through H and details of each can be found in Table 3-9. The extent of the 2019 erosion repair was estimated by BGC from site photographs. May 6, 2020 lidar imagery and excavation data provided by TETLP.**

Table 3-9. Documented excavations and repairs at the FCI Site as provided by TETLP.

Excavation or Repair	Pipeline	Year	Reason	Relevant Comments/Findings
A	Line 10	1986	Pipe Replacement	
B	Line 10	2012	Pipe Rehab/Recoat	A dent/mechanical damage was observed, suspected to be construction related.
C	Line 10	2010	ILI Anomaly Inspection	Metal loss and a dent/mechanical damage was observed, suspected to be construction related. Only a single coordinate was provided by TETLP, though their records indicate the excavation was 25 ft in length along Line 10.
D	Line 15	2012	Pipe Rehab/Recoat	Metal loss was observed due to historical corrosion.
E	Line 15	2018	Pipe Rehab/Recoat	Metal loss was observed due to historical corrosion.
F	Line 25	2012	ILI Anomaly Inspection	No defects were observed during the inspection.
G	Line 25	2011	ILI Anomaly Inspection	Metal loss was observed due to historical corrosion.
H	Entire Corridor Width	2019	Erosion Repair	Repair completed to infill erosion and rutting on TETLP corridor. Involved removing soil cover over Line 25 and placing over Line 10.

The pipeline activities that are of greatest relevance for slope stability are grading, disruption or alteration of surface or subsurface drainage and the short-term disturbances related to construction equipment traffic. The only past activity that BGC was able to get information on in relation to the above factors was the 2019 ROW restoration work covering the area designated as location H in the above figure and table. This work was associated with ROW restoration that was done in June and July of 2019 following corrosion protection anode bed installations during the winter of 2018/2019 beyond the toe of the slope (west of the area covered in Figure 3-15). The ROW was used as access and there was a need to repair rutting and erosion in the mid-slope area. BGC conducted a scheduled geohazard inspection on July 8, 2019, that happened to coincide with the completion of the restoration work. The area of disturbance shown on Figure 3-15 is the area covered by the erosion control matting observed by BGC during the visit. Anecdotal information from TETLP personnel indicated that a relatively limited quantity of soil (in the order of 1 ft) was taken from the southern portion of the corridor in the general area of Line 25 and used to fill in wheel ruts and “wash-outs” (referred to as “erosion” elsewhere in this report) in the northern part of the corridor, which is where Line 10 is located.

It is noted that pipeline depth of cover (DOC) measurements and BGC observations during pipeline exposures post-FCI showed that Line 10 had a greater DOC than either 25 or 15. Based on surveys completed along Line 10 following the Incident and the November 2019 lidar topography, the DOC over Line 10 along the failed section was between 7 and 10 ft, while the DOC over Line 15 in the same area was typically between 3 and 5 ft. The DOC directly over GW 11330 (the weld that failed) appears to have been nearly 10 ft. While some of this extra cover is likely related to the 2019 grading activities, it is possible that similar works over the life of the pipelines may have incrementally added to the DOC for Line 10. Subsidence related to the on-going slide movement discussed in preceding sections would have produced noticeable settlement and cracking at times that would have been natural for construction crews to fill in when activities were occurring at or near the FCI. There is however no direct confirmation of these past grading activities.

4.0 FLEMING COUNTY INCIDENT GEOTECHNICAL CAUSATION ASSESSMENT

BGC's post-incident geotechnical causation assessment is based on results of the various field and office-based assessments described in Sections 3.1 through 3.7. The objectives of the post-event geotechnical site investigation were to characterize the mechanisms of both the landslide movement and the consequent soil loading that was imposed on Line 10 from the moving ground, which are addressed separately in the following two sections. Section 4.3 then provides a summary of BGC's assessment of the acceleration in ground movements that was evident leading up to the FCI, and the factors that contributed to the acceleration.

4.1. Landslide Mechanism

Slopes in the Appalachian Plateau generally consist of a relatively thin veneer of colluvium (landslide debris) overlying flat-lying sedimentary rock, with thicker accumulations of colluvium in the lower sections of the slopes, and within incised gullies, or hollows. Landslide activity is common and is dominantly related to movement of the colluvium over the more stable in-place rock surface. Groundwater and surface water are typically a key factor in saturating the colluvium and driving instability. Deeper instability seated in the bedrock is rare in natural slopes but can be more of an issue in deep rock cuts for highways, quarries or other facilities (Gray et al., 1979).

The characteristics of the slope containing the FCI site, and the landslide that has been active at the Site fits the pattern that is characteristic of the region that is described above. The pipelines descend a 1300 ft long slope, oblique to the fall line. Over much of the slope, the pipelines traverse shallow, discontinuous colluvial soil over rock, and are often trenched within rock. The mid-slope bench where the Line 10 rupture occurred has distinctly different conditions than the rest of the slope. The pipelines were installed across the headward section of an old gully feature, incised into the underlying rock, but completely infilled with a deep deposit of colluvium, forming the bench. The landslide that caused the FCI involves downslope, translational movement along a slip plane at depth in the colluvium along the axis of the infilled gully. The landslide moved diagonally across the pipelines, was 140 ft wide, 370 ft long, and had clear slide margins that are illustrated on Figure 3-2. A more detailed description of the landslide materials, the role that precipitation and seepage played and the historical movement pattern and rates that can be inferred from site data is provided in the following subsections.

4.1.1. Landslide Materials

The colluvium the landslide is occurring within is thicker across the bench along the TETLP corridor, particularly beneath Lines 10 and 15 and there is a drop in the elevation of the bedrock surface across the bench. On both the upslope and downslope edge of the bench, shale bedrock tends to be within 10 ft of the surface, but across the bench, the depth to rock increases to 30 ft beneath Line 10 and 20 ft beneath Line 15 (see Appendix H). This is because the colluvial material has infilled a former gully. Throughout the Appalachian Plateau, gullies, or hollows, are known for being unstable due to the accumulation of weak colluvium and the concentration of both surface and ground water. Lidar imagery shows landslide morphology within neighboring hollows, indicating local unstable conditions (Figure 2-1). The colluvium is predominantly clay, derived from the Ohio Shale and the overlying Borden and Sunbury Shale as well as isolated boulders from the Farmers Member sandstone near the crest of the slope. Clay-rich colluvium has a low shear strength and is prone to movement. The shear strength of the soil is further reduced along pre-existing slip surfaces as the clay particles along the slip surface were aligned in the direction of slope movement during past landslide movement, reducing the frictional strength of the soil to a residual value. These slip surfaces also have much higher permeabilities due to past landslide movement, making them more susceptible to the influence of groundwater pressures (Gray et al.,1979). Landslide morphology is visible in the lidar imagery at similar elevations within neighboring hollows and was apparent at the Site, and the pipelines were installed within colluvium across the Site, indicating that pre-existing shear surfaces and landslides were present at the Site before the installation of the TETLP corridor. The colluvium derived from these bedrock units and groundwater conditions, particularly within the Ohio Shale, created naturally unstable conditions.

4.1.2. Influence of Precipitation and Seepage

Precipitation and seepage played a key role in driving landslide movement at the Site before the FCI. BGC's analysis of the air photo records indicate that seepage has likely been a problem at the Site since the initial construction of Lines 10 and 15 in the 1950s. Wet spots and erosion from seeps are clear throughout the air-photo record. During the excavation of Lines 10 and 15, saturated soil was observed along the pipeline trenches and seeps were observed exiting both the Line 15 and Line 25 trenches upslope and adjacent to the landslide. BGC's subsurface investigation indicated groundwater was being delivered to the slide mass prior to the FCI through preferential groundwater flow along the Line 10, 15 and 25 trench backfill and where water-bearing beds of the Ohio Shale contacted the overlying colluvium within the slide mass. During test pit excavations, certain layers within the Ohio Shale were observed to be fractured and water bearing. Elevated pore water pressures, driven by fractured water-bearing beds within the Ohio Shale, would further decrease slope stability as the ground water pressures create a buoyant effect on the slip plane, reducing the effective stress and decreasing stability. Gray et al. (1979) also report that pre-sheared colluvial surfaces tend to have much higher permeabilities than portions of the colluvium with no pre-sheared surfaces, allowing for more rapid increases in pore pressure along the slip surface.

The groundwater pressures are related to rainfall infiltration on the uplands and slope above the Site. The elevated precipitation amounts observed since 2008 (Figure 3-12) would lead to increased groundwater pressures within the Ohio Shale water bearing zones. As ground movement at the Site continued, tension cracks and scarps would have served as direct conduits for surface water to infiltrate the slide mass and reach the sliding plane. This compounding effect would further increase pore water pressures specifically along the sliding plane, further accelerating ground movement. The high rainfall beginning in 2017 would increase the amount of surface water infiltrating into the cracks, driving more movement, which in turn would increase the number and size of cracks within the landslide mass. The influence of post-incident precipitation on ground movement rates at the Site is illustrated in the monitoring hub data shown in Figure 3-4.

4.1.3. Landslide Movement Rates

Lidar change detection, pipeline OOS measurements and detailed field mapping confirmed that the landslide had been active since the initial June 2007 Line 10 ILI tool run with some level of ground movement predating the tool run. Figure 4-1 shows the amount of ground movement before the FCI inferred from OOS measurements on Lines 10 and 15 as well as the lidar change detection while Figure 4-2 shows the calculated movement rates. From these plots, it is evident that prior to 2007, both Lines 10 and 15 had experienced some amount of slope movement. The plots show a movement rate that assumes an average rate of around 0.75 inches/yr on Line 10 and 0.36 inches/yr on Line 15 between June 2007 and the year the pipelines were originally installed (Line 10 in 1952 and Line 15 in 1957). Following 2007, the average ground movement rates increased and maintained a fairly consistent rate of movement up until November of 2019. In general, average movement rates for this period were between 10 and 11 inches/yr on Line 10 and in the slide mass downslope of the TETLP corridor and between 3.6 and 7 inches/yr on Line 15. As evident in the Line 10 OOS (June 2019 and May 2020), the Line 15 OOS (October 2019 and May 2020) and lidar change detection data (November 2019 and May 2020), ground movement rates increased sometime between June 2019 and the May 2020 FCI. The Line 15 OOS and lidar change detection results indicate this acceleration occurred sometime between November 2019 and May 2020. Assuming ground movement rates accelerated in November 2019, the movement rate between November 2019 and May 2020 was 17.9 ft/yr on Line 10 and 2.1 ft/yr on Line 15.

This rapid rate of ground movement was evident during the detailed mapping immediately following the FCI. The landslide had well-defined scarps and tension cracks at the headward end on the TETLP corridor, clear lateral cracks along the northern flank, and recent over-thrusting at the landslide toe, evident by fresh soil overriding and bending live trees. Monitoring hub data captured the active ground movement following the FCI (see Figure 3-4). Figure 4-3 shows the ground movement recorded at monitoring hub MP 107 between May 12 and August 14, 2020. From these figures, it is apparent that the ground movement rate immediately following the FCI was similar to the rate of ground movement that deflected Line 10 since November 2019. A period of acceleration occurred during the initial investigative and mitigative construction activities, with movement rates at MP 107 averaging 25.8 ft/yr through the month of June 2020. Rates slowed to an average of 1.7 ft/yr, starting in early July 2020 following the completion of initial investigative activities and the installation of interim drainage measures. The monitoring hubs indicate that slope movement was likely a combination of slow, on-going creep-type movement with episodic, more rapid ground movement, often related to large precipitation events. The monitoring pins show that the slide can move up to 9.5 inches in one day following large precipitation events and especially when construction activities are underway on the corridor (Figure 3-4).

Another thing that is evident from ground observations, the monitoring pins, lidar change detection and the OOS measurements, is that ground movement throughout the landslide mass was not uniform. In the field, the northern portion appeared to be moving more rapidly, with clearly visible lateral ground cracks while the southern flank was less well defined, with only minor cracking.

As can be seen in Figures 4-1 through 4-3, the total ground movement inferred form the OOS measurements on Lines 10 and 15 and the lidar change detection are not the same. One component of this is differing ground movement rates within the slide mass, as discussed above. While Line 15 was within the landslide mass, inferred ground movement rates were much less than in the location of Line 10, based on the OOS data, which is also supported by the lidar change detection results. The lidar change detection shows increased downslope movement along both Lines 10 and 15 between 2017 and November 2019, but the movement along Line 15 is less than along Line 10. This is likely due to Line 15 being further upslope than Line 10, in an area closer to the edge of the landslide mass, where the landslide was less active and less movement was occurring. Similarly, the difference in ground movement rates between Line 10 and the lidar change detection results may be due to different movement rates at Line 10 and the slide mass downslope off the TETLP corridor. This could have been due to the presence of additional seepage near Line 10 or differing thicknesses of colluvium beneath Line 10 and downslope of the TETLP corridor. Assuming that the overall volume of soil moving past any single point within the more active part of the landslide was the same, ground movement would be greater in areas where the landslide mass was thinner. Based on test pitting and drilling, the depth of the slide mass increased downslope of Line 10. This means that, assuming a similar volume of soil was moving along Line 10 and in the downslope landslide mass, slope movement rates along Line 10 would have been higher.

An additional factor related to the difference within the plots shown in Figure 4-1 through Figure 4-3 may also be the actual mechanics of the pipelines and the impact of the external loading of the soil. Line 15 may have had lower OOS because it was subjected to smaller soil loads due to its shallower burial depth and lower confining pressure than Line 10. The greater depth and associated confining pressure would induce higher loads on Line 10 and increase strain and OOS for similar amounts of ground movement. The ground movement inferred from the Line 10 OOS at the time of the FCI may also have been greater than actual ground movement due to the deformation pattern of Line 10 changing between the June 2019 IMU and the FCI. This is apparent in Figure 3-7. The changing OOS pattern may have been due to plastic strain shifting the load of ground movement to a different portion of the impacted length of Line 10. This would mean that the Line 10 OOS measured following the FCI may not be directly comparable to the OOS measured from the preceding IMU runs. This could result in an overestimation of the ground movement at Line 10, potentially explaining a component of the difference between the inferred amount of ground movement along Line 10 and those from the lidar change detection.

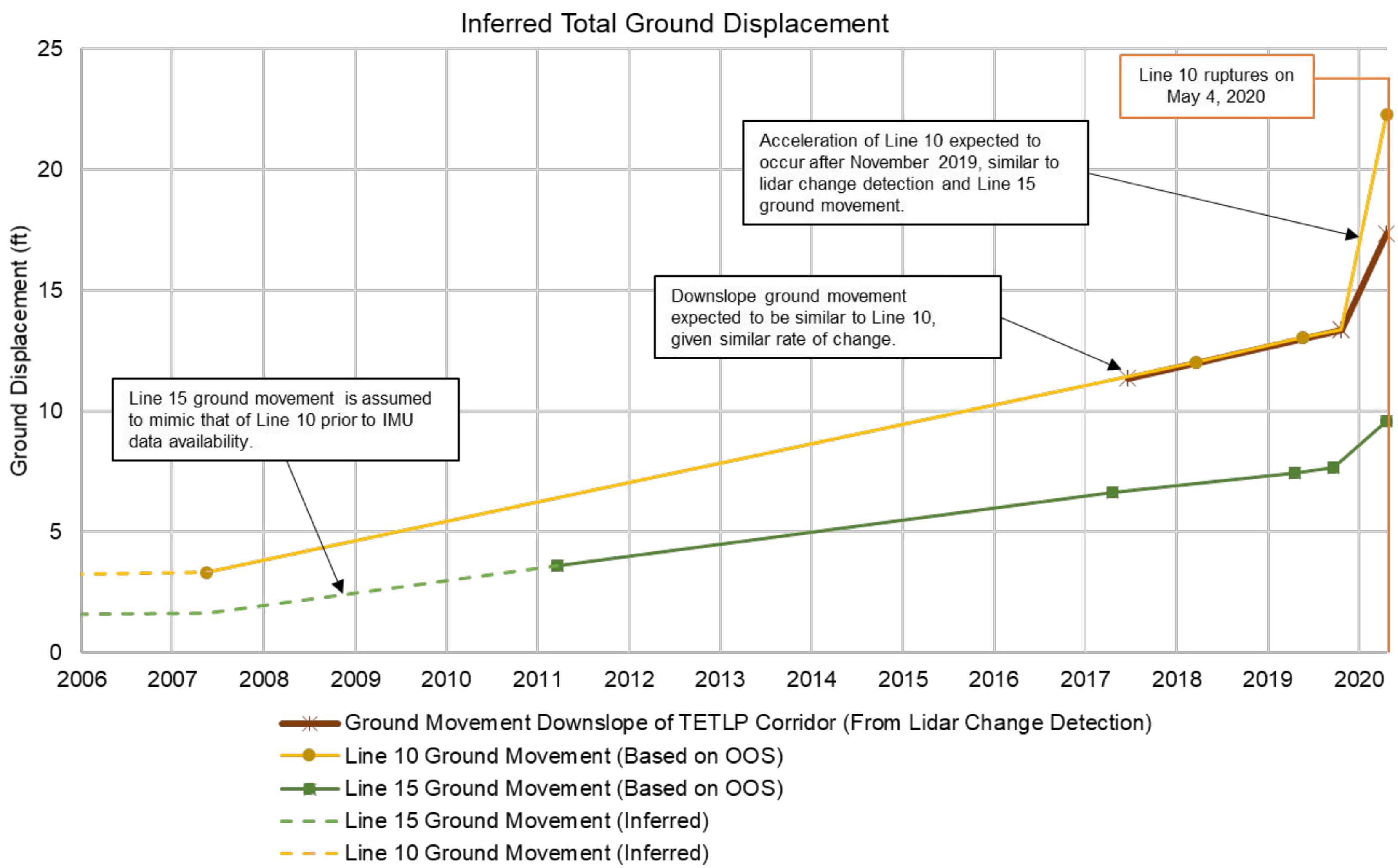


Figure 4-1. Plot showing inferred ground movement at the FCI site based on IMU and field-based OOS measurements and lidar change detection.

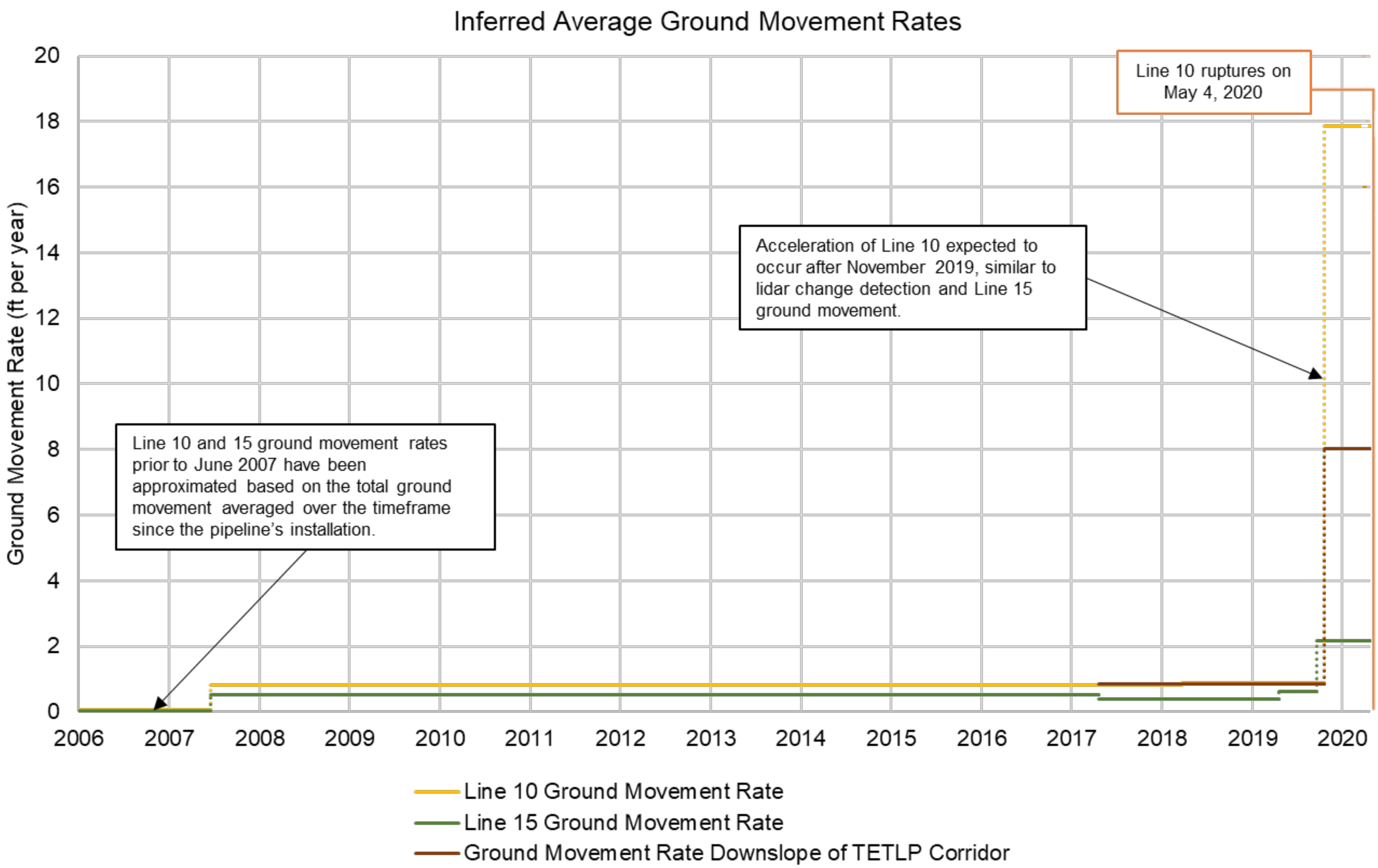


Figure 4-2. Plot showing inferred ground movement rates at the FCI site based on IMU and field-based OOS measurements and lidar change detection.

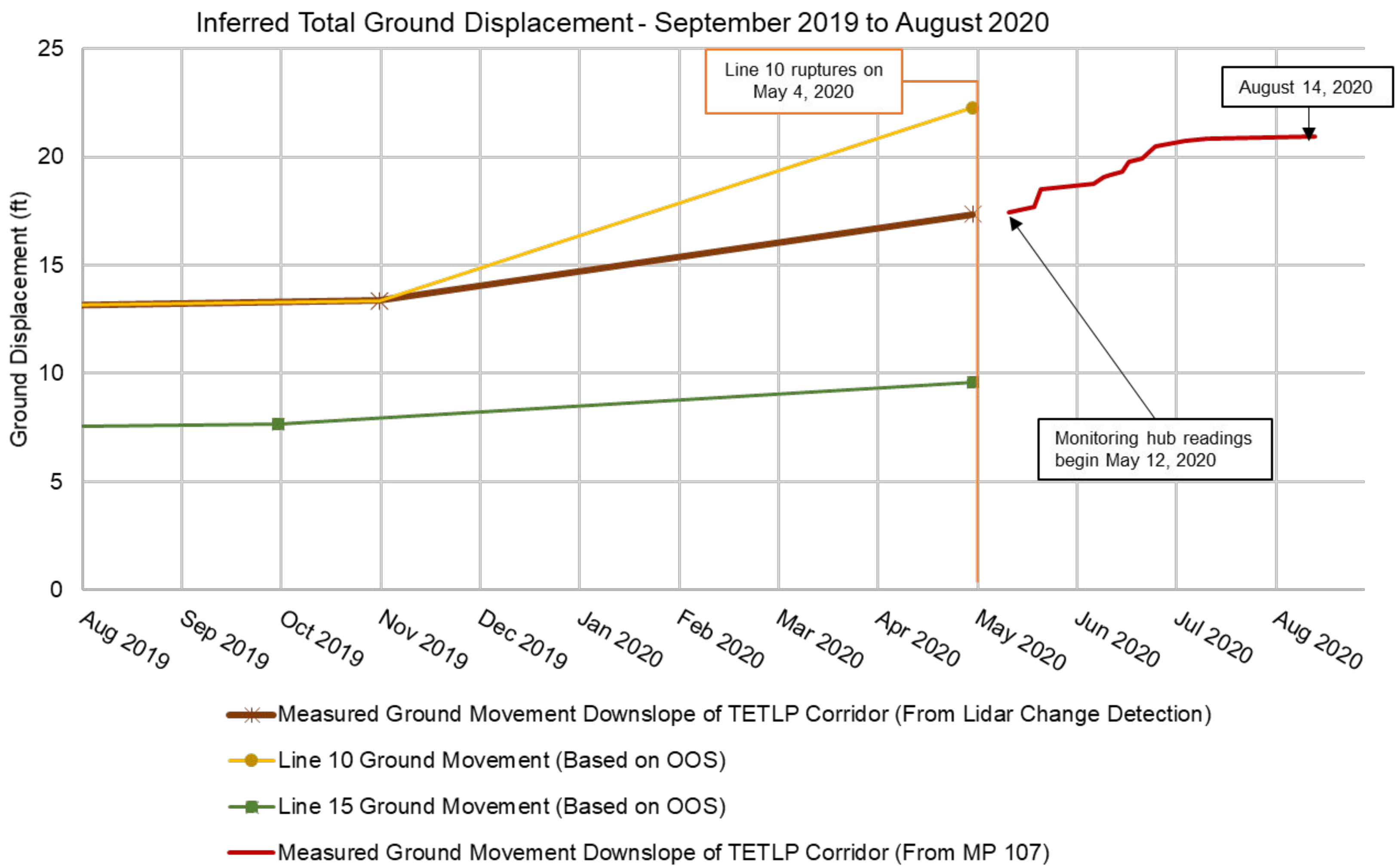


Figure 4-3. Plot showing inferred ground movement between August 2019 and August 14, 2020. Ground movement from Monitoring hub MP 107 is shown to illustrate ground movement at the Site following the FCI.

4.2. Pipeline Vulnerability

At the Site, approximately 165 ft of Line 10 was situated within the active landslide. Rather than perpendicular to the pipeline orientation, ground movement was oblique, between 20 and 25 degrees to the orientation of the pipeline. This movement vector led to a combination of lateral and axial strains that eventually led to failure at GW 11330.

The bending strains on Line 10 correlate with where Line 10 was observed to be trenched within colluvium. The bending strain anomaly occurs between GW 11310 and 11360 which corresponds to where Line 10 went from a bedrock trench, through the deep colluvium infilling the old gully and then back into a bedrock trench. When a pipeline transitions from a stable bedrock trench to moving ground, acute bending strains are typical at the transition. However, the oblique movement vector of the landslide at FCI led to asymmetric loading and deflection which led to the most acute bending strains occurring both at the downslope transition (near GW 11310) and in the location of maximum OOS (near GW 11330). At the downslope transition, bending strain was highest, but predominantly within the pipe body. In the 2019 IMU data, bending strain on GW 11310 was greater than on GW 11330(0.452% at GW 11310 and 0.357% at GW 11330). However, GW 11330 was located adjacent to a formed horizontal bend that had been nearly reversed between June 2007 and June 2019. Additionally, there was no measurable change on GW 11310 between the April 2018 and June 2019 IMU plots, but GW 11330 had a bending strain growth of 0.011% in the same time period. As discussed in the following section, it is likely that accelerated movement of the slide mass between the June 2019 ILI tool run and the May 2020 FCI likely led to an accelerated increase in both axial and bending strain on GW 11330, leading to the rupture.

Another key factor to the vulnerability of Line 10 would be the elevated traction loads associated with the greater pipeline burial depth. Traction loads are induced on pipelines by moving ground and the magnitude of the traction forces is related to burial depth (confining pressure). The greater the depth, the greater the traction forces exerted on the pipeline by moving ground and also the greater resistance of the non-moving soil beyond the edge of the movement zone to deformation around the pipeline. As traction loads increase, the loading on the pipeline from soil movement increases as does the deformation of the pipeline. Depth of cover measurements completed during the July 2019 ground inspection indicated that Line 10 had approximately 7.2 ft of cover at the time. This is supported by the surveyed pipeline location plotted with the November 2019 lidar ground surface, which indicates a higher depth of cover between 7 and 10 ft along Line 10 within the slide mass (see Appendix H). This is notably higher than the depth of cover on Line 15 (4.7 ft of cover measured in July 2019, with a range between 3 and 5 ft using the survey and November 2019 lidar data), also situated within the moving slide mass. The higher cover depth would have increased confining pressure on Line 10, which would proportionally increase the ground movement traction loads on Line 10. Thus, for every foot of ground movement experienced by Line 10, the resulting traction load on the pipeline applied by the moving ground would have been significantly larger than a foot of ground movement on Line 15 given the large difference in burial depth.

4.3. Triggering Factors and Activity Changes

As part of the FCI causation investigation, BGC has assessed the changes in landslide movement in detail and has identified key external factors that likely contributed to changes in movement rates, including timber harvesting, TETLP corridor construction activities, and above average precipitation. The movement rates of the landslide, discussed in Section 4.1.3, show three distinct movement rates over three periods: Line 10 installation in 1952 to June 2007, June 2007 to November 2019 and November 2019 to the FCI on May 4, 2020. These periods and the factors that likely impacted ground movement at the Site are discussed in the subsections below.

4.3.1. Line 10 Installation (1952) to June 2007 – Average Ground Movement Rate 0.75 inches/yr

Prior to the June 2007 IMU, Line 10 had already experienced about 3.3 ft of ground movement, causing an approximate OOS of 1.3 ft on Line 10. Assuming the failed section of Line 10 is original, the cumulative movement up to June 2007 could have been caused by slow, creeping movement over the lifespan of the pipeline or during discrete episodes. Lidar imagery and the colluvial soil observed along the Line 10 trench indicates the Site was a pre-existing landslide prior to the installation of the TETLP corridor. Movement may have already been occurring prior to installation or may have been reactivated during or following construction.

Based on the rapid and episodic movement observed in the monitoring hubs following the FCI, it is also possible this cumulative movement occurred over several short periods, likely due to a combination of above-average precipitation and corridor construction activities, as multiple corridor repairs were observed throughout the air photo record. The high DOC over Line 10 at the Site indicates that additional fill was likely placed over Line 10 over the lifespan of the pipeline, as it would be uncommon practice to have such a deep trench for a conventional trenched installation. Given the position of Line 10 in the head of the slide mass, adding fill to this area would increase the driving forces within the mass, either triggering or accelerating ground movement. Various activities such as anomaly digs, grading and fill placement all could have led to increased loading of the headward portion of the landslide. These activities could also have increased surface water and groundwater flows directed into the landside via the pipeline trenches and surface grading.

4.3.2. June 2007 to November 2019 – Average Ground Movement Rate 10 inches/yr

Beginning in 2007 and continuing to the November 2019, ground movement rates at the Site significantly increased, causing nearly an additional 10 ft of ground movement along Line 10 over 12 years. Over this period, multiple events occurred that likely increased the ground movement rate including timber harvesting, long-term increasing trends in annual precipitation, and documented corridor construction activities. Figure 4-4 provides a timeline of events and the inferred total ground displacement on Line 10 and 15 between 2006 and the May 2020 FCI. Timber harvest activities likely led to destabilization through cuts and fill along access roads, redirection of surface water into unstable areas on the slope, and the removal of vegetation. The increase in movement rate beginning after June 2007 correlates with the timing of timber harvesting activities crossing the TETLP corridor at the Site. Following the timber harvesting activities, the average movement rate over this period held constant, likely due to a combination of increased precipitation and TETLP corridor construction activities. Rainfall data indicates that from 2008 through 2019, 8 years recorded above average annual precipitation. Through this time, periods of intense rainfall were likely followed by episodic higher rates of ground movement. 2018 and 2019 saw particularly high amounts of precipitation (2018 is the wettest year since the installation of Line 10 in 1952), which led to regional slope movement at FCI and on neighboring natural slopes as seen in lidar change detection between the 2017 and November 2019 lidar datasets. Documented integrity digs in 2012 and undocumented construction activities, such as using the corridor for access, could have caused periods of higher ground movement as well due to vibrations from heavy equipment and associated access grading. These activities may have led to some amount of additional fill being placed over the northern side of the TETLP corridor and over Line 10. This would increase the loading over Line 10, driving continued ground movement and increasing the OOS. In total, an additional 10 ft of ground movement is estimated to have occurred over this time period, causing an additional 3.9 ft of OOS to develop along Line 10. This accounts for 45% of the total OOS that occurred on Line 10 before the FCI.

4.3.3. November 2019 to May 4, 2020 (FCI) – Average Ground Movement Rate 17.9 ft/yr

Between November 2019 and the May 4, 2020 FCI, the average ground movement rate increased over 20 times. Figure 4-5 provides a timeline of events and the inferred total ground displacement on Line 10 and 15 between June 2019 and the May 2020 FCI as well as ground displacement downslope of the TETLP corridor from survey monitoring hub data. Over this time period, two major factors likely contributed to the dramatic increase in ground displacement. The first, would be the high levels of precipitation over the fall and winter of 2019-2020. Starting in October 2019 above average precipitation fell on the Site. In the months of October 2019, December 2019, and February 2020, 118%, 128% and 82% above average rainfall fell in each month, respectively. This was greater than the amount of precipitation over similar time periods than in the previous two years (including 2018). The impact of this high level of precipitation on slope stability is greater than at other times of the year due to lower evaporation from less sunlight and minimal evapotranspiration allowing more surface runoff to infiltrate the soil. However, similar ground movement rates were not observed in lidar change detection at neighboring landslides on similar aspects. This indicates that the landslide movement and rapid acceleration that occurred during this time was driven by conditions unique to the Site.

One differentiating factor is a corridor erosion repair that occurred in the early June and July of 2019. During this repair work, some amount of additional fill was placed over Line 10 from the Line 25 side of the TETLP corridor to repair erosion related to TETLP maintenance activities from the previous winter. The additional fill would have increased the load on Line 10 (increasing the traction forces on the pipeline) and at the head of the landslide (causing ground movement acceleration). The July 2019 BGC ground inspection observed a scarp crossing Line 10, but the scarp was obscured immediately upslope of Line 10 by erosion matting. Inspectors did not find consistent topographic changes beneath the matting that would be expected of a drop-down feature, indicating that the scarp and associated cracks was infilled. Cracks off the TETLP corridor were not repaired as part of this restoration work. These cracks would intercept surface water flows that would have otherwise been shed off the slope, conveying the water directly into the slide mass, driving further movement. Continued ground movement likely led to reopening of infilled ground cracks and the further development of cracks on the TETLP corridor allowing additional infiltration and driving further acceleration of the landslide.

Additional water was also directed into the moving landslide feature at the Site via the three existing backfilled pipeline trenches. Seepage was observed along the pipeline trenches following the FCI and it is suspected the trenches served to collect and convey additional groundwater from upslope seepage sources directly into the landslide mass. The ground cracks and the preferential groundwater flow along the backfilled pipeline trenches would increase the impact of the high levels of precipitation over the winter months and are suspected to have led to the rapid acceleration of the landslide between November 2019 and May 2020. This elevated movement rate of the landslide is what appears to have led to an additional 8.9 ft of ground movement and an additional 3.6 ft of OOS on Line 10 by May 4, 2020. This movement induced additional strain on GW 11330 and likely resulted in the failure of GW 11330. Between November 2019 and May 4, 2020, nearly 40% of the OOS on Line 10 occurred, approximately the same amount that had occurred on Line 10 in the preceding period between June 2007 and the June 2019.

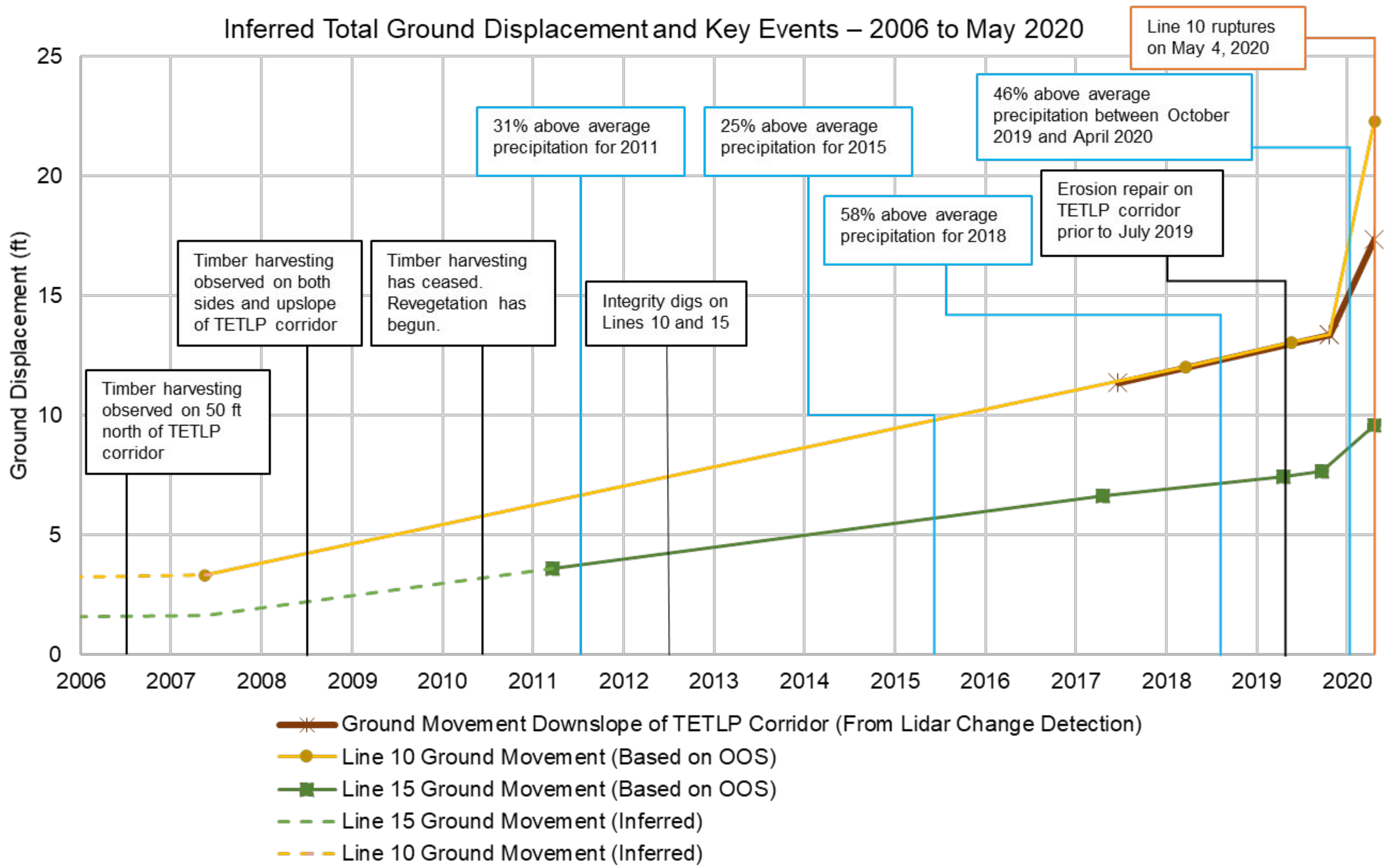


Figure 4-4. Plot showing the inferred approximate total ground movement on Lines 10 and 15 as well as downslope of the TETLP corridor over time along with notable corridor activities (black boxes) and precipitation anomalies (blue boxes).

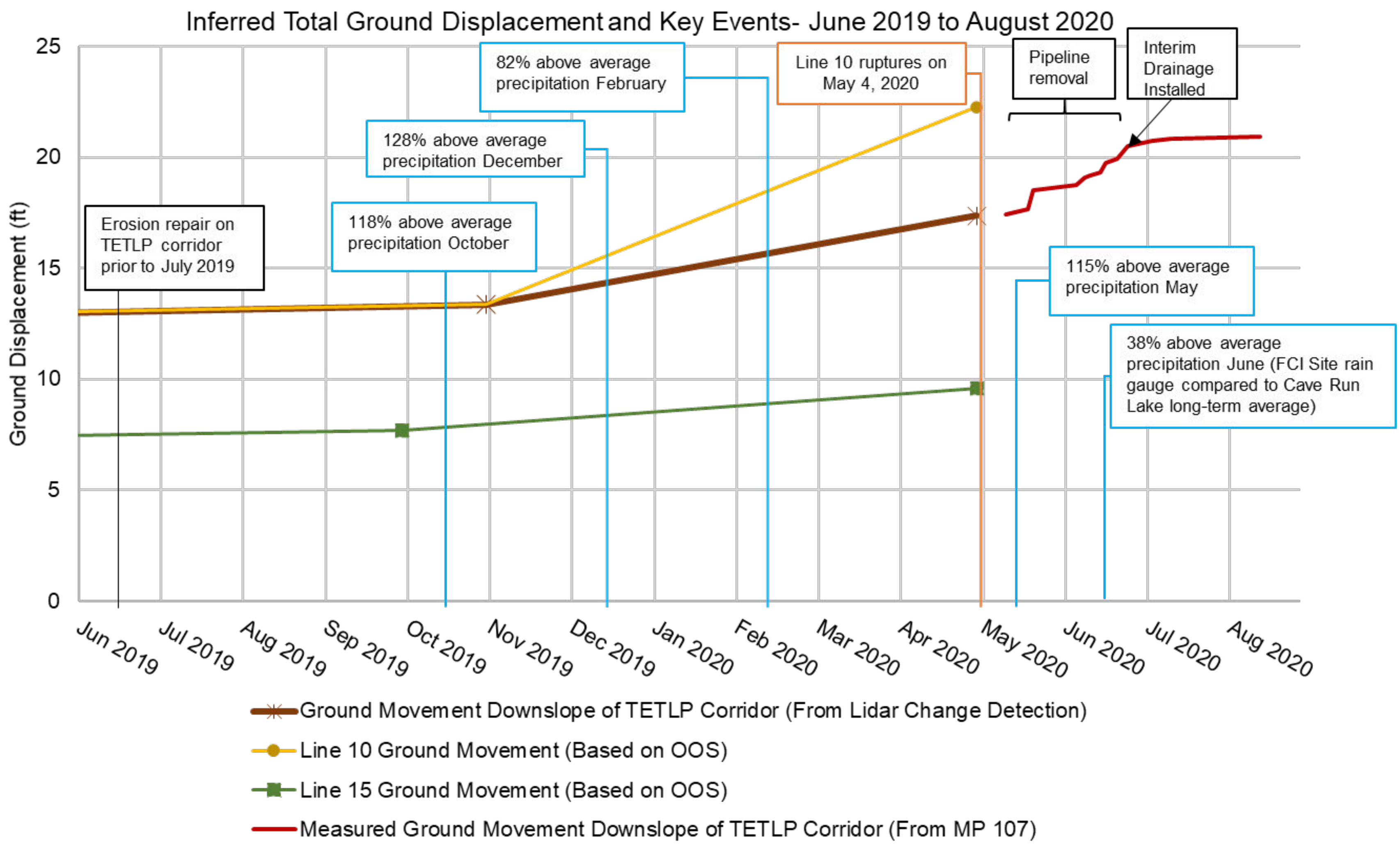


Figure 4-5. Plot showing notable TETLP corridor activities (black boxes) and precipitation anomalies (blue boxes) with the inferred ground movement on Lines 10 and 15 between as well as downslope of the TETLP corridor between June 2019 and August 14, 2020. Ground movement from monitoring hub MP 107 is shown to illustrate ground movement at the Site following the FCI.

5.0 CONCLUSIONS

On May 4, 2020 Line 10 of the TETLP system ruptured in Fleming County, Kentucky. The Site had been previously assessed and had been scheduled for a mitigation to be completed in 2020. At TETLP's request, BGC responded to the FCI and was on-site starting the morning of May 6, 2020 to perform an investigation to support the geotechnical section of the causation report. To determine if geotechnical conditions had any role in the rupture, BGC performed field-based site investigations and a desktop analysis. The investigation included:

- Detailed landslide mapping
- Installation of survey monitoring hubs
- Subsurface investigation
- A review of geologic maps and literature on regional landslide processes
- IMU Assessment of run-to-run data for Lines 10, 15 and 25
- Lidar change detection
- Air photo review
- Historic precipitation review
- Review of past construction activities.

Based on multiple lines of evidence observed during this investigation, BGC concludes that acceleration of the landslide feature that Line 10 was installed within was a key contributing factor to the rupture of Line 10. On-going slope movement producing a gradual accumulation of strain had likely been occurring over much of the life of the pipeline, but significant acceleration of movement in recent years, and particularly the large acceleration over the winter preceding the rupture would have caused an unexpectedly rapid change in pipe strain leading to the rupture. The key points supporting accelerating slope movement as a key contributing factor to the pipeline rupture include:

- An active and well-defined landslide was observed on and downslope of the TETLP corridor intersecting approximately 165 ft of Line 10 and 160 ft of Line 15. Clay colluvium and clear slip planes were observed within the excavation for the cut outs of Lines 10 and 15. Instrumentation installed following the FCI and lidar change detection confirmed active ground movement along the former Line 10 alignment and within the landslide downslope of the rupture site.
- Bending strain consistent with downslope ground movement was measured across a length of 250 ft of Line 10, the majority of that within the landslide, in the June 2007, April 2018, and June 2019 IMU data. Definite strain change and additional OOS had occurred between each of the time intervals in the IMU data. Reported bending strain was observed increasing at the failed girth weld (GW 11330) between April 2018 and June 2019. While this girth weld did not have the highest reported girth weld bending strain in June 2019, ground movement between November 2019 and May 2020 likely led to strains that exceeded the strain capacity of the weld. Tensile strains would also have been present at the rupture location associated with the axial component of movement which are not directly measurable in the IMU data.

- Ground displacement estimates were inferred from the IMU data but also from OOS estimation following the FCI and the lidar change detection assessment in the landslide mass downslope of the TETLP corridor. Based on these assessments, three distinct periods of ground movement have been identified:
    1. 1952 to June 2007: 0.7 inches/yr (3.3 ft of ground movement, 15% of total ground movement) – Overall long-term average movement rate. Ground movement may have been natural, related to a pre-existing landslide, or impacted by TETLP pipeline construction.
    2. June 2007 to November 2019: 10 inches/yr (10.1 additional ft of ground movement, 45% of total ground movement) – More than a ten-fold increase in slope movement rate compared to pre-2007 levels. Elevated rate is sustained for 12 years, until the fall of 2019. This significant increase in rate is likely related to the combined influences of timber harvesting, construction activities on the TETLP corridor, and long-term increases in regional precipitation between 2008 and 2019.
    3. November 2019 to May 2020 FCI: 17.9 ft/yr (8.9 additional ft of ground movement, 40% of total ground movement) – A more than twenty-fold increase in slope movement rate compared to the June 2007 to November 2019 period. This large change in rate is considered to be related to the combined influence of TETLP grading activities in June and July 2019, the high precipitation between October and April 2020 and the fact that the high precipitation occurred when the site was at an increased vulnerability with existing open ground cracks, and preferential groundwater flow paths related to the existing backfilled pipeline trenches.

The landslide impacting Line 10 was a pre-existing feature that would likely have been in a marginal state of equilibrium and sensitive to changes in slope geometry and groundwater conditions. The changes that would have had a destabilizing influence were associated with vegetation removal and ground disturbance associated with construction activities, and precipitation. Various construction activities have occurred at this site prior to 2007, including the construction of Lines 10 and 15 in the 1950's, Line 25 in the 1965, and TETLP corridor maintenance (excavations, grading and equipment vibrations). These activities would have led to additional fill being placed on Line 10 and in the headward portion of the landslide, accelerating slope movement and increasing the traction loads on Line 10. These activities would also have increased slope instability through the long-term redirection of seepage flows into the landslide feature along the pipeline trenches and changes to surface drainage.

Beginning after June 2007, ground movement rates increased significantly from the low average rate of movement over the past five decades, due to both natural and man-made events. The ground movement rate increase after June 2007 was likely related to timber-harvesting activities on the slope. Average ground movement rates remained elevated following conclusion of the harvesting activities in 2010 likely due to various construction activities on the TETLP corridor at the Site but also due to a prolonged period of above average annual precipitation beginning in 2008. The decade between 2010 and 2020 was the wettest on record since the installation of Line 10 in 1952, and 2018 was the wettest year over this same time period. This prolonged period of above average precipitation would have increased pore water pressures, driving further movement at the Site. Many neighboring landslides near the Site experienced similar movement rates between 2017 and November 2019, due to the precipitation over 2018.

The acceleration between November 2019 and May 2020 was dramatic. The acceleration corresponded to an abnormally wet fall and winter, with October, December and February all having nearly or more than double the average amount of precipitation. While 2018 overall had greater precipitation, the October 2019 to April 2020 period had greater precipitation than the same period in the two previous years. Lower evaporation rates due to less sunlight and minimal evapotranspiration increases the impact of elevated precipitation during the winter on slope stability as more surface water infiltrates the soil. However, the elevated precipitation alone does not account for the rapid increase in slope movement.

A 20-fold increase in ground movement was unique to the Site and was not observed at neighboring landslides on similar aspect slopes. This is suspected to be due to the unstable state of the landslide prior to November 2019 and its heightened vulnerability to being destabilized by precipitation. Grading activities in June and July of 2019 had placed additional load at the head of the landslide and while ground cracks were repaired on the TETLP corridor, field inspections confirmed they were still present downslope and off the corridor. These cracks would serve as conduits to intercept surface water flows that would have otherwise been shed off the slope, conveying the water directly into the slide mass, driving further movement. As additional movement occurred, existing cracks would widen and new cracks would form, allowing additional infiltration and driving further acceleration of movement. Another key difference between the Site and neighboring landslides is that three existing pipeline trenches were directing water into the moving landslide feature at the Site. As observed in the field, the backfilled pipeline trenches served as preferential seepage paths, directing ground water intercepted by the trenches on the slope into the landslide mass. This additional source of water would not be present in landslides off the TETLP corridor. It is suspected this combination of the high levels of precipitation between October 2019 and April 2020, pre-existing cracks, additional ground water conveyance along the pipeline trenches and loading associated with the June and July 2019 grading activities drove the large acceleration between November 2019 and May 2020. This rapid acceleration is suspected to have caused great enough strain to fail GW 11330.

While Line 15 was also within and impacted by the landslide feature, overall strains on the line were lower than Line 10 likely due to a combination of lower ground displacement rates as Line 15 was likely in a less active part of the landslide along the upslope periphery of movement, and lower amounts of soil cover reducing the soil loading on the pipeline that would cause out-of-straight deformation and associated pipe strain. Line 25 was found to not be impacted by the landslide as it was predominantly trenched within bedrock along the upslope margin of the slide.

6.0 CLOSURE

We trust the above satisfies your requirements at this time. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

BGC ENGINEERING USA INC.
per:

[redacted]

[redacted]

Pete Barlow, M.Sc., P.Eng. (AB)
Principal Geotechnical Engineer

Casey Dowling, M.Sc., P.E. (KY)
Senior Geological Engineer

Reviewed by:

Michael Porter, M.Eng., P.Eng. (BC), LEG (WA)
Principal Geological Engineer

BW/MP/syt

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APPENDIX A
CAMBIO INSPECTIONS PRIOR TO THE FLEMING COUNTY INCIDENT

Site view
Slope (8800)

Site information

Site name
Slope (8800)

Pipeline name
OWSV-WHEE/10 VS-01

Hazard type
Geotechnical

Site active
Yes

Location comments
OWSV_10 Strain 017 (IMU 2019 vs 2007)

ATV access required
No

Access key required
No

Helicopter access required
No

FNR access required
No

Site overview

Overview Status

Site location

Latitude
[redacted]

Longitude
[redacted]

Location details

Chainage

Land survey

Site length

Start point latitude
[redacted]

Start point longitude
[redacted]

End point latitude
[redacted]

End point longitude
[redacted]

Site attachments

Outstanding tasks

Inspection summary

Oct 30, 2019 - Geotechnical Inspection

Inspection status
Authorized

Date	Inspector	Organization
Oct 30, 2019	CRS	BGC

Inspection type		Min DoC(m)	Timing	
Office		2.22	< 1 years	

Vulnerability	PoF	Category	PoE/PoI	Rating
0.025	0.023	1	0.91	very high

Observations

This office inspection documents 2019 IMU for Lines 10 and 15 and the results of an Enbridge strain review. IMU results are outlined with condensed July 2019 field findings and attached as a slide deck. Overview: The Line 10 and 15 data both show patterns consistent with downslope movement. Both plan views show increasing out-of-straight (OOS) with respect to the baseline IMU run. The bending strains also have reported run-to-run (RTR) change. The IMU and field-staking results indicate that Lines 10 and 15 are engaged in a landslide. Field inspectors observed an arcuate scarp that intersected the upslope portion of the Line 10 deflection. The scarp was obscured by grading and straw matting immediately after crossing the Line 10 centerline. Some cracking was apparent immediately behind the visible scarp length. Seepage zones were present over Lines 15 and 25, approximately in line with the scarp. An incised washout gully was present near the bottom of the bench, leading off ROW. The washout was approximately in line with an apparent scarp in aerial imagery Line 10: The 2019 data, when compared to the 2007 baseline, had 0.724% RTR change. The 2018 data, when compared to the same baseline, had 0.593% change. This indicates approximately 0.13% change occurred on Line 10 between April 2018 and June 2019. The strain pattern is consistent with slope movement. The July 2019 site visit located line Line 10 with pin flags and observed approximately 4’4” (1.36 m) of OOS over 180 ft (58 m). This value was approximately consistent with the 2018 IMU. The 2019 IMU may show an increased OOS with respect to 2018, but is difficult to determine with certainty based on the differing extents of the two plots. Line 15: The 2019 data, when compared to the 2011 baseline, had 0.103% bending strain change. This is smaller than the 0.141% reported for 2017 versus the baseline, suggesting tooling differences or differently delineated "blue boxes" at the formed bends. The Line 15 data is consistent with downslope deflection and shows approximately 3 ft out-of-straight over approximately 200 ft. The July 2019 OOS for Line 15 was field-measured as approximately 2-3 ft over approximately the same length as Line 10. The Line 15 deflection pattern was more gentle than on Line 10 and delineating the end of OOS was challenging. Line 25: The Line 25 flagged centerline, in the upslope position, did not show consistent deflections. No new strain data has been received. Email communication with Enbridge PI (October 30, 2019) indicated that total strains on the girth welds are manageable. Given the activity level indicated in the available data, Enbridge recommended: -monitoring pipeline and scheduling stress relief as needed -scheduling geotechnical improvement of the site to reduce the movement rate

Recommended action

Mitigation

Recommendations

Per discussions with Enbridge PI, plan to perform a mitigation at the site. Given current site information, mitigation activities may include strain relief, instrumentation, and/or drainage improvements.

IMU slide deck used during email discussions of next actions.

Jul 8, 2019 - Geotechnical Inspection

Inspection status

Authorized

Date		Inspector	Organization	
Jul 8, 2019		CRS	BGC	

Inspection type		Min DoC(m)	Timing	
Ground		2.22	< 1 years	

Vulnerability	PoF	Category	PoE/PoI	Rating
0.025	0.023	1	0.91	very high

Observations

Three pipelines are oriented oblique (30 degrees) to the fall line of a west-facing slope. Listed from upslope to downslope (south to north), the lines are Line 25, Line 15, and Line 10. The site visit was prompted by a Tier 1 strain (~0.9%, primarily horizontal) from a 2018 ILI run on Line 10. Four smaller vertical strains on Line 25 were identified from 2014 data and were inconclusive with respect to ground movement. The ROW slope was generally 22 degrees, with a 16 degree bench at midslope. The midslope bench and lower slope were recently graded and covered in coconut matting, reportedly due to surface washouts. A weathered shale/siltstone outcrop (Feature A) covered portions of the steep upper slope. BGC located and flagged the three lines in the ROW. Compared to a taught straight-line datum, Line 10 was deflected downslope on the midslope bench by approximately 4’4” (1.36 m) over 180 ft (58 m), which was approximately consistent with the 2018 IMU. Line 15 showed a smaller magnitude deflection (approximately 2-3 ft) over a similar length. The flagged centerlines returned to straight at the lower edge of the bench. The Line 25 flagged centerline, in the upslope position, did not show consistent deflections. An arcuate scarp intersected the upslope portion of the Line 10 deflection (Feature B). The scarp was obscured by grading and straw matting immediately after crossing the Line 10 centerline. Some cracking was apparent immediately behind the visible scarp length. Seepage zones were present over Lines 15 and 25, approximately in line with the scarp. An incised washout gully was present near the bottom of the bench, leading off ROW. The washout was approximately in line with an apparent scarp in aerial imagery (Feature C). West of the ROW, downslope of the deflections, inspectors found exposed sandy clay soil in the west side of the gully. Angular sandstone clasts were common in the drainage itself and typically measured less than 1 ft.³. Large sandstone boulders were observed in the woods, within 50 ft of the cleared-ROW, but no source outcrop was located. The boulders may be a result of excavating through bedrock on the ROW. Pistol-butted trees were observed downslope (west) of the ROW, but the pattern was inconsistent and did not yield a clear interpretation. The pistol-butting may be associated with surficial movement into the gullies. East of the ROW, inspectors identified a 5 ft high scarp (Feature D). Some exposed soil was present in the scarp and nearby trees were pistol-butted. The scarp may be associated with the grade cut required for the ROW, particularly since it is upslope of Line 25 and no evidence of bulging or deflection was observed on Line 25, even within the 2015 strain extents.

Recommended action

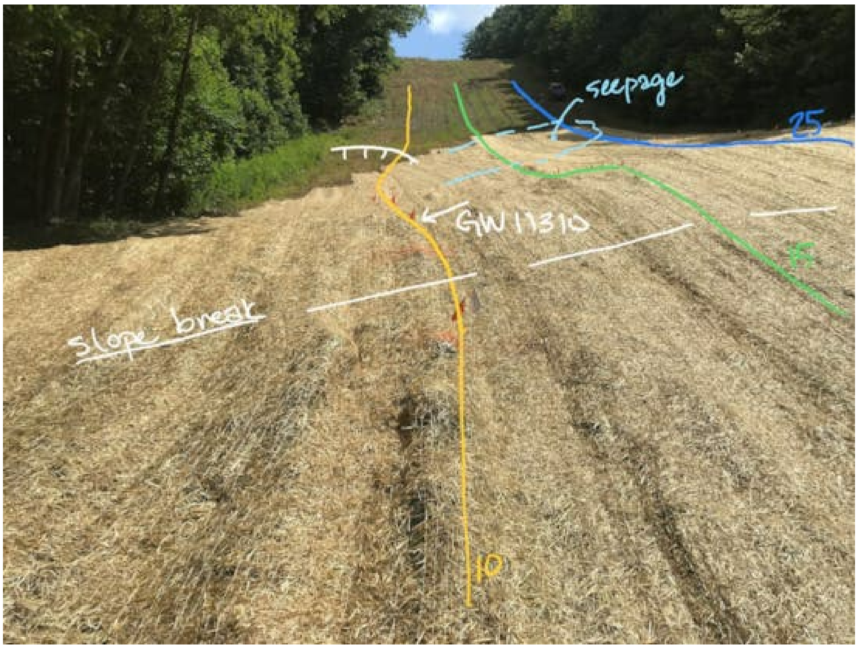
Mitigation

Recommendations

Assess the strain demand on Lines 10 and 15 using the to-scale maps produced during the ground inspection. Consider a strain relief and drainage at the site to improve site conditions.

Looking north at head scarp east of ROW (Feature D). Note some fresh soil and pistol-butted trees.

Standing on Line 15 at the lower slope break, looking upslope at the bench and deflections on Line 15



Standing at lower slope break on line 10, looking upslope at bench and lateral deflections.

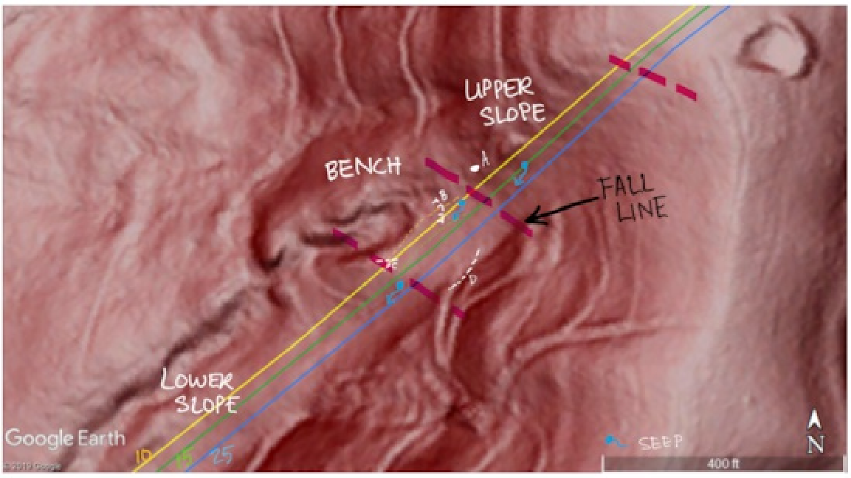

Standing on Line 15, looking downslope. Note defelction in flag lines for Line 10 (yellow) and Line 15 (green). Possible scarp noted in white. Evidence of weathered siltstone from Feature A is present in foreground.

Out-of-straightness map for Line 10.


East of ROW near Line 25 strain 23, looking at possible overgrown scarp. Area on ROW very swampy, with ponded water and thick grasses.


Standing near Line 25 strain 23, looking upslope at main slope.

Looking south at scarp east of ROW (Feature D).



Sketch map of features and deflections.

Jul 5, 2019 - Geotechnical Screening Inspection

Inspection status

Authorized

Date		**Inspector**	**Organization**
Jul 5, 2019		CRS	BGC
Inspection type		**Timing**	
Office		< 1 years	
Vulnerability	**Category**	**Rating**	
0.029		very high	

Observations

Lines 10 (installed 1952), 15, and 25 traverse a 22-degree slope oblique to the fall line. An Inertial Measurement Unit (IMU) bending strain anomaly was reported on Line 10 with a total bending strain magnitude of 0.925% (reported at southern inflection point) and a girth weld bending strain magnitude of ~0.55% (occurs at the southern inflection). 2018 Run to Run comparison data for Line 10 shows a 4-foot increase in downslope deflection and a 1.5-foot increasing in vertical sag bending between 2007 and 2018. Four bending strain anomalies were reported on Line 25 along same slope in 2014 single-run IMU, but without horizontal components. No IMU bending strain data is available for Line 15 yet. A scarp is visible in Google Earth imagery (appears sometime 2010-2013) and hummocky ground is visible in lidar data of an unknown age. Scarps are also visible in south of the RoW in the lidar data. The Line 10 strain is interpreted as consistent with ground movement. The Line 25 strains are inconclusive. Strain interpretations and observations follow: Strain Interpretation -Strains are consistent with downslope movement on Line 10 Strain Observations Line 10 -Downslope deflection grew by ~4 ft between 2018 and 2007 -Vertical strains increasing -Largest strain (0.925%) reported at southern inflection point -Largest strain on weld at southern inflection (~0.55%) Line 25 -Consistently showing vertical W-shapes when horizontal shapes expected (023, 024, 025) Proximity -Line 25 strains 023-026 are on same slope but do not show same signature.

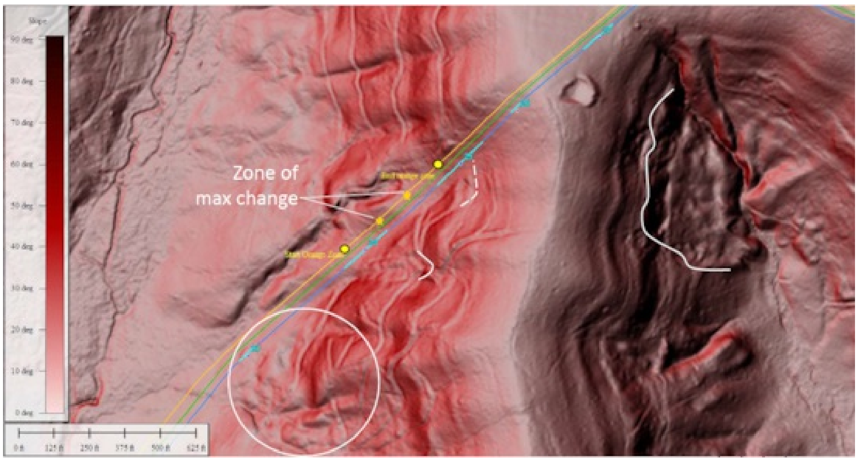
Recommended action

Inspections - Ground

Recommendations

Tier 1 – Critical site with ground movement related strains. Requires site visit as soon as practical. The tier designation is based on the combined analysis of digital terrain data and Inertial Measurement Unit (IMU) strain data. Review next available IMU for strain change as part of interim office inspection. During ground inspection: 1. Measure out-of-straightness (OOS) in plan for all three pipelines. 2. Measure horizontal distances to scarps along the staked sections, so we can relate them with to pipe features. 3. Look around Line 25 STR23 at the slope toe to see if there are ground-surface-visible signs of bulging there. 4. Look around Line 25 STR24 and 25 for signs of vertical bulging there as well. Check for sandstone outcropping at the same elevation as those two strain hits. 5. Check for a scarp forming around Line 25 STR 26. 6. Inspect north (downslope) off the RoW to see if you can identify how far downslope the ground movement extends. Try to find an exposure that tells you something about the mechanism.

Slide deck with lidar, aerial imagery, and strain interpretations.



Page 1 - aerial imagery

Jan 28, 2019 - Geotechnical Screening Inspection

Inspection status

Authorized

Date	**Inspector**	**Organization**
Jan 28, 2019	CRS	BGC

Inspection type	**Timing**
Air	< 1 years

Vulnerability	**Category**	**Rating**
0.014		very high

Observations

BGC and Enbridge conducted helicopter reconnaissance between Tompkinsville and Uniontown as part of the immediate Noble County Incident response. The flyover observed surficial erosion and gulling. This inspection is back-dated to the date of the flyover, but the photo was identified for additional review during response to the Fleming County Incident. Prior lidar desktop review identified hummocky, disrupted terrain on both sides of pipeline. Movement hazard morphology is carried forward from the desktop review.

Recommended action

Inspections - Ground

Recommendations

Complete a ground inspection to assess features observed in lidar.

Looking approximately northeast at ROW. Note apparent erosion feature crossing ROW.

Oct 9, 2018 - Geotechnical Screening Inspection

Inspection status

Authorized

Date		**Inspector**	**Organization**
Oct 9, 2018		BLW	BGC
Inspection type		**Timing**	
Office		< 1 years	
Vulnerability	**Category**	**Rating**	
0.014		very high	

Observations

Hummocky disrupted terrain on both sides of pipeline. Incised drainage parallel to and northwest of pipeline.

Recommended action

Inspections - Ground

Recommendations

APPENDIX B
MARCH 2020 MONITORING AND MITIGATION PROPOSAL

BGC ENGINEERING USA INC.
AN APPLIED EARTH SCIENCES COMPANY
701 12th Street – Suite 211
Golden, CO USA 80401
Telephone (720) 598-5982

March 24, 2020
Proposal No. P19293-02

Doug Cook
Supervisor, Geohazards Program
Enbridge Gas Transmission
5400 Westheimer Court
Houston, TX 77056

Dear Mr. Cook,

Re: Proposal for Strain Gauge and Drainage Installation at Cambio™ Site IDs 8800, 8801 and 8802, OWSV-10 and OWSV-15

1.0 INTRODUCTION

BGC Engineering USA Inc. (BGC) is pleased to present the following proposal to provide services in support of strain gauge and drainage installation on the OWSV Section of Enbridge Gas Transmission's (Enbridge's) Texas Eastern Pipeline System, at Cambio™[1] Site IDs (SIDs) 8800, 8801 and 8802 (Figure 1-1).

The site was first identified as a potential landslide during BGC's initial desktop inventory work in October 2018. Review of run-to-run Inertial Measurement Unit (IMU) data indicated that both OWSV Lines 10 and 15 were likely impacted by downslope ground movement which continues to contribute to an increase in bending strains at this location. BGC completed a ground inspection on July 8, 2019 which confirmed evidence of recent ground movement including scarps, ground cracks and seepage. Based on the oblique pipeline orientation on the slope, ground movement is expected to induce both bending and axial strain on the pipelines, of which only the bending strain component is measured in the IMU data.

Given the magnitude of change in bending strain data and the details of the BGC ground inspection, Enbridge decided a stress relief was not warranted at the site, but that additional strain accumulation on the pipelines should be monitored. BGC recommended installing strain gauges on the pipelines to assess axial and bending strain changes at locations coinciding with strain

[1] Cambio™ is proprietary software developed and hosted by BGC to systematically and objectively prioritize geohazard sites for future inspection, detailed investigation, maintenance, monitoring, and mitigation as part of their integrity management system. It is used to store site observations, historical studies or actions at the sites (e.g., surveys, as-built reports, inspections, etc.), and recommendations, and to maintain an audit trail for each site. Enbridge is a subscriber to Cambio and uses the application as part of their overall pipeline integrity management program.

anomalies and observed landslide features. BGC also recommended installing drainage to reduce ground movement potential.

This proposal presents a plan to install the instrumentation and drainage recommended by BGC. Strain gauges will be installed at critical bending strain locations identified in the IMU data and will be connected to an automated data acquisition system which will enable Enbridge to monitor pipe strain remotely and in real-time without having to mobilize personnel to site to obtain readings. Subdrains will be installed to intercept and transport ground water downslope and off the right-of-way (RoW).

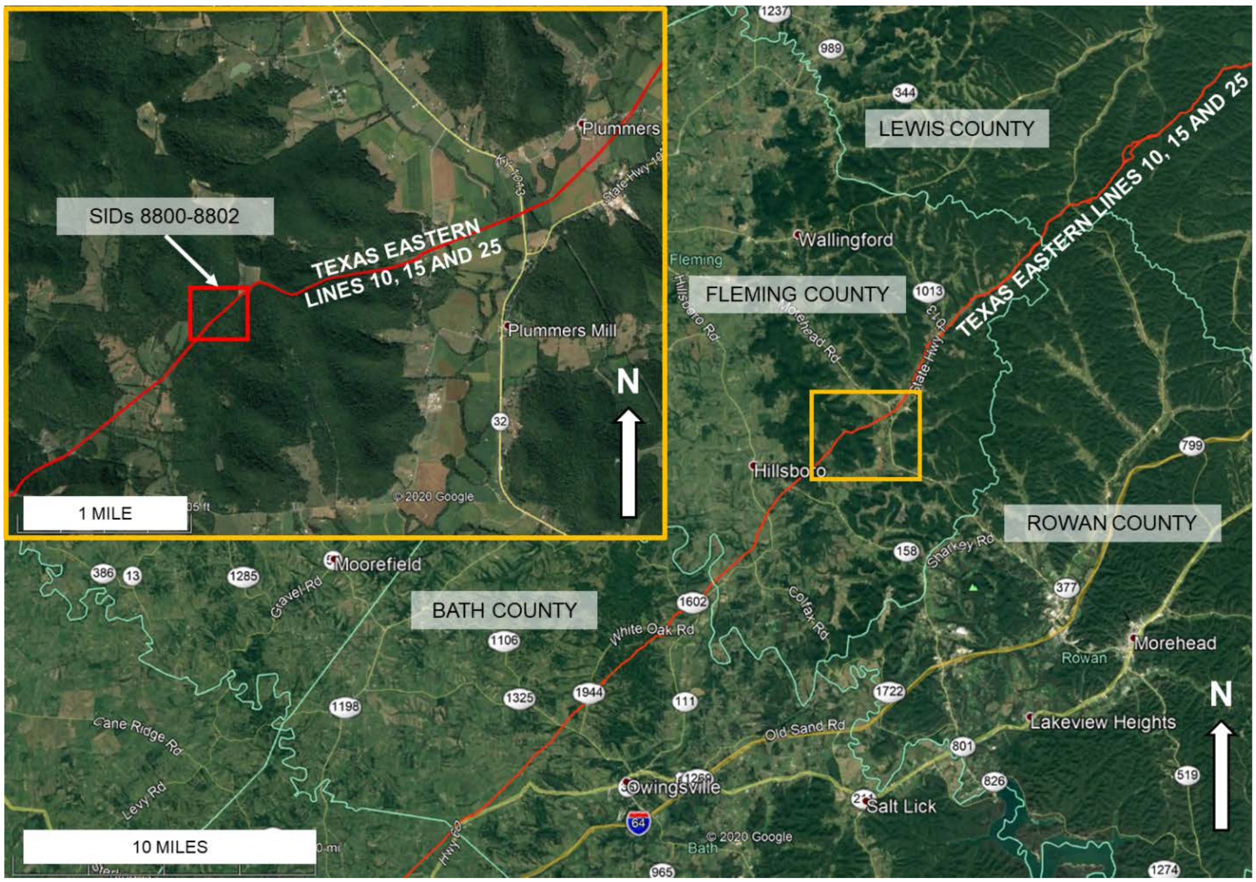


Figure 1-1. Regional overview of the SIDs 8800-8802. Imagery from Google Earth (2020).

Key tasks outlined in this proposal include:

- Field preparation and planning
- A site visit to assess proposed locations of strain gauges and drainage with Enbridge Operations and excavation contractor
- Field support during strain gauge and drainage installation to document materials observed in excavations and provide guidance on field adjustments of drainage locations
- Preparation of a report documenting the installation of the strain gauges, drain features, and geotechnical learnings from the excavations

- Evaluation of data produced by the strain gauges and collaboration with Enbridge to establish thresholds for strain readings which will automatically trigger various levels of response actions

The services provided under this assignment will be governed by the Master Services Agreement CW2227833 between Enbridge (formerly Spectra Energy Services, LLC) and BGC, effective March 1, 2016, as amended April 19, 2018, December 11, 2018, and January 31, 2019 and December 16, 2019.

2.0 PROJECT SCOPE AND METHODOLOGY

2.1. Task 1 – Project Management

This task encompasses all activities required to manage the project to ensure that it meets Enbridge's expectations. Activities include maintaining communication amongst all parties, documenting progress and maintaining schedule and budget. Project management will be conducted concurrently with other tasks.

2.2. Task 2 – Field Preparation

BGC will review the IMU data, lidar imagery and ground inspection observations to work with Enbridge to establish the locations of strain gauges to be installed along Line 10 and Line 15 and the design of the subdrains. BGC assumes Enbridge will coordinate access to the site and ensure all buried facility locations are identified.

BGC will complete and prepare necessary safety training, materials, and procedures for BGC staff prior to the field component of the instrumentation installation.

2.3. Task 3 – Field Program

One geotechnical engineer from BGC will meet with Enbridge Operations and the excavation contractor at the field program kickoff to identify site access constraints, potential hazards, and any necessary site preparation. Locations of both the bell holes and the drainage measures will be refined and confirmed based on input of all parties. BGC has budgeted a separate mobilization for the kickoff meeting; costs may be reduced if the kickoff meeting takes place immediately prior to commencement of construction.

BGC will monitor excavation of the bell holes for the installation of strain gauges along Lines 10 and 15. BGC will also document the geologic conditions observed in the bell holes.

BGC proposes five sets of strain gauges to be installed on Line 10, and three sets of strain gauges on Line 15, requiring a total of eight bell holes to be excavated. Proposed strain gauge locations correspond to maximum bending strains and girth welds with high bending strains on Lines 10 and 15 (shown on Figure 2-1 and Figure 2-2). Preliminary locations of strain gauge sets have been provided in Table 2-1 and shown on Figure 2-3 and Figure 2-4. These locations are subject to final approval from Enbridge.

BGC will provide assistance installing and initializing the real-time monitoring system. In addition to the strain gauges, the following equipment will also be required:

- A data logging station to automatically collect, store, and transmit data from the various instruments
- Cable and conduit to connect the strain gauges to the datalogger

It is recommended that BGC is responsible for building the datalogger to ensure that the system is designed to be installed efficiently and data are reliably collected and transmitted. This task includes the cost (time and materials) to build the datalogger as well as the time for BGC to support installation and to setup the instrumentation on BGC's multilogger data management system. Enbridge will need to provide a concrete pad and steel mast on which to mount the datalogger, the specifications of which can be determined during field preparation.

BGC will also provide guidance on the installation of subsurface drains to improve stability conditions at the site. The proposed locations of the subdrains are shown in Figure 2-4. Drainage will be targeted to intercept seepage observed during the July 2019 ground inspection and transport the intercepted water to the north side of the RoW. The final locations of the drains will be field-fit based on observations made during construction. Drainage construction is expected to occur concurrently with the strain gauge installation so bell hole excavations can be utilized for routing drains beneath Lines 10 and 15.

Eight days of field time and four days of travel time have been budgeted for this task. BGC assumes Enbridge is the prime contractor for this project and will direct field logistics, including: retaining the excavation contractor; retaining a surveyor to record the as-built locations of all drainage, instrumentation, and conduit; and procuring and installing the strain gauges, cable and conduit for the monitoring system. If coordination support is requested, BGC can provide Enbridge with an updated cost estimate.

Table 2-1. Proposed strain gauge locations, subject to final approval by Enbridge.

Pipeline	Strain Gauge Set	Nearest Upstream Girth Weld	Distance from Upstream Girth Weld (ft)	Latitude	Longitude	Reason
Line 10	10-01	11320	0	[redacted]	[redacted]	Girth weld with highest bending strain (0.414%).
Line 10	10-02	11320	8.6	[redacted]	[redacted]	Peak leftward horizontal strain on western limb of deflection.
Line 10	10-03	11330	11.5	[redacted]	[redacted]	Near peak right-ward horizontal strain in center of deflection.
Line 10	10-04	11340	0.0	[redacted]	[redacted]	Second highest strain on girth weld (0.375%), highest change in bending strain on girth weld (0.25%).
Line 10	10-05	11370	6.5	[redacted]	[redacted]	Peak leftward strain on eastern limb of deflection.
Line 15	15-01	11260	14.0	[redacted]	[redacted]	Peak bending strain and strain change on western limb of deflection.
Line 15	15-02	11270	21.6	[redacted]	[redacted]	Greatest strain change on rightward bend in mid-portion of deflection.
Line 15	15-03	11320	16.2	[redacted]	[redacted]	Peak leftward bending strain on eastern limb of deflection.

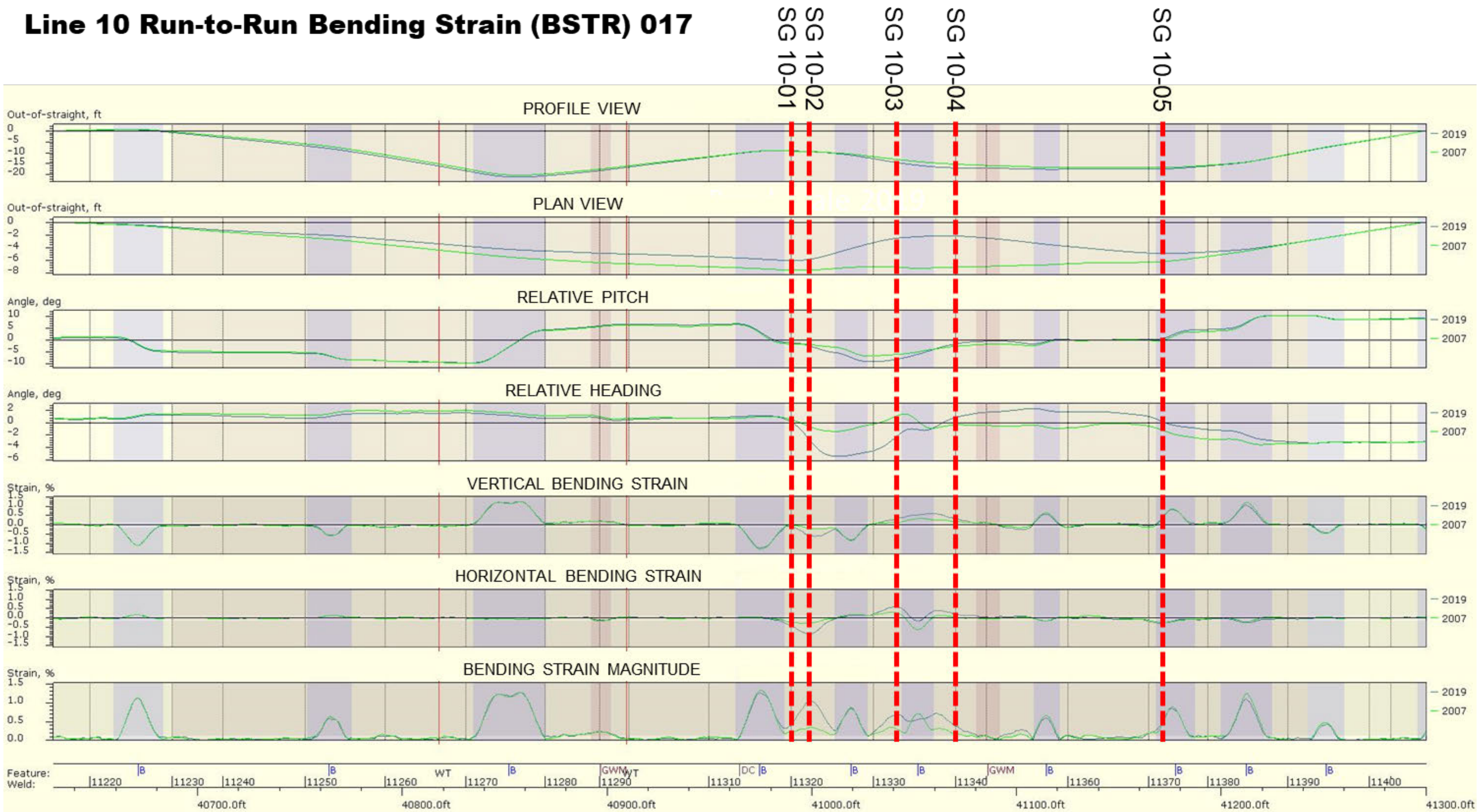


Figure 2-1. Strain plot for Line 10 2019-2007 run-to-run bending strain 017 showing proposed strain gauge set locations (red dashed lines). Plots provided by Baker Hughes (2019a).

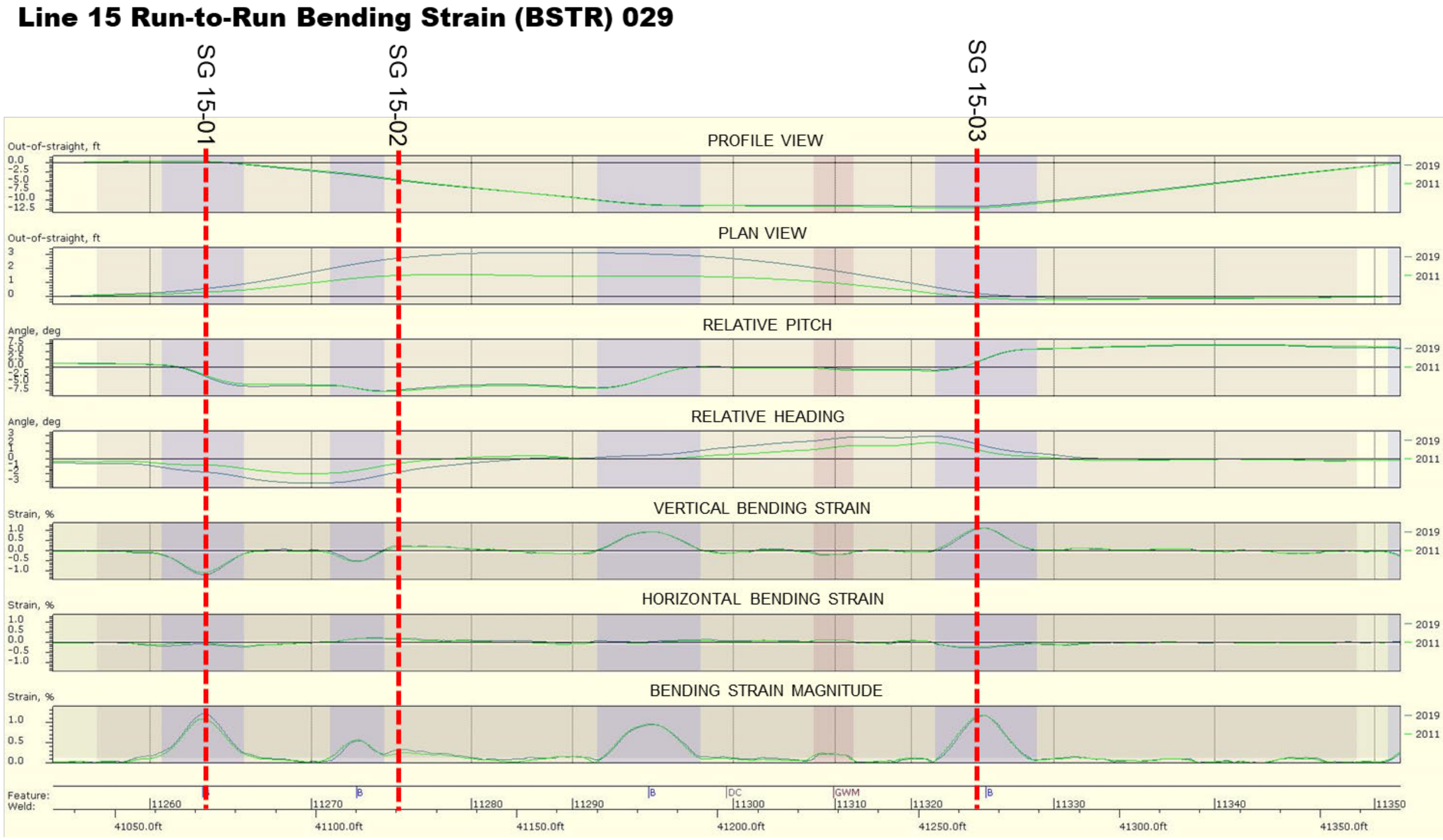


Figure 2-2. Strain plot for Line 15 2019-2011 run-to-run bending strain 029 showing proposed strain gauge set locations (red dashed lines). Plots provided by Baker Hughes (2019b).

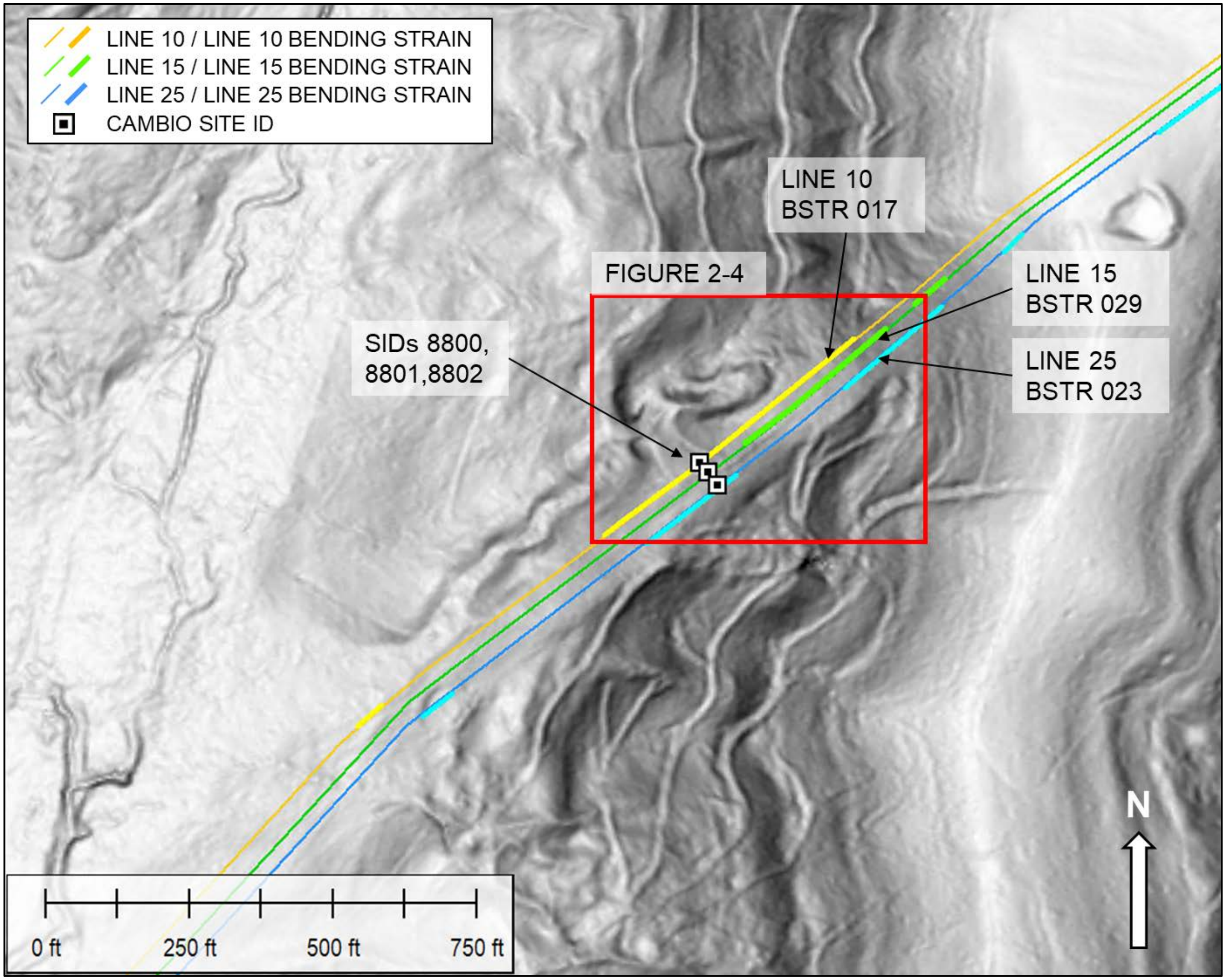


Figure 2-3. Overview lidar imagery of the site, showing the locations of the Line 10 and 15 run-to-run bending strains. Lidar imagery from Kentucky Division of Geographic Information (2017a and 2017b).

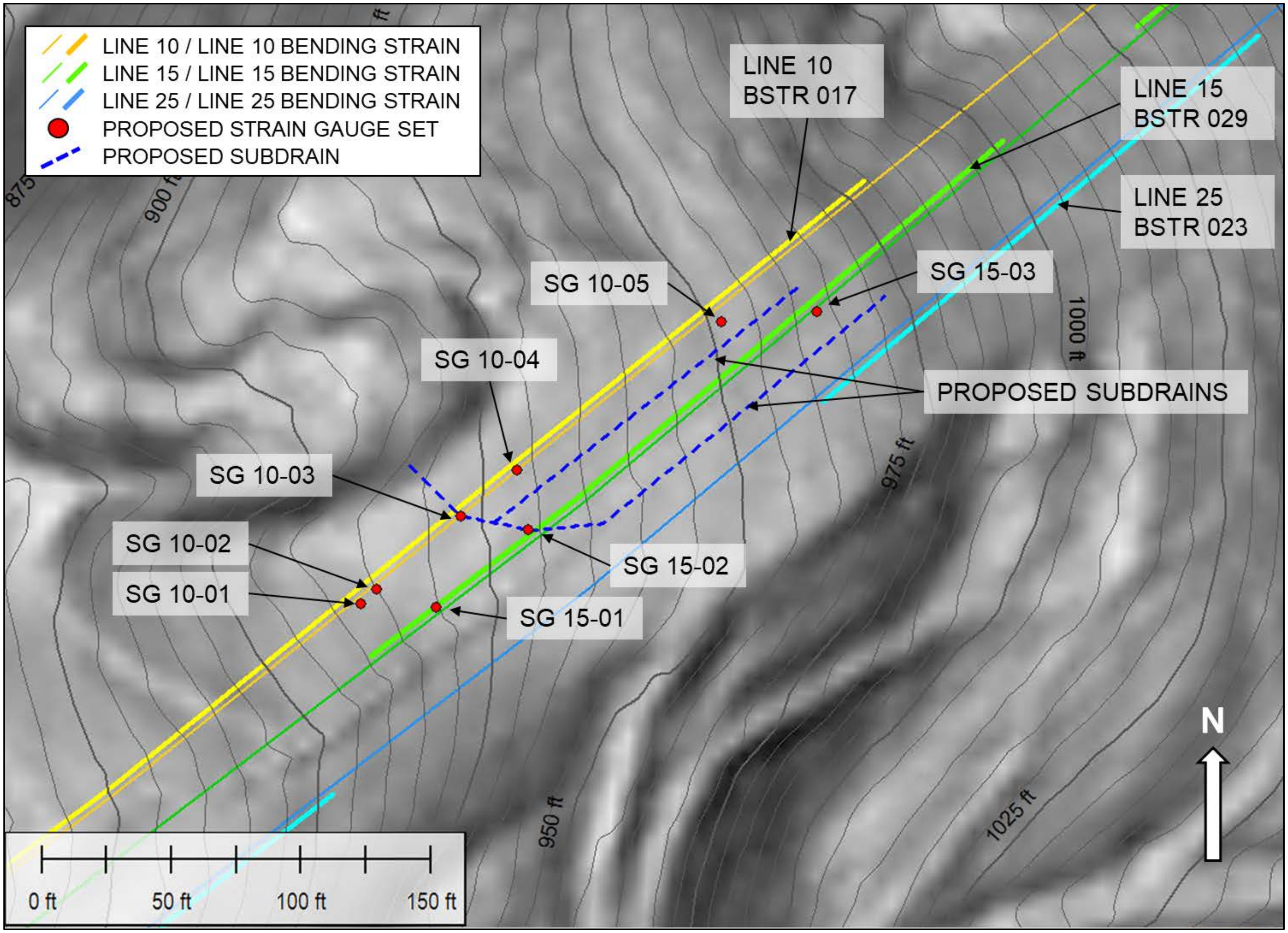


Figure 2-4. Lidar plan-view of the proposed strain gauge sets and subdrain locations. Note that pipe linework may vary from actual: strain gauge locations are to be based on relation to girth welds as shown in the IMU plots.

2.4. Task 4 – Data Compilation

This task includes:

- Producing a plan-view drawing and drainage typicals using field data from BGC personnel and survey data documenting the as-built locations of the strain gauges, supporting hardware and subdrains
- Preparing bell hole logs including soil and rock descriptions and photographs

2.5. Task 5 – Reporting

BGC will prepare a report detailing site observations and instrumentation and drainage installation. The report will include:

- Summary of scope-of-work, background, methodology and observations
- Logs of the bell holes
- A digital plan drawing showing the locations of the strain gauges and drainage measures
- Discussion of interpreted ground movement mechanisms identified from the site observations, as possible.

2.6. Task 6 – Strain Gauge Monitoring

This task includes providing support for monitoring the real-time strain gauges installed on the slope for the remainder of 2020. Data produced by the strain gauges will be evaluated for movement, continuity and power budget on a weekly basis by BGC. Additionally, a monthly summary memorandum, including plots of strain with discussion will be provided to the client though the end of 2020.

Once baselines for the instruments have been established, BGC will recommend alert thresholds for strain measurements which trigger recommended actions. The data acquisition system can provide automated alerts to project personnel and clients if any of the thresholds are exceeded. These thresholds and actions will be developed in close collaboration with Enbridge. This proposal covers monitoring through 2020. After 2020, ongoing monitoring will fall under a separate scope.

3.0 PROJECT TEAM

BGC proposes that Ms. Beth Widmann, P.G., will be the project manager and BGC's main point of contact. Senior technical review will be provided by Mr. Pete Barlow, P.Eng., and Mr. Casey Dowling, P.E., will act as the primary Technical Lead. BGC will only utilize qualified geoscientists or engineers who have experience assessing geotechnical geohazards in the office and in the field. BGC understands that Mr. Doug Cook will be the primary contact at Enbridge.

4.0 COST ESTIMATE

Table 4-1 presents an approximate distribution of the budget and BGC's hourly rates for the tasks outlined in this proposal. The total cost is estimated to be $----- US dollars (USD).

Included in the Task 3 – Field Program disbursements:

- Round-trip flights (2)
- Rental Truck (12 days)
- Hotels (12 nights)
- Per diem (12 days)
- Datalogger (materials, shipping to site, and time to assemble)

The Task 3 disbursement does not include any other instrumentation materials; Enbridge will need to provide all instruments, cable, conduit, concrete pad, steel mast, and any other materials necessary for instrumentation installation.

Every effort will be made to stay within this budget both on a task-by-task and overall project basis. The budget will not be exceeded without prior written approval from Enbridge. This cost is based on the estimated hours required to complete the work and is not a lump sum. Any hours above or below the estimate will be added or subtracted at the rates provided. The cost estimate shown in Table 4-1 is valid until the end of 2020. All disbursements will be charged at cost (no mark-up). Billing will be monthly, usually on the tenth day of the month following the period in which the costs were incurred. No allowance has been made for formal/scheduled project meetings or progress reporting; however, BGC tracks task and overall project costs weekly in order to ensure that the project is within scope, on time, and on budget.

Table 4-1. Approximate budget distribution for tasks outlined in this proposal.

[redacted]

5.0 SCHEDULE

BGC will work with Enbridge to develop a schedule which is reasonable for both parties considering the recent world events surrounding the Coronavirus.

Once initiated, the field program is estimated to take 1.5 to 2 weeks, depending on the sequencing of activities and weather conditions at the site. A final report will follow within one month of the completion of the field program. Instrument monitoring by BGC has been forecasted until the end of 2020, following project completion.

6.0 CLOSURE

We trust the above satisfies your requirements at this time. The information presented in this proposal document is proprietary and was prepared and submitted in confidence solely for consideration by Enbridge. The contents of this proposal document are not to be communicated, disclosed, duplicated, or distributed in whole or in part to anyone or any organization outside of BGC by Enbridge without the express written permission of BGC. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

BGC ENGINEERING INC.
per:

[redacted]

Casey Dowling, M.Sc., PE (KY)
Geological Engineer

Reviewed by:

Pete Barlow, P.Eng., P. Geo.
Principal Geotechnical Engineer

BW/PJB/md/syt

REFERENCES

Baker Hughes. (2019a, September 6). *IMU Strain Reporting: Level 2 Bending Strain and Strain Change Assessment Report (Repeat IMU Run, 2011, April 20 and 2019, May 24), OWSV_15 – Owingsville to Wheelersburg, Contract 451343_30I* [Report]. Prepared for Enbridge Inc.

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Kentucky Division of Geographic Information. (2017a). *Kentucky LiDAR Point Cloud Data Tile N071E352* [GIS Data]. Extracted the KyFromAbove website: https://kygeonet.ky.gov/govmaps/KyFromAboveGallery/map.html?webmap=b5ff91df6309491090c20333c8f58f52.

Kentucky Division of Geographic Information. (2017b). *Kentucky LiDAR Point Cloud Data Tile N072E352* [GIS Data]. Extracted the KyFromAbove website: https://kygeonet.ky.gov/govmaps/KyFromAboveGallery/map.html?webmap=b5ff91df6309491090c20333c8f58f52.

APPENDIX C
PHOTOGRAPHS

Photo C-1. Looking southwest at the FCI site. The blast crater from the FCI is within the orange safety fence in the middle portion of the photo. BGC photo taken May 7, 2020.

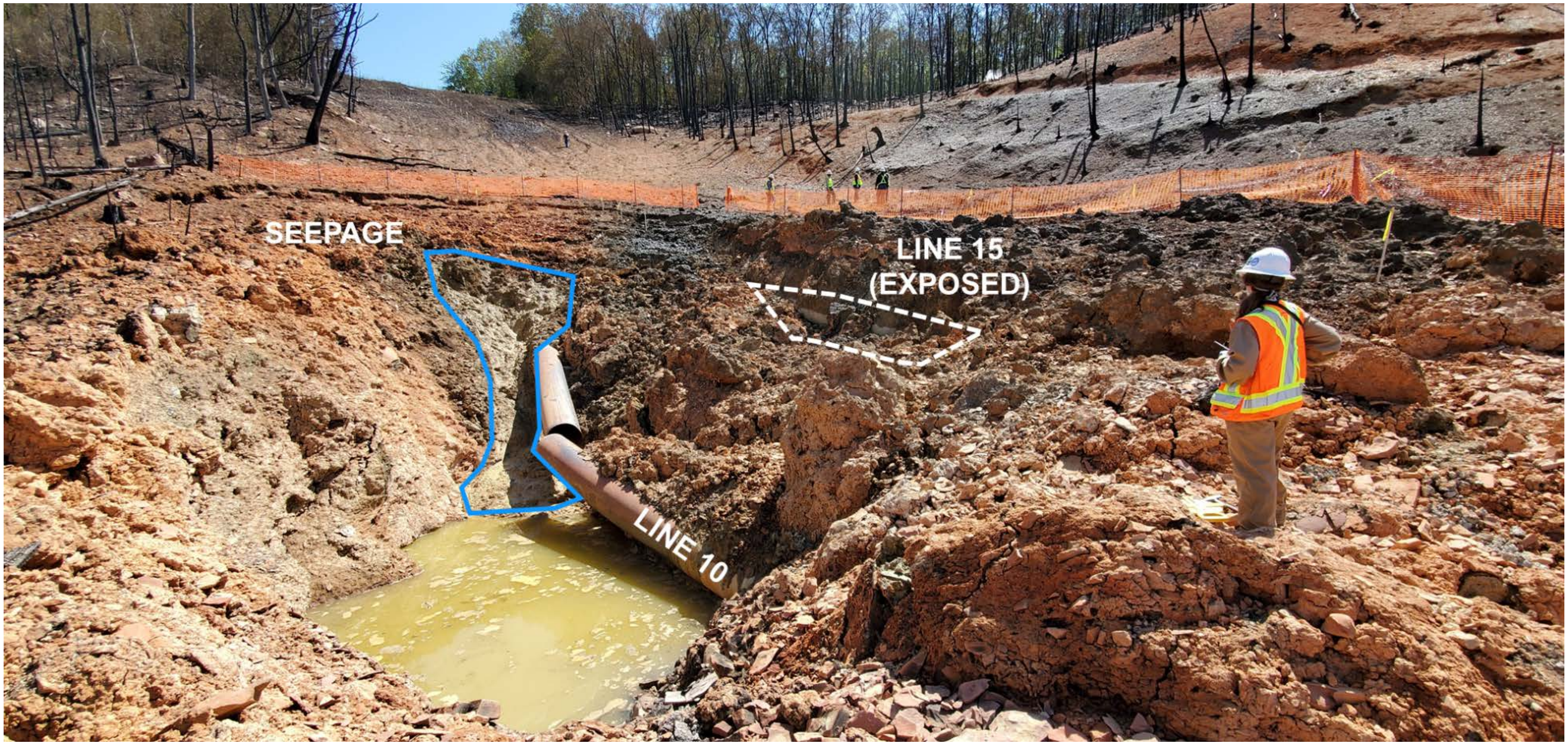


Photo C-2. Looking northeast (upslope) at the Line 10 blast crater. The failed girth weld is GW 11330. Seepage can be observed from the Line 10 trench backfill on the upslope side of the crater. Note the unstable material calving off the right (upslope) wall. Line 15 is within the upslope wall. BGC photo taken May 7, 2020.

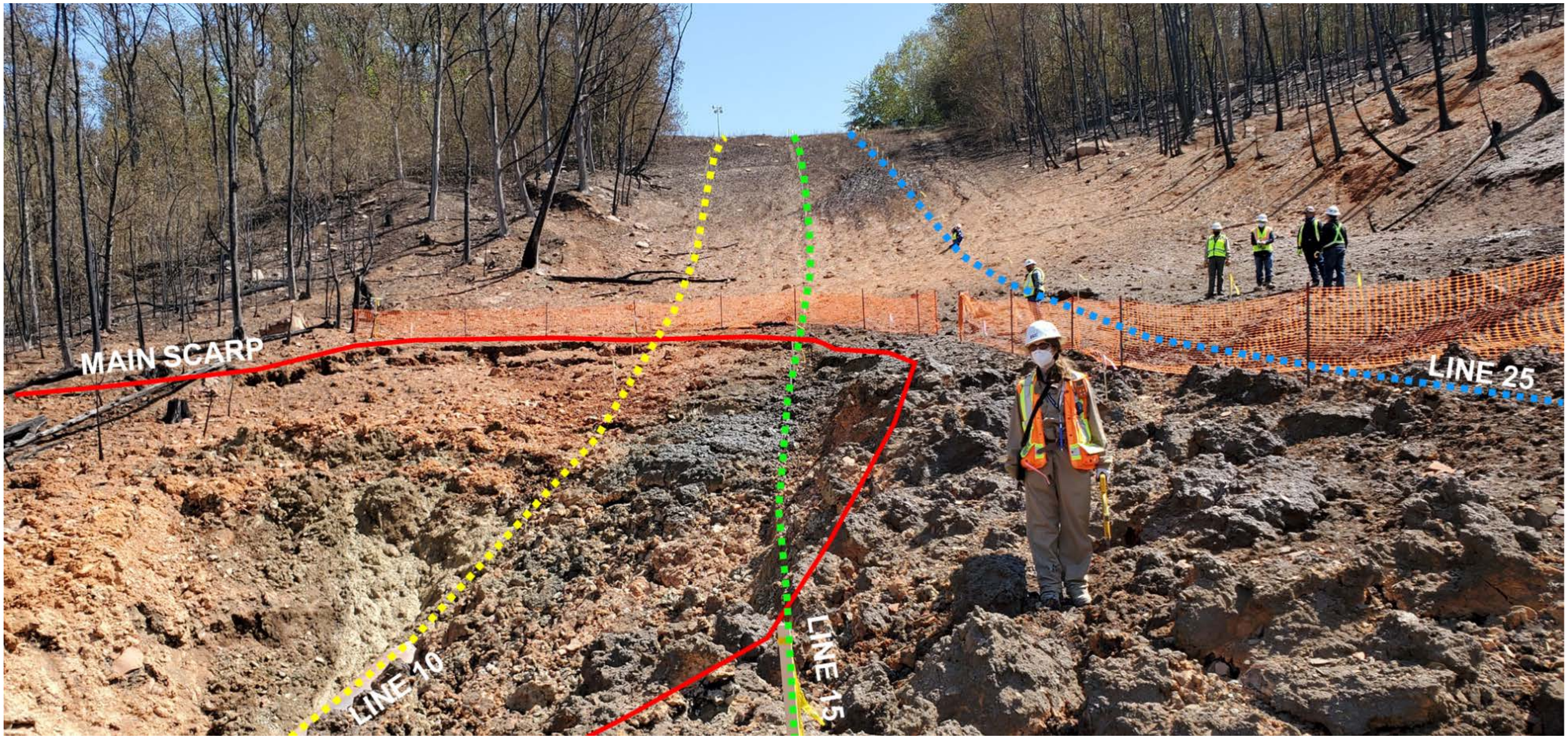


Photo C-3. Looking northeast (upslope) at the headscarp (denoted by the red line). Line 10 is exposed in the blast crater in the lower left portion of the photo. BGC photo taken May 7, 2020.

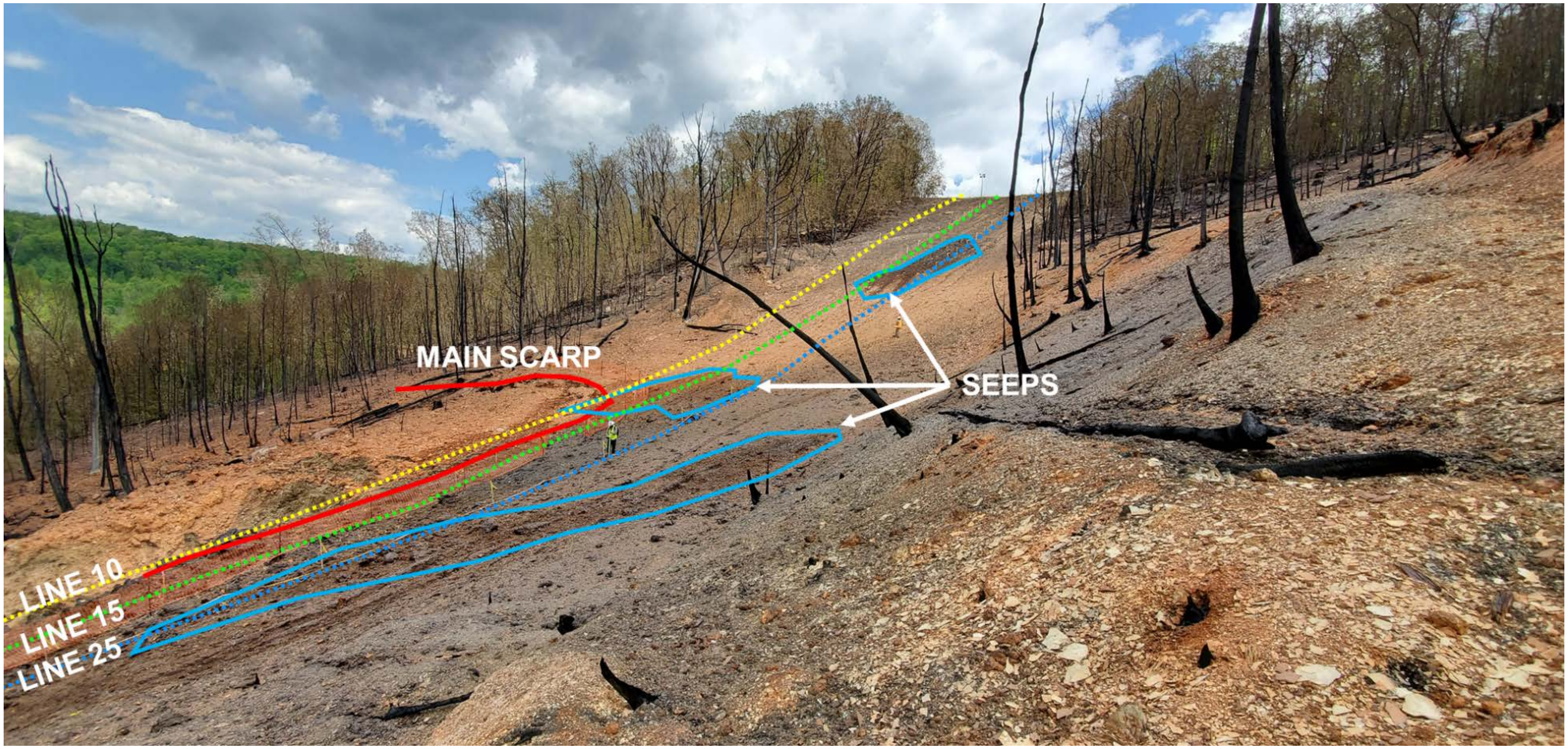


Photo C-4. Looking north (cross slope) at the seepage observed following the FCI.

Photo C-5. Looking southeast (upslope) at lateral cracking on the northern flank of the landslide downslope of the TETLP ROW. Note tree roots in tension across the crack. This area is also where unburnt roots were observed, indicating additional movement following the FCI. BGC photo taken May 7, 2020.

Photo C-6. Looking southeast (upslope) at the active toe. Note the fresh, saturated soil and the living trees being overridden by the landslide toe. BGC photo taken May 7, 2020.

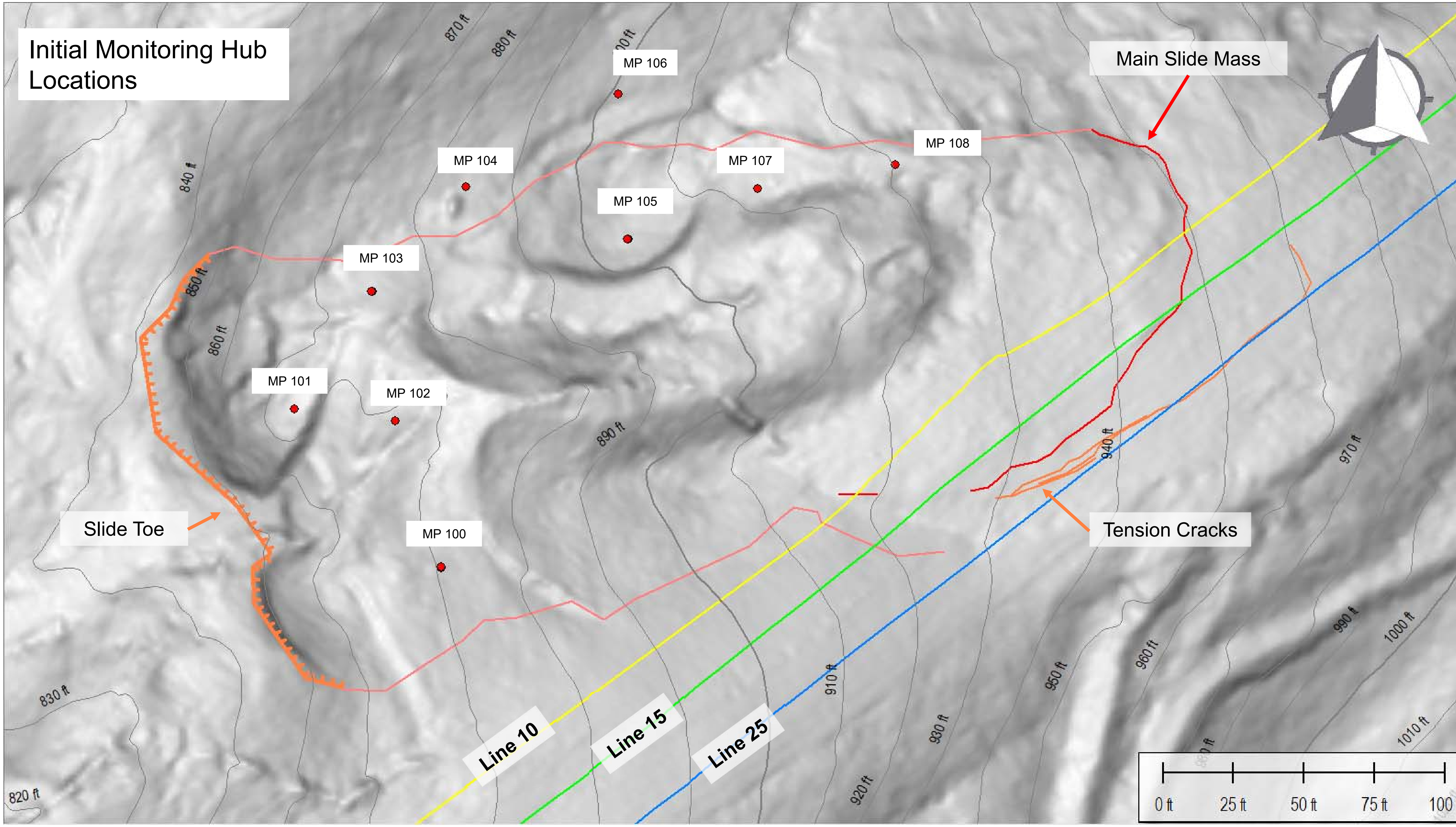
APPENDIX D
DOWNSLOPE MONITORING HUB DATA

Monitoring Hub (MP)	BASE COORDINATES			Location	Date Installed	Date Removed	Total Displacement at Time of Removal (ft)	Notes
	Northing	Easting	Elevation (ft)					
MP 100	[redacted]	[redacted]	870.5	Landslide Mass	2020-05-11	2020-06-11	0.96	Obliterated by construction
MP 101	[redacted]	[redacted]	872.6	Landslide Mass	2020-05-11	2020-08-28	2.66	Obliterated by tree removal
MP 102	[redacted]	[redacted]	869.0	Landslide Mass	2020-05-11	2020-07-14	1.95	Obliterated by construction
MP 103	[redacted]	[redacted]	873.3	Landslide Mass	2020-05-11	2020-08-29	2.44	Obliterated by tree removal
MP 104	[redacted]	[redacted]	884.1	North of Landslide Mass	2020-05-11	2020-05-22	0.16	Obscured by shifted tree
MP 105	[redacted]	[redacted]	904.4	Landslide Mass	2020-05-11	2020-09-04	4.03	Obliterated by construction
MP 106	[redacted]	[redacted]	900.8	North of Landslide Mass	2020-05-11	2020-08-28	0.20	Obscured by shifted tree for part of the monitoring period
MP 107	[redacted]	[redacted]	912.3	Landslide Mass	2020-05-11	2020-08-17	3.59	Obliterated by construction
MP 108	[redacted]	[redacted]	920.4	Landslide Mass	2020-05-11	2020-05-14	0.13	Obliterated by construction

NOTES:
1. This Figure should be read in conjunction with BGC's report titled “May 4, 2020 Fleming County Incident Geotechnical Causation” and dated April 2021.
2. Monitoring points were installed and surveyed by SGC Engineering LLC.
3. All coordinates are provided in UTM Zone 17N NAD83 US Survey Feet. Elevation values are in reference to the NAVD88 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: WCD	FIGURE TITLE: MONITORING HUB SUMMARY	
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP	
APPROVED BY: CAD	SCALE: -	PROJECT NO: 1607024 / FIGURE NO: D-1

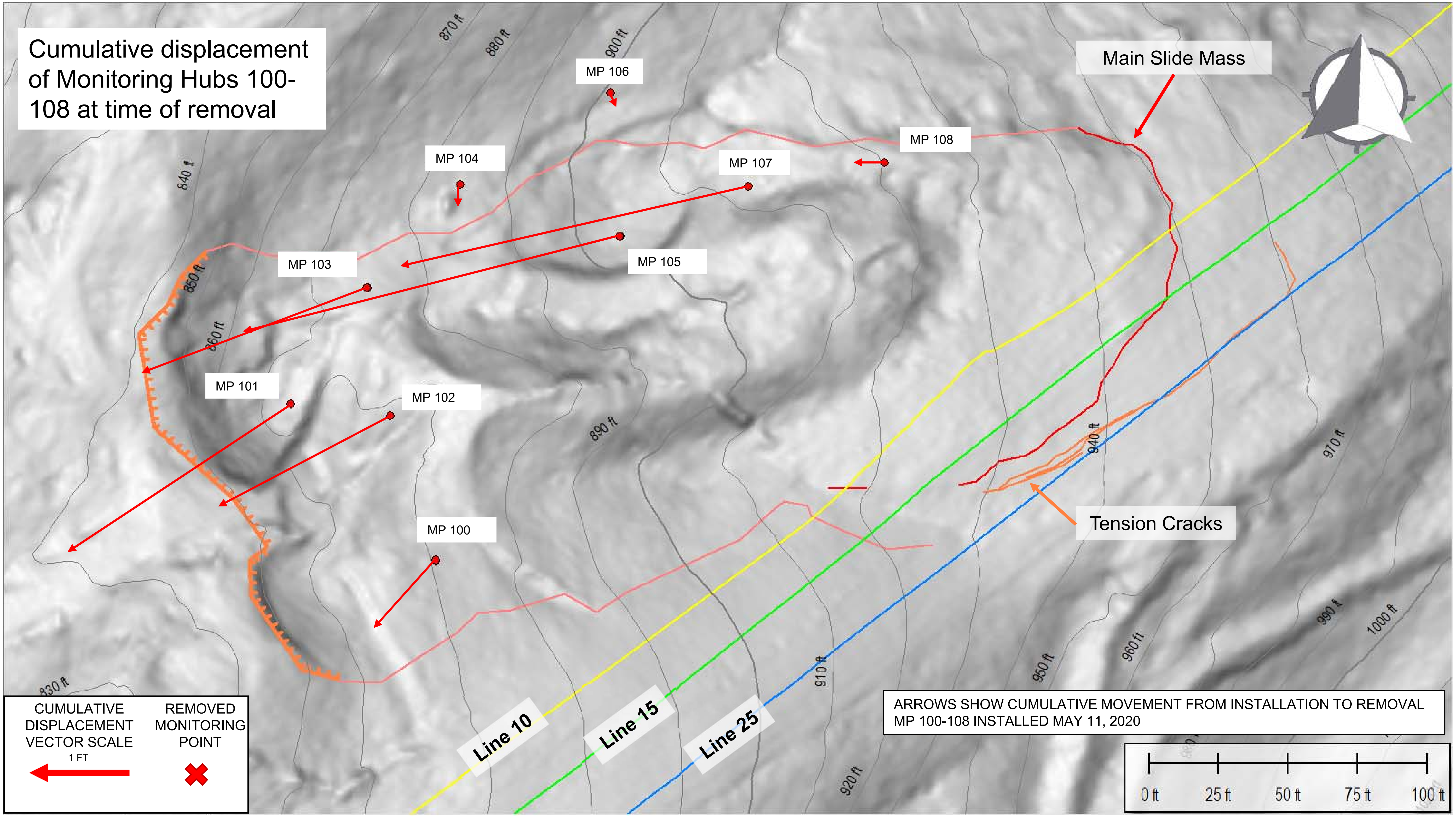
0 5 10 mm in ANSI B sized paper



NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Monitoring points were installed and surveyed by SGC Engineering LLC.
3. Base image based on digital elevation model from November 2019 lidar data provided by TETLP.
4. Map shows the initial monitoring point locations (red dots) in relation to the main slide mass (outlined in red), tension cracks (orange lines), and Lines 10, 15 and 25.
5. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: WCD	FIGURE TITLE: INITIAL MONITORING HUB LOCATIONS		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: D-2

0 5 10 mm in ANSI B sized paper



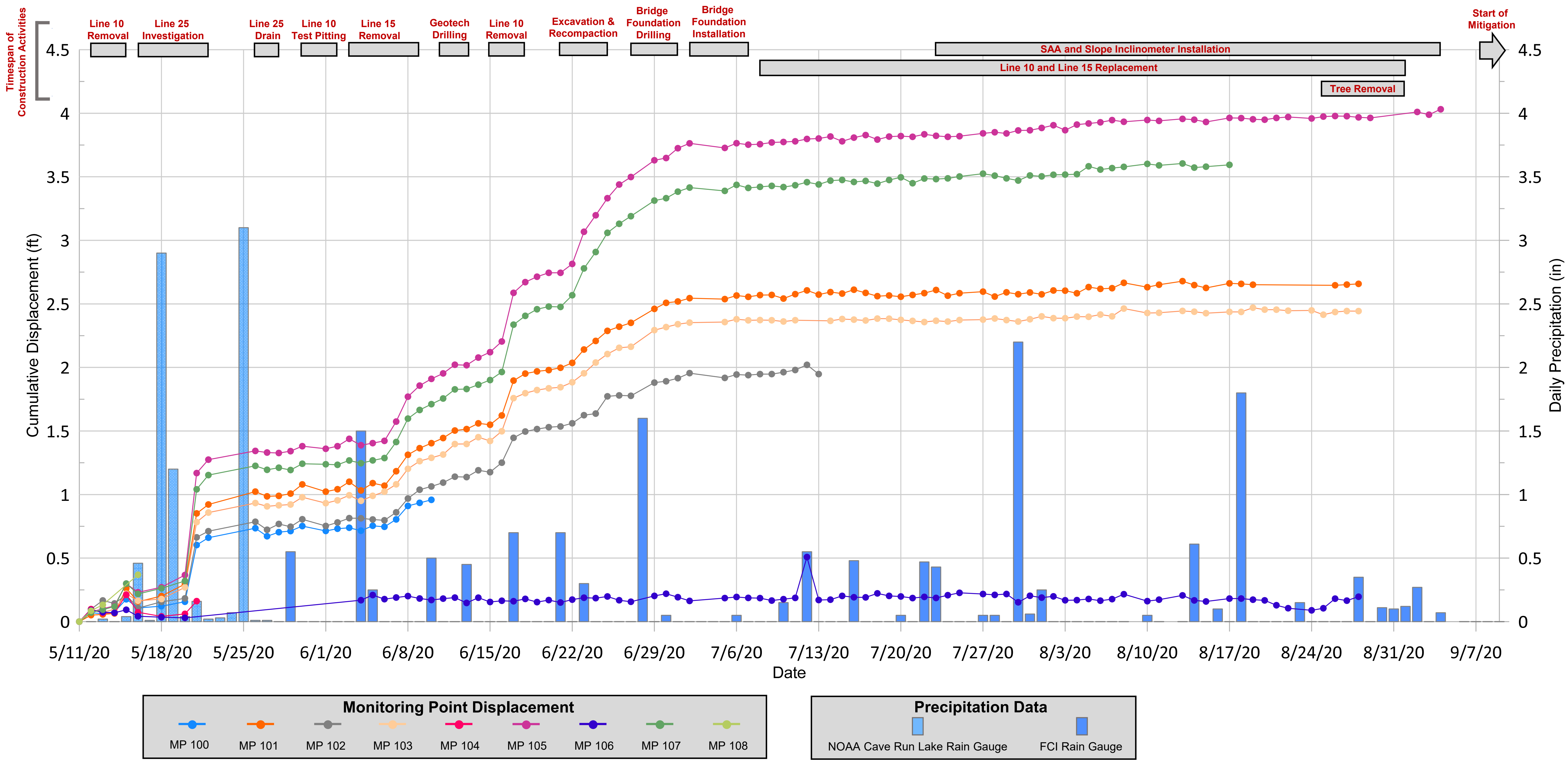
NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Monitoring points were installed and surveyed by SGC Engineering LLC.
3. Base image based on digital elevation model from November 2019 lidar data provided by TETLP.
4. Map shows the initial monitoring point locations (red dots) and movement vectors (red arrows) in relation to the main slide mass (outlined in red), tension cracks (orange lines), and Lines 10, 15 and 25.
5. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk

PREPARED BY: WCD	FIGURE TITLE: MONITORING HUB DISPLACEMENT AS OF 08/14/2020		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: D-3

0 5 10 mm in ANSI B sized paper

Monitoring Hub Movement Downslope of FCI Site

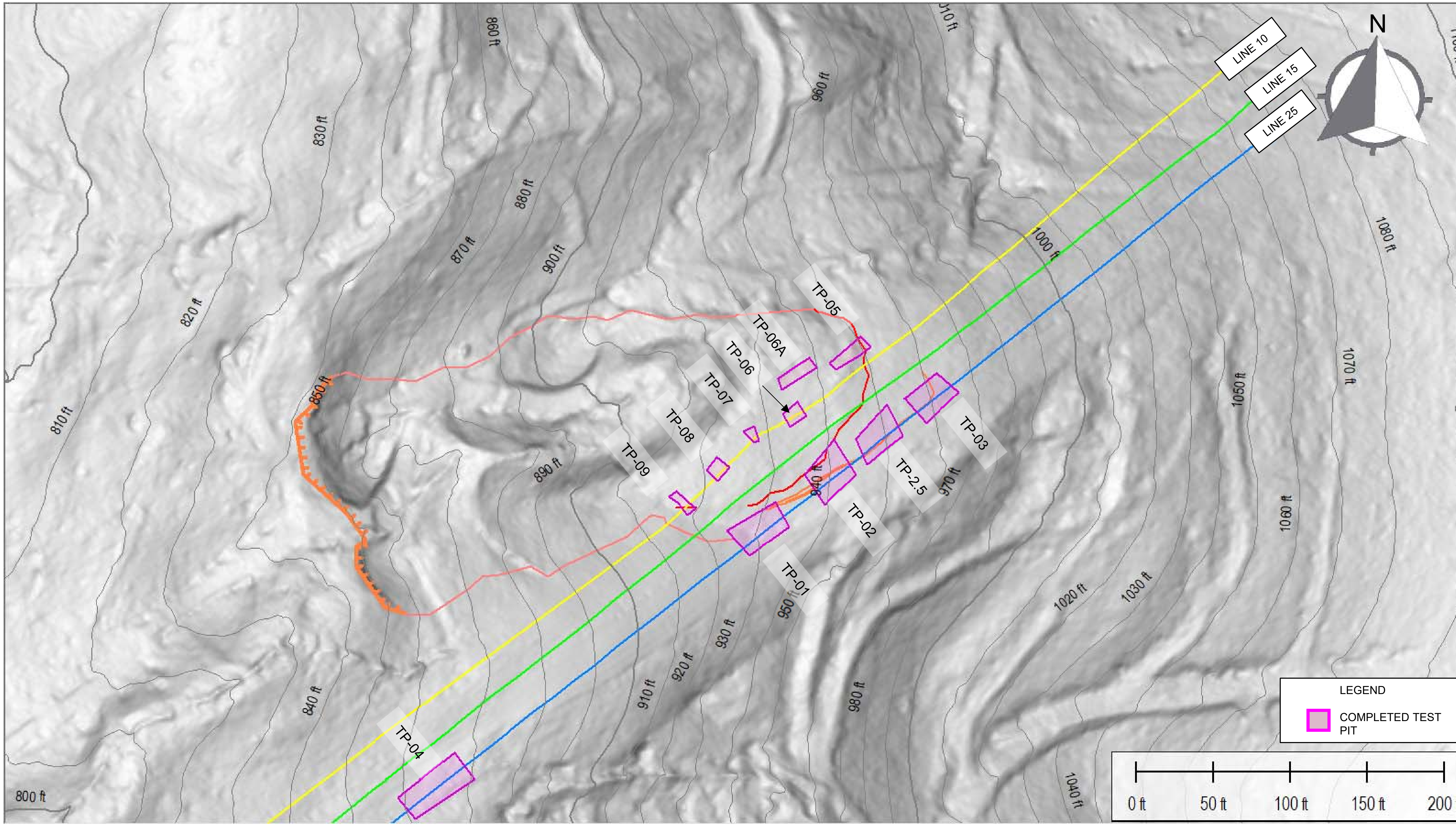


NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Monitoring points were installed and surveyed by SGC Engineering LLC.
3. Precipitation observed at the FCI site and at the nearby NOAA Cave Run Lake Station are shown by blue bars. Precipitation data from the NOAA Cave Run Lake Station is shown in the in the timespan before the rain gauge at the FCI site was installed.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: WCD	FIGURE TITLE: CUMULATIVE MONITORING HUB DISPLACEMENT
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP
APPROVED BY: CAD	SCALE: AS SHOWN; PROJECT NO: 1607024; FIGURE NO: D-4

0 5 10 mm in ANSI B sized paper

APPENDIX E
TEST PIT PHOTO LOGS



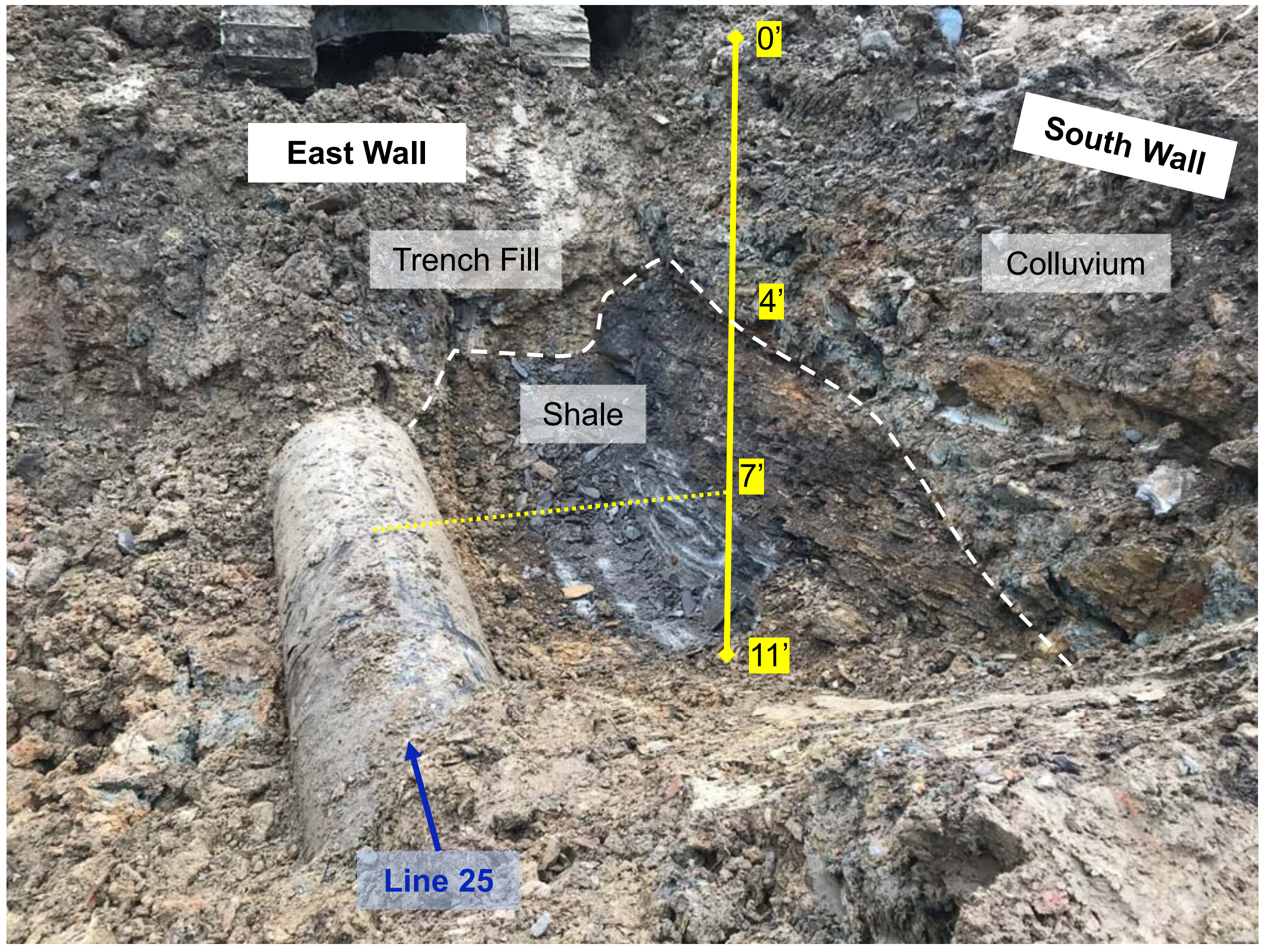
NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Test pits were excavated by Otis Eastern Service, LLC and logged by BGC.
3. All dimensions are in feet and are approximate.
4. Base image based on digital elevation model from November 2019 lidar data provided by TETLP. Surveyed pipeline centerlines and test pit locations provided by SGC Engineering LLC.
5. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: WCD	FIGURE TITLE: PLAN VIEW – TEST PITS 1 TO 9		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-1

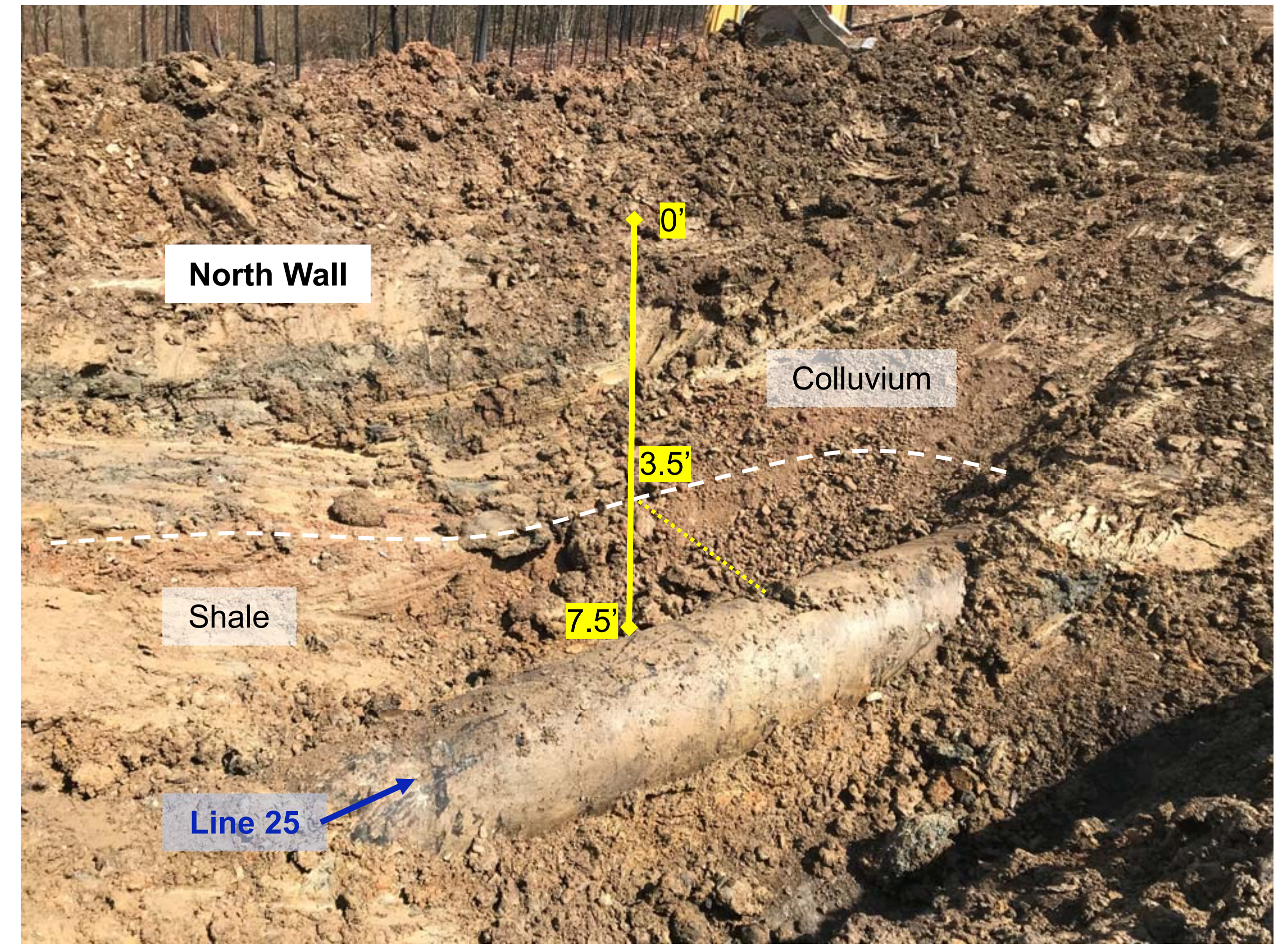
0 5 10 mm in ANSI B sized paper

BGC ENGINEERING INC.

Test Pit 01: Excavated along Line 25. Excavation shows that Line 25 is trenched in shale bedrock.



Feature	Depth (ft)
Bedrock contact	4
Top of Pipe	7
Bottom of excavation	11



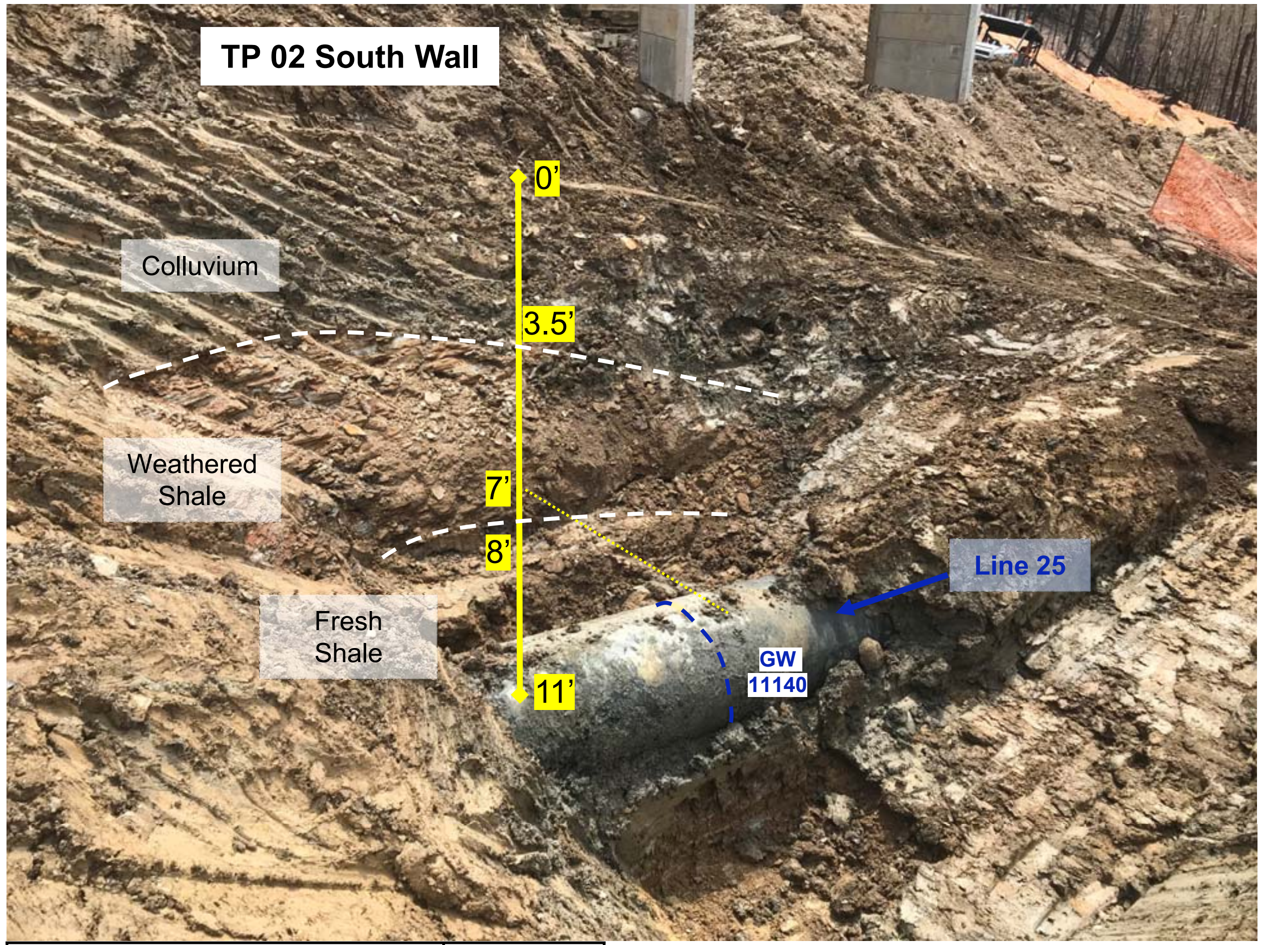
Feature	Depth (ft)
Bedrock contact/top of pipe	3.5
Bottom of excavation	7.5

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Test pits were excavated by Otis Eastern Service, LLC and logged by BGC.
3. All dimensions are in feet and are approximate. Depths were measured using a measuring tape or estimated using the excavator bucket and arm.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

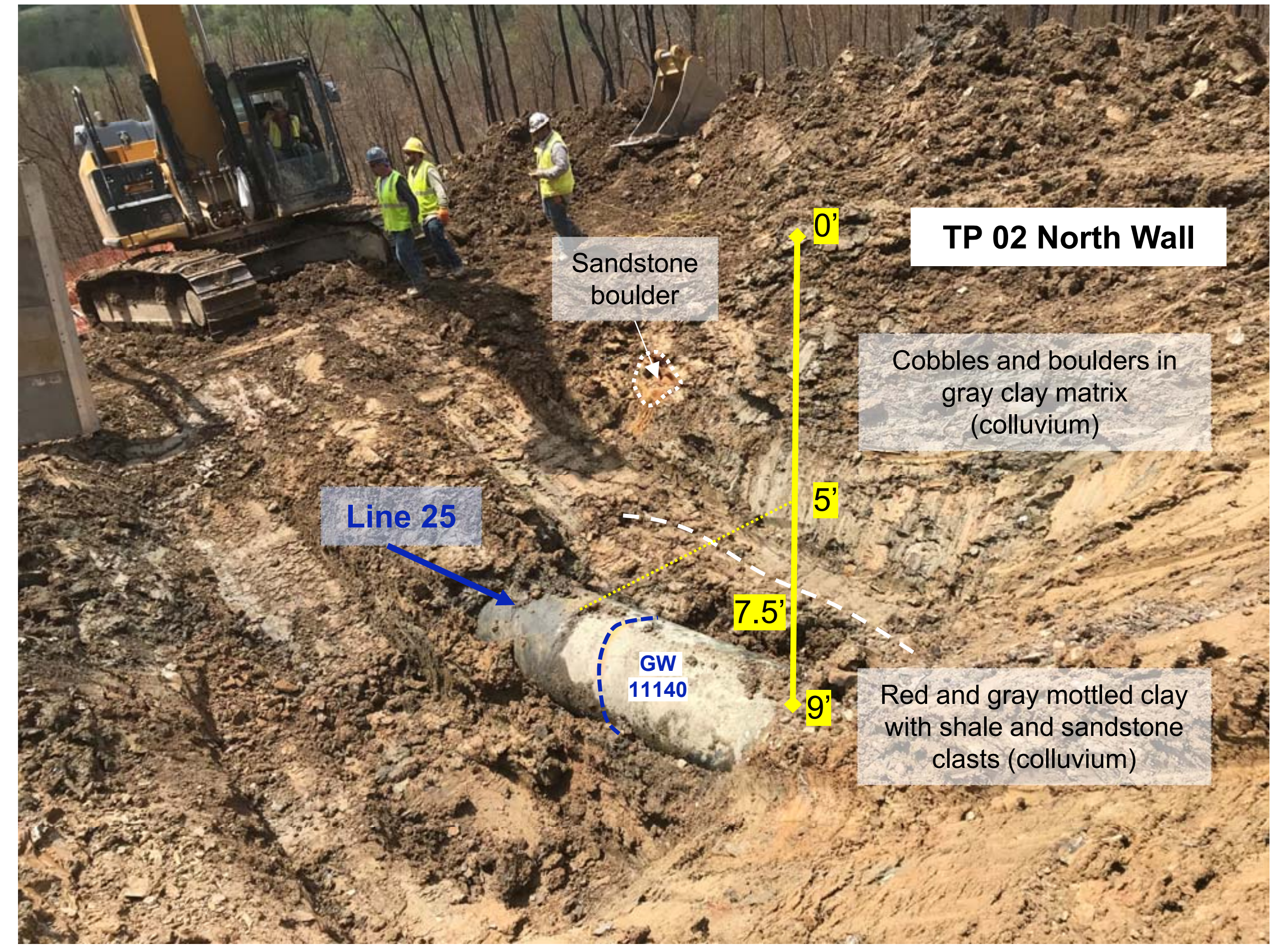
PREPARED BY: WCD	FIGURE TITLE: TP 01 PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-2

0 5 10 mm in ANSI B sized paper

Test Pit 02: Photo logs of the south wall (left) and north wall (right) of a bell hole around GW 11140 of Line 25. The excavation shows shale bedrock above the elevation of Line 25 on the south wall, but not on the north wall.



Feature	Depth (ft)
Colluvium-Weathered Shale Contact	3.5
Top of Pipe	7
Weathered-Fresh Shale Contact	8
Bottom of Excavation	11



Feature	Depth (ft)
Top of Pipe	5
Mottled colluvium contact	7.5
Bottom of Excavation	9

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Test pits were excavated by Otis Eastern Service, LLC and logged by BGC.
3. All dimensions are in feet and are approximate. Depths were measured using a measuring tape or estimated using the excavator bucket and arm.
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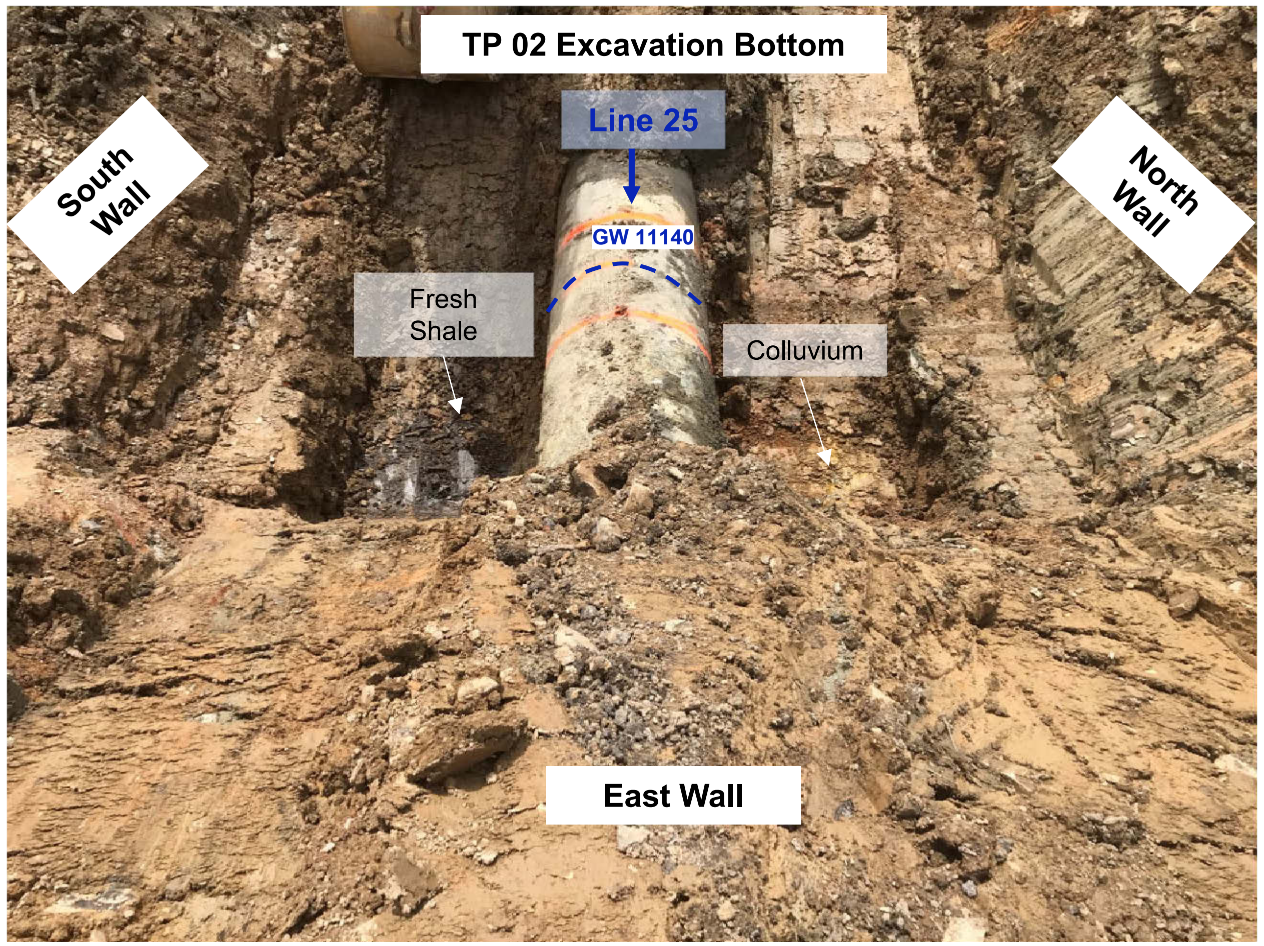
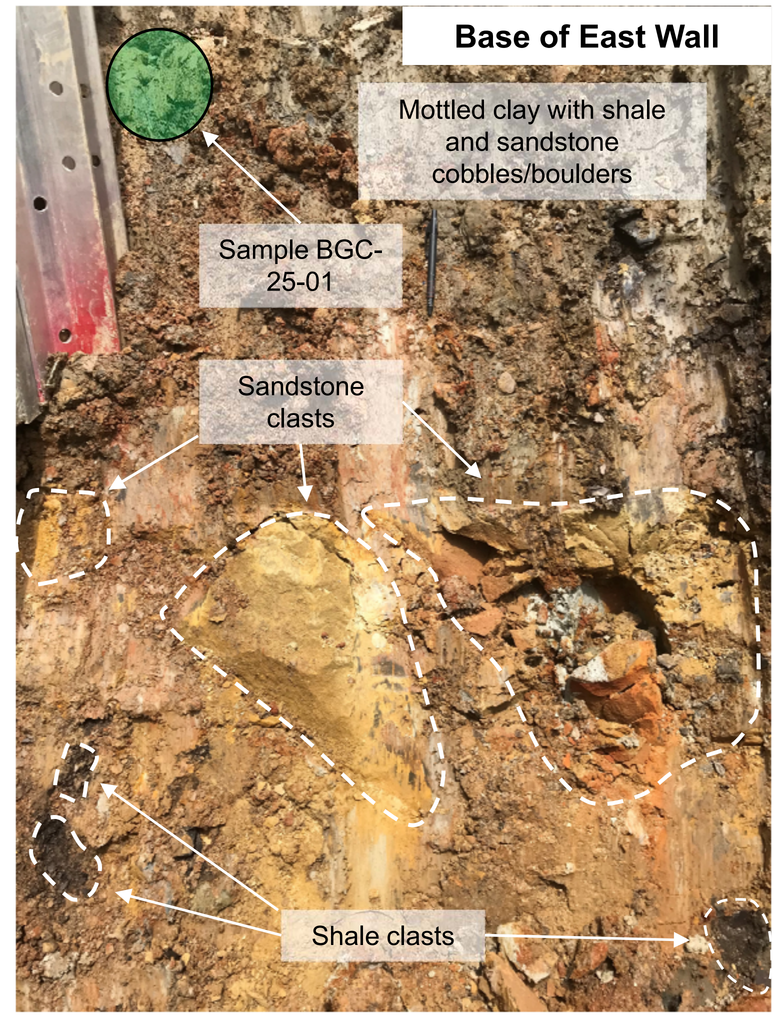
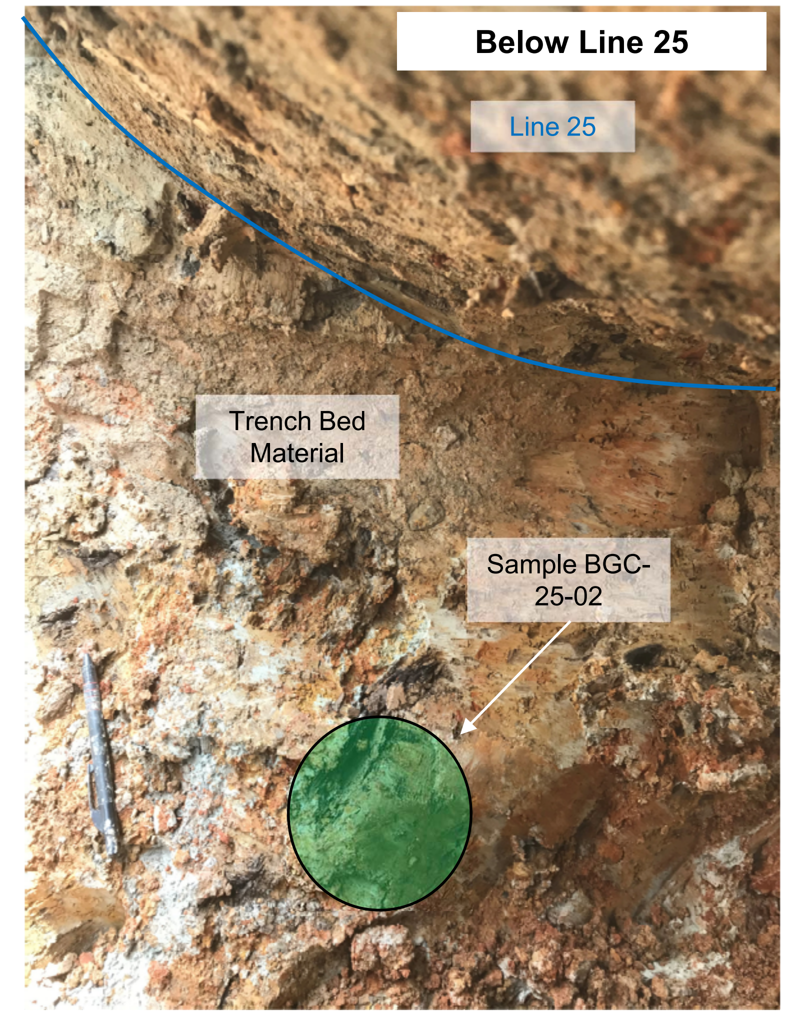
PREPARED BY:	FIGURE TITLE		
WCD	TP 02 PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-3

0 5 10 mm in ANSI B sized paper

Test Pit 02 (continued): Photo logs showing the stratigraphy at the base of the TP 02 bell hole. Left photo shows fresh shale bedrock on the south side of the pipeline, but not on the north side. The middle and right photos show the location of samples collected in TP 02.







NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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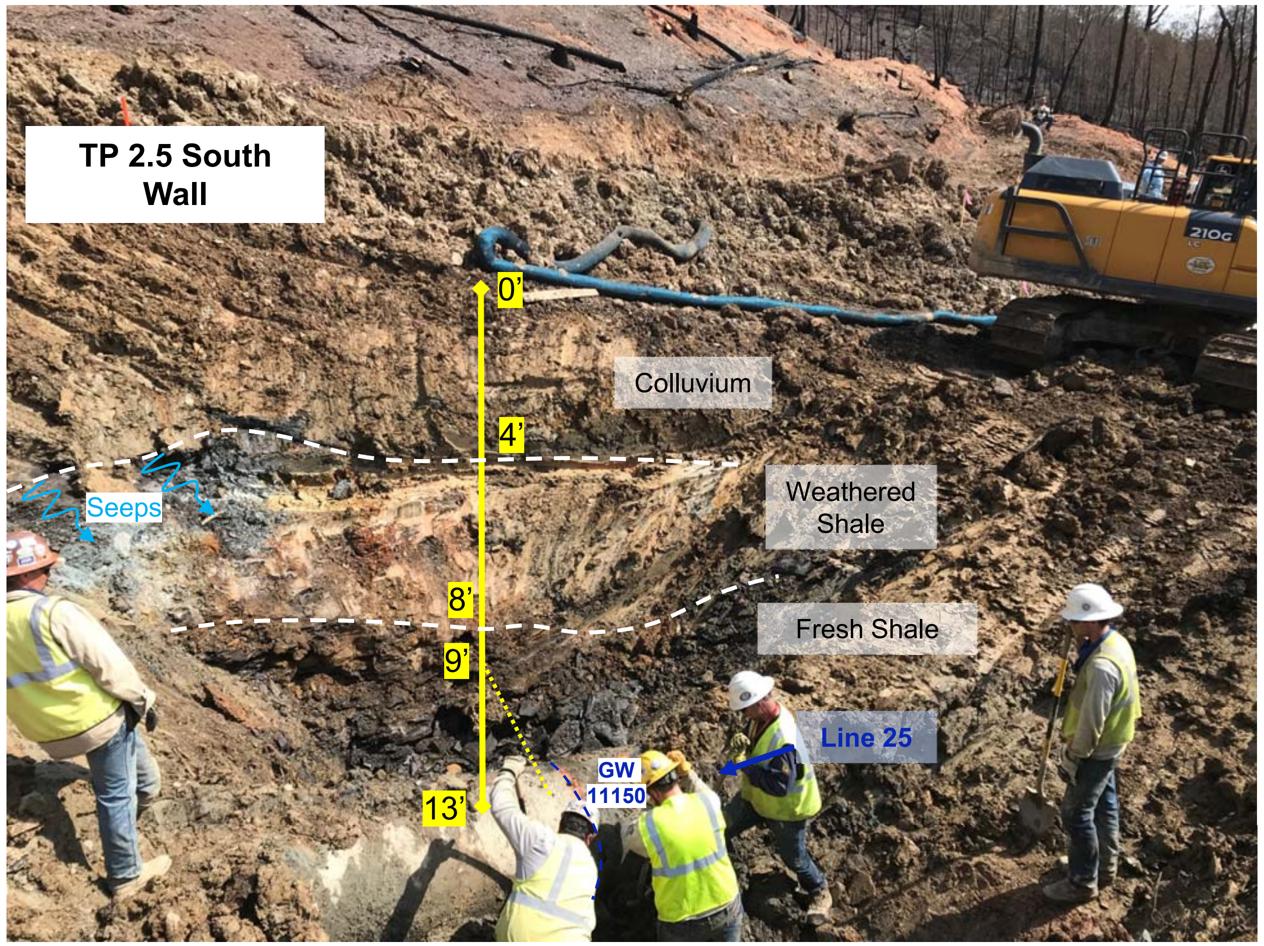
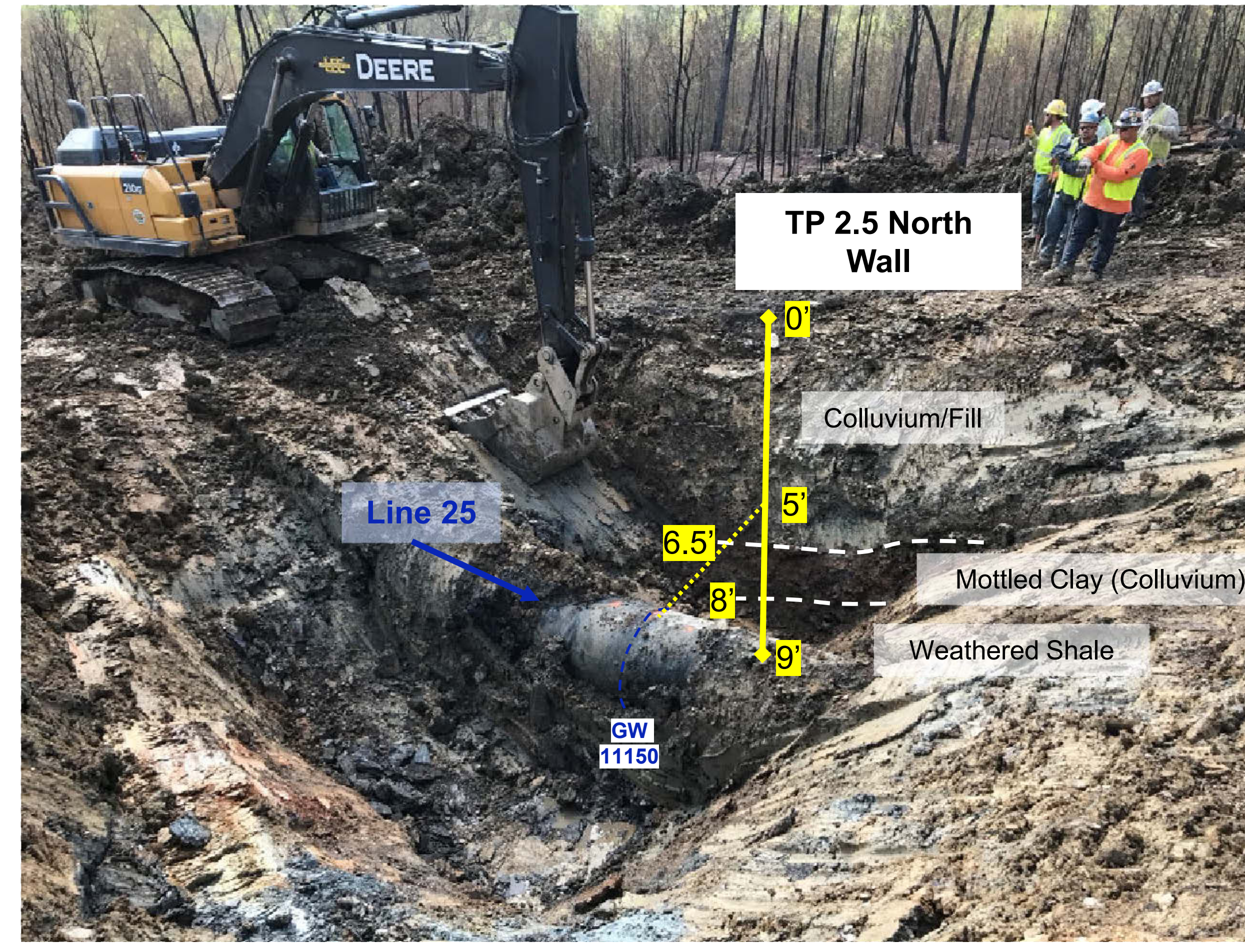
PREPARED BY: WCD	FIGURE TITLE: TP 02 PHOTO LOG (cont.)		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-4

0 5 10 mm in ANSI B sized paper

Test Pit 2.5: Photo logs of the south wall (left) and north wall (right) of a bell hole around GW11150 of Line 25. The excavation shows that Line 25 is trenched in shale bedrock.



Feature	Depth (ft)
Colluvium-Weathered Shale Contact	4
Weathered-Fresh Shale Contact	8
Top Of Pipe	9
Bottom of Excavation	13



Feature	Depth (ft)
Top Of Pipe	5
Colluvium/Fill-Mottled Clay (Colluvium) Contact	6.5
Mottled Clay (Colluvium)-Weathered Shale Contact	8
Bottom of Excavation	9

NOTES:
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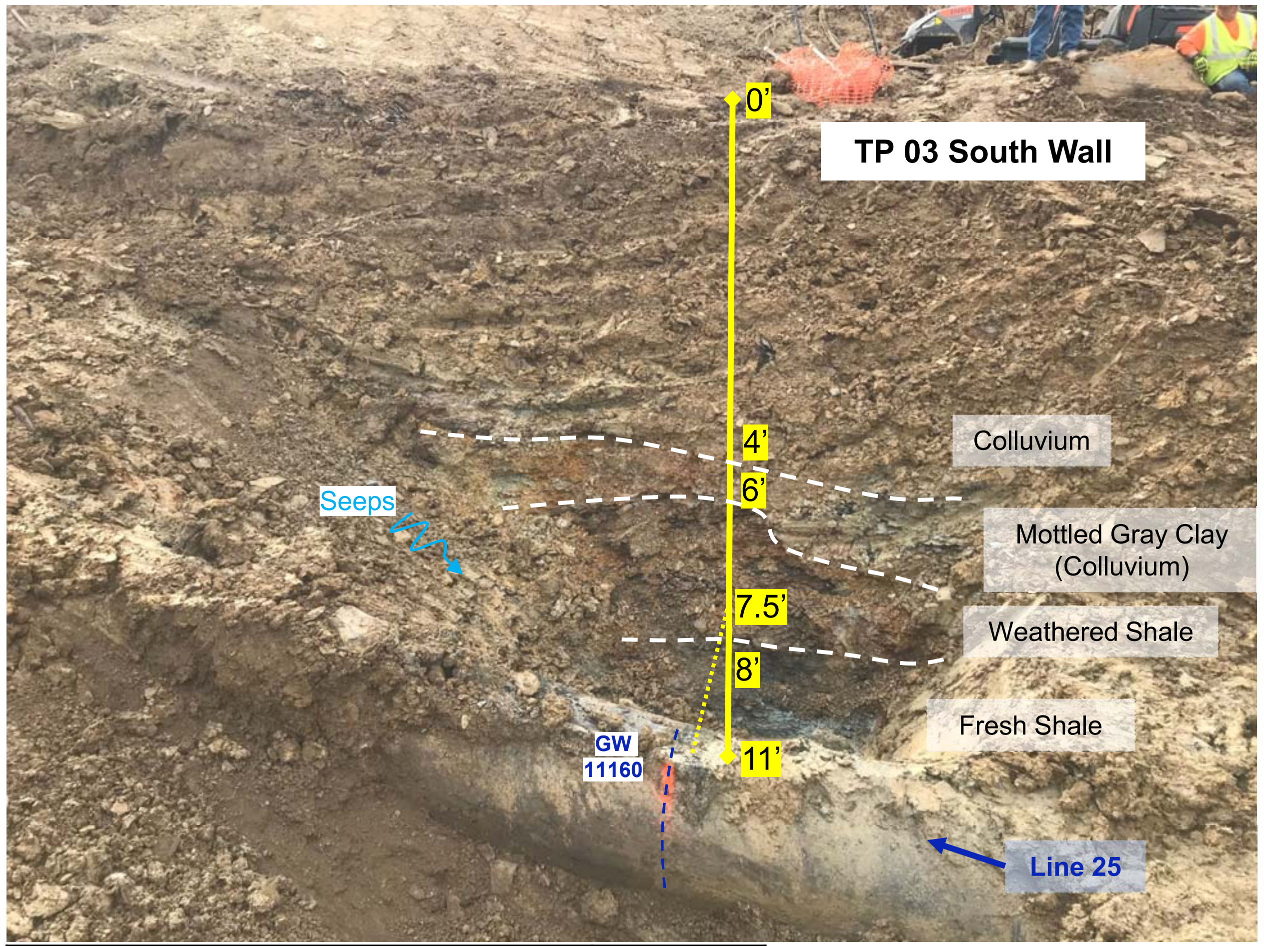
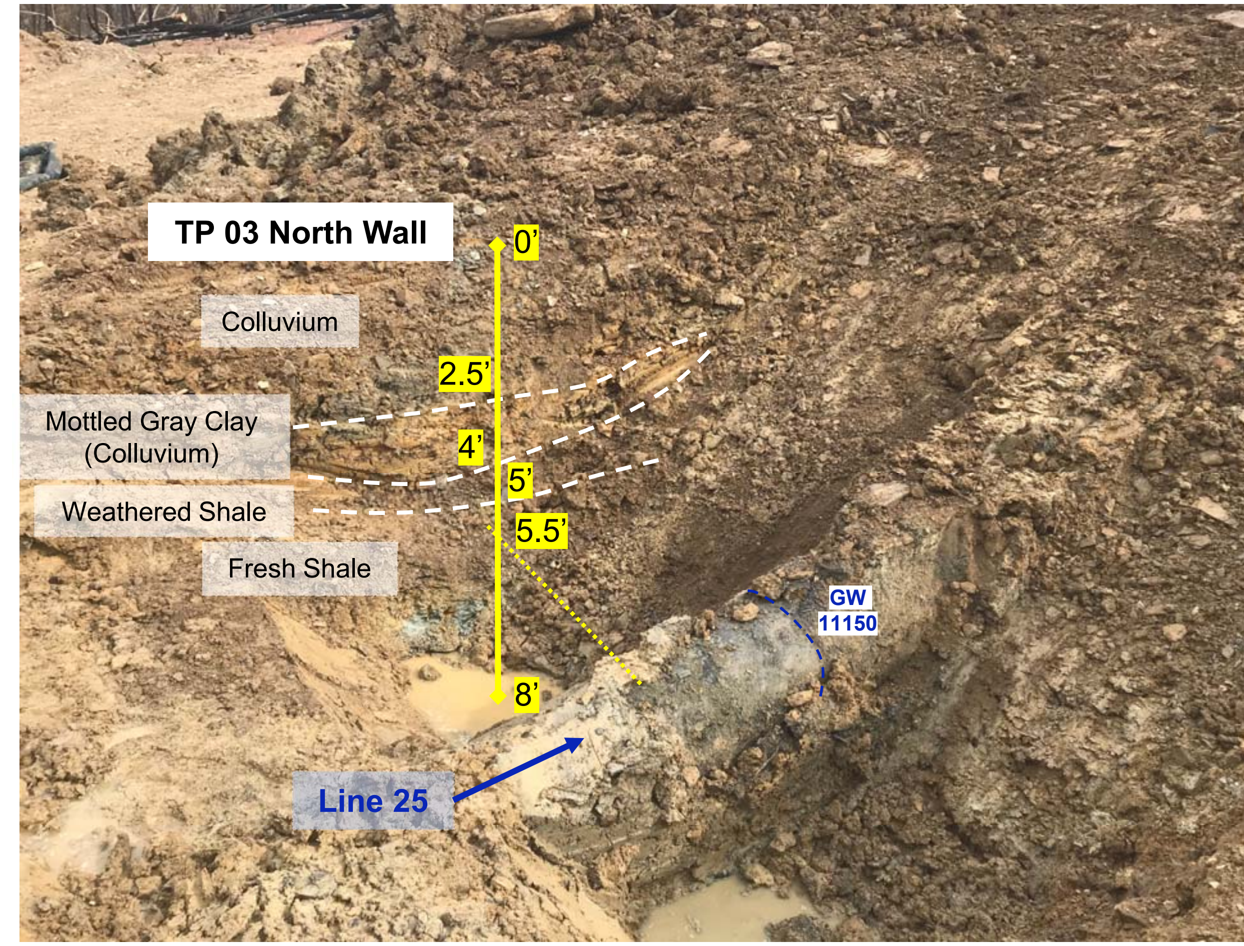
PREPARED BY: WCD	FIGURE TITLE: TP 2.5 PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-5

0 5 10 mm in ANSI B sized paper

Test Pit 03: Photo logs of the south wall (left) and north wall (right) of a bell hole around GW 11160 of Line 25. The excavation shows that Line 25 is trenched in shale bedrock.



Feature	Depth (ft)
Colluvium-Mottled Gray Clay Contact	4
Mottled Gray Clay- Weathered Shale Contact	6
Top Of Pipe	7.5
Weathered Shale-Fresh Shale Contact	8
Bottom of Excavation	11



Feature	Depth (ft)
Colluvium-Mottled Gray Clay Contact	2.5
Mottled Gray Clay- Weathered Shale Contact	4
Weathered Shale-Fresh Shale Contact	5
Top of Pipe	5.5
Bottom of Excavation	8

NOTES:
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3. All dimensions are in feet and are approximate. Depths were measured using a measuring tape or estimated using the excavator bucket and arm.
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PREPARED BY: WCD	FIGURE TITLE: TP 03 PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-6

0 5 10 mm in ANSI B sized paper

Test Pit 04: Photo log showing fresh shale exposed above the elevation of Line 25.

Feature	Depth (ft)
Bedrock contact	8

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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3. All dimensions are in feet and are approximate. Depths were measured using a measuring tape or estimated using the excavator bucket and arm.
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PREPARED BY:	FIGURE TITLE		
WCD	TP 04 PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-7

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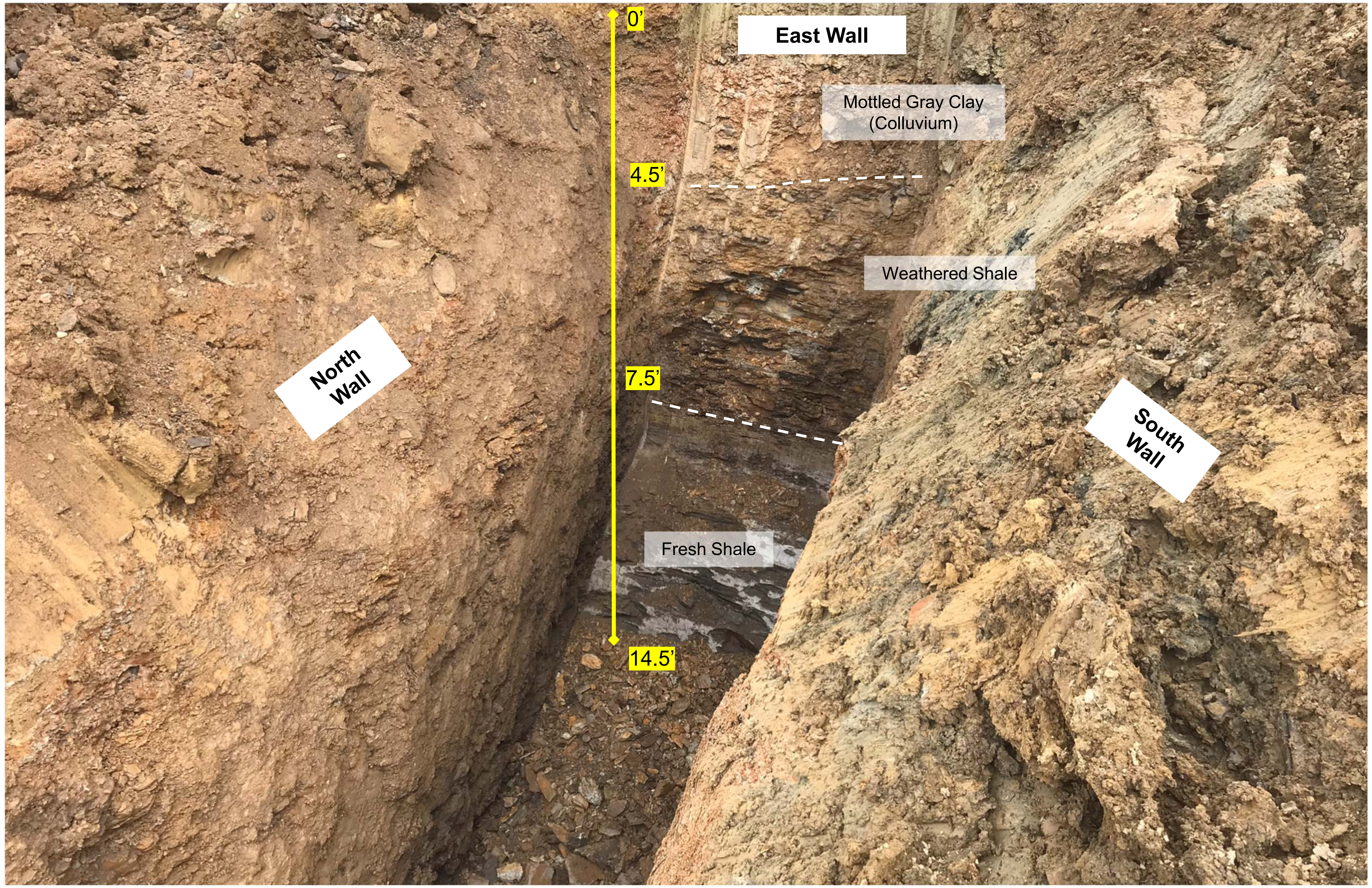

Feature	Depth (ft)
Mottled Gray Clay- Weathered Shale Contact	4.5
Weathered Shale-Fresh Shale Contact	7.5
Bottom of Excavation	14.5

Test Pit 05: Photo log showing fresh shale exposed at the base of the excavation.

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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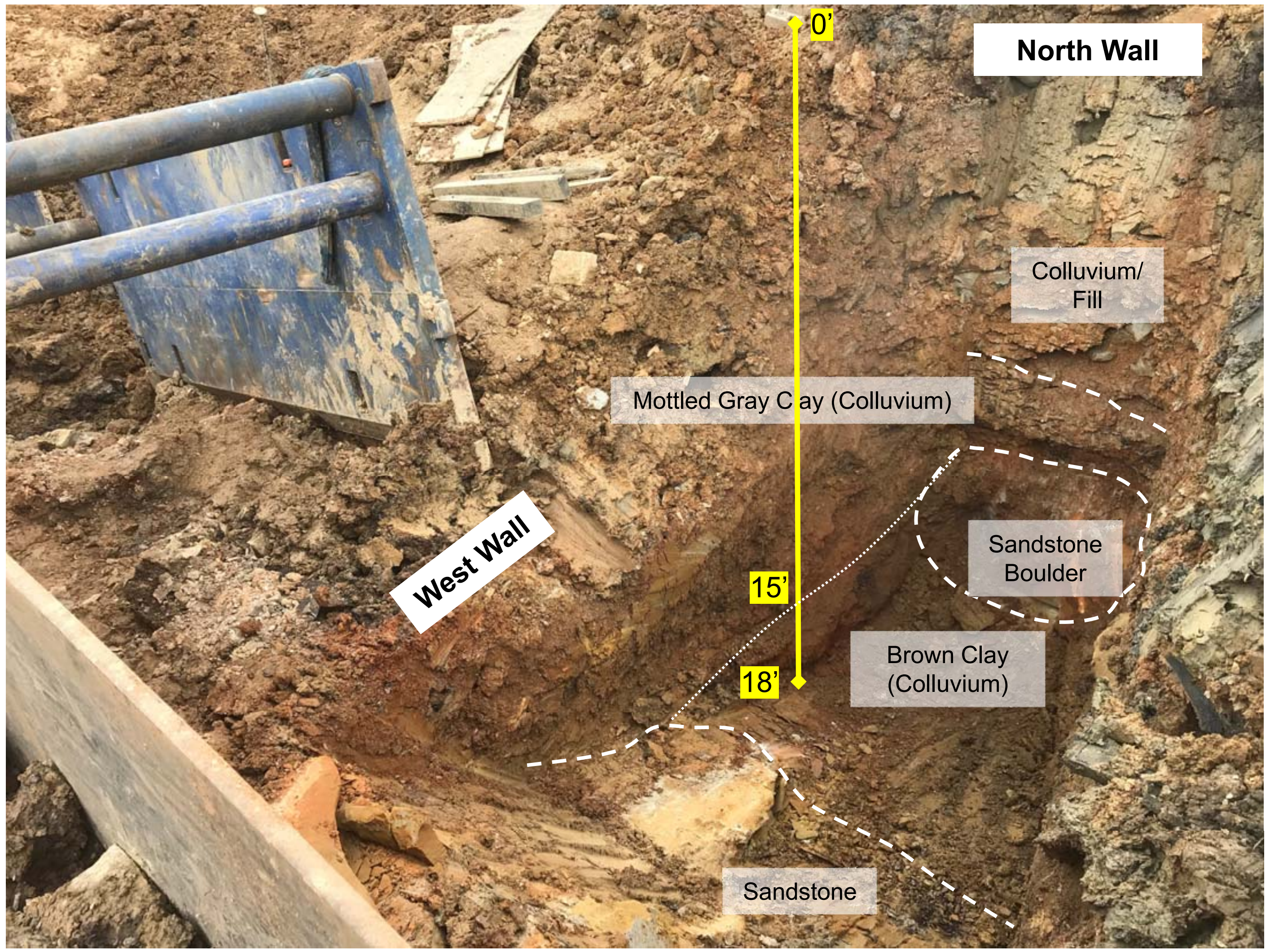
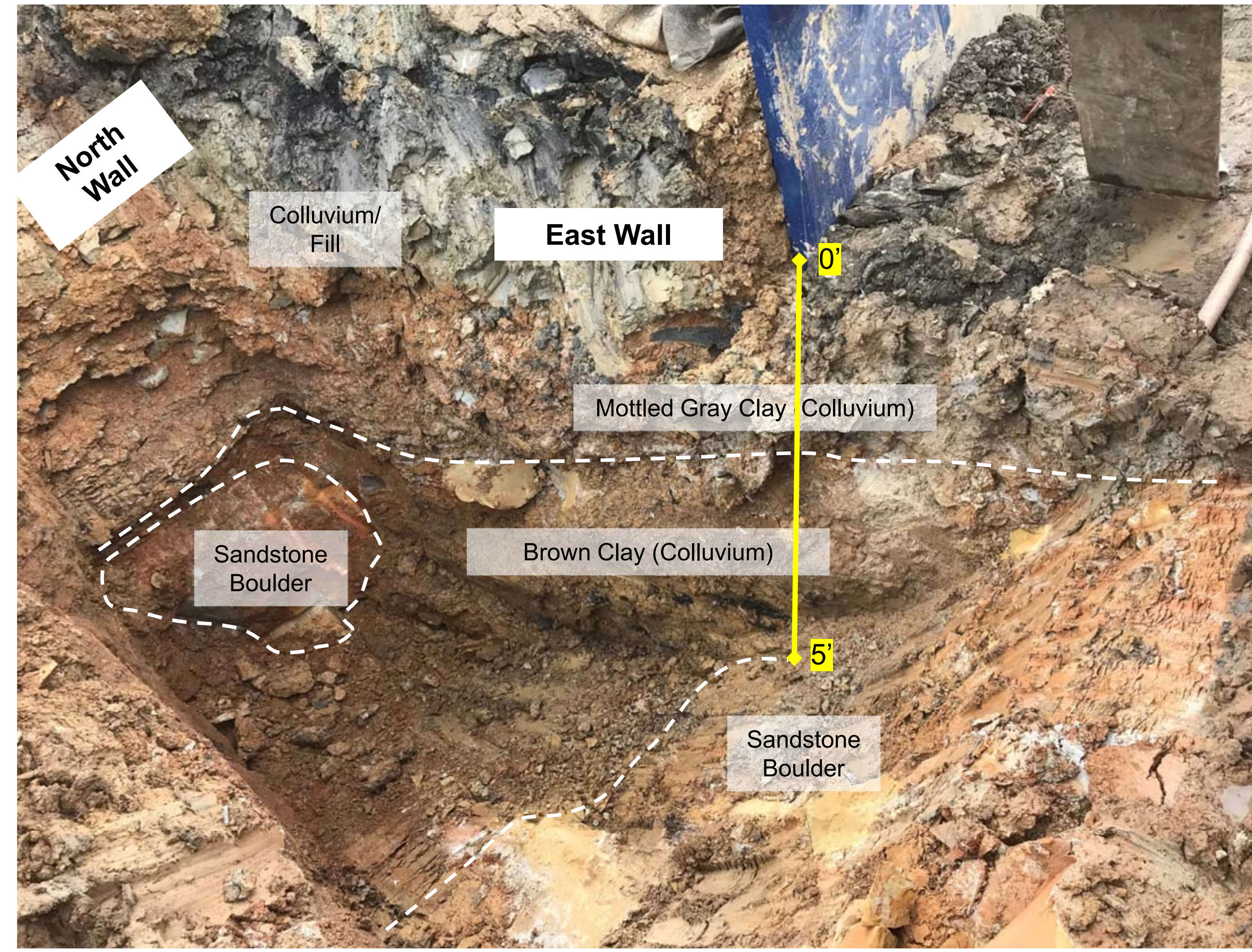
3. All dimensions are in feet and are approximate. Depths were measured using a measuring tape or estimated using the excavator bucket and arm.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: WCD	FIGURE TITLE: TP 05 PHOTO LOG			
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-8	

0 5 10 mm in ANSI B sized paper

Test Pit 06: Photo logs of the west wall (left) and east wall (right) showing sandstone (interpreted as boulders) exposed at the base of the excavation.





Feature	Depth (ft)
Top of Sandstone Boulder	15
Bottom of Excavation	18

Feature	Depth (ft)
Top of Sandstone Boulder	5 (from trench bottom)

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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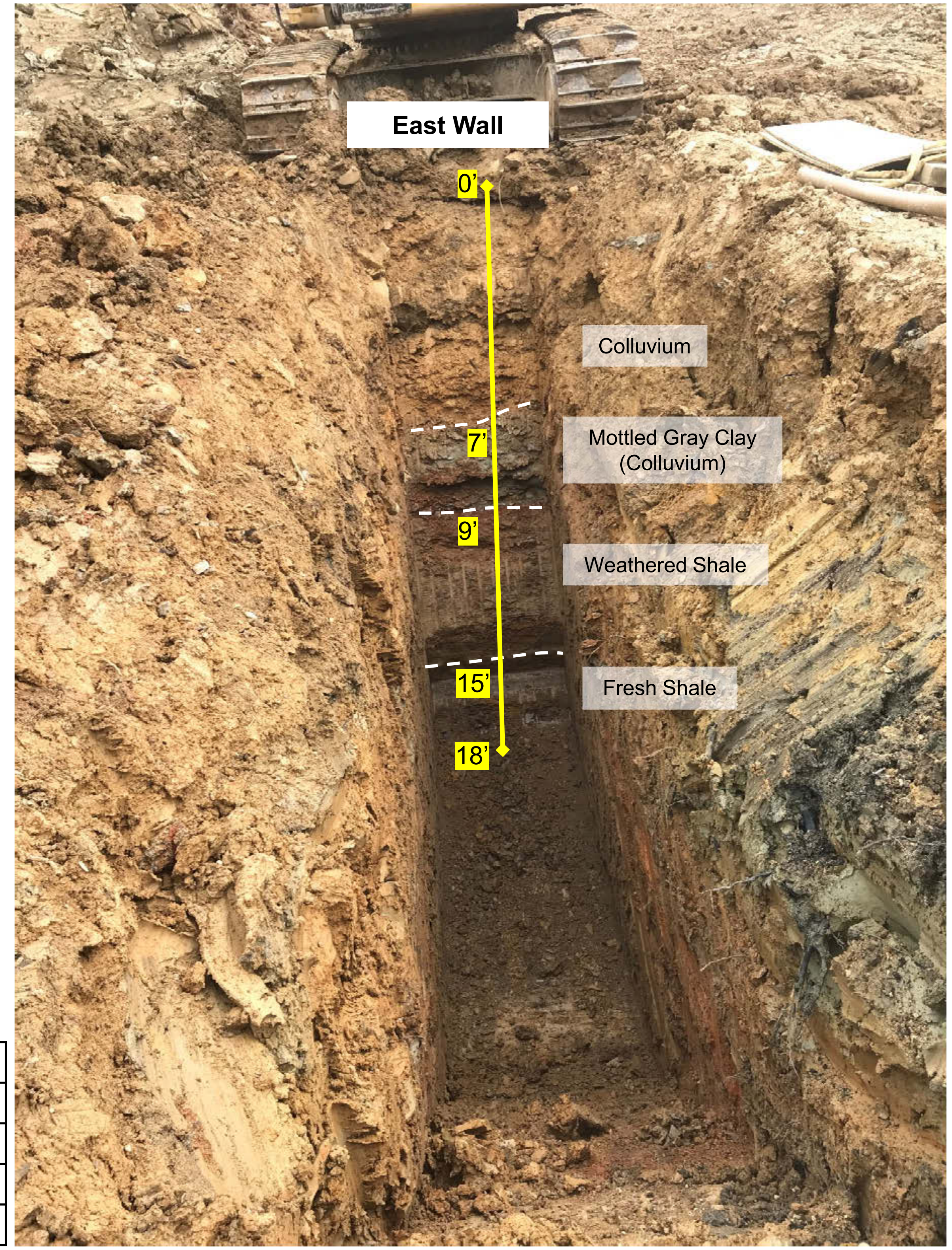
PREPARED BY: WCD	FIGURE TITLE: TP 06 PHOTO LOG			
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-9	

0 5 10 mm in ANSI B sized paper



Test Pit 6A: Photo log showing fresh shale exposed at the base of the excavation.

Feature	Depth (ft)
Top of Mottled Gray Clay	7
Mottled Gray Clay- Weathered Shale Contact	9
Weathered Shale-Fresh Shale Contact	15
Bottom of Excavation	18

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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3. All dimensions are in feet and are approximate. Depths were measured using a measuring tape or estimated using the excavator bucket and arm.
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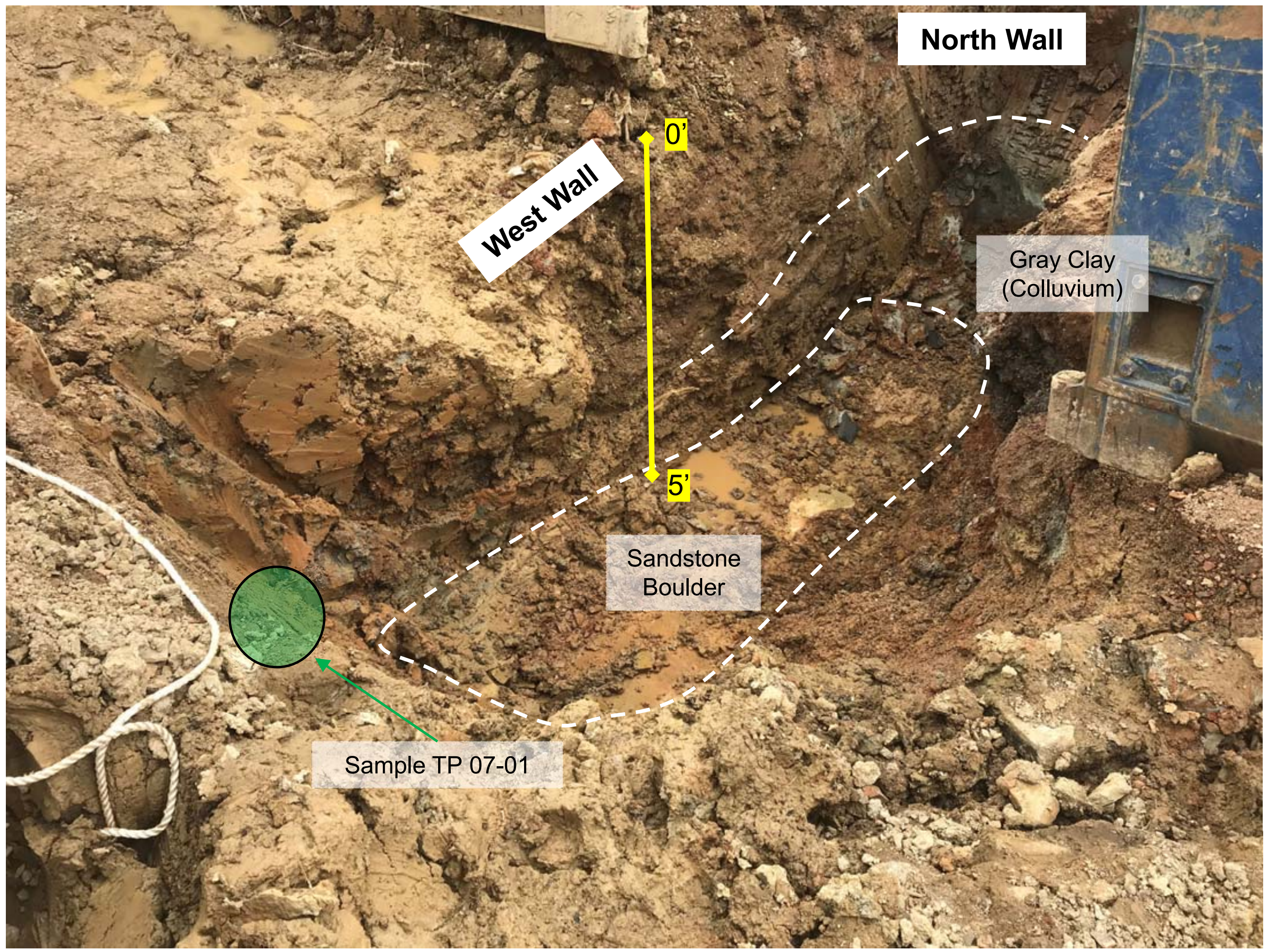
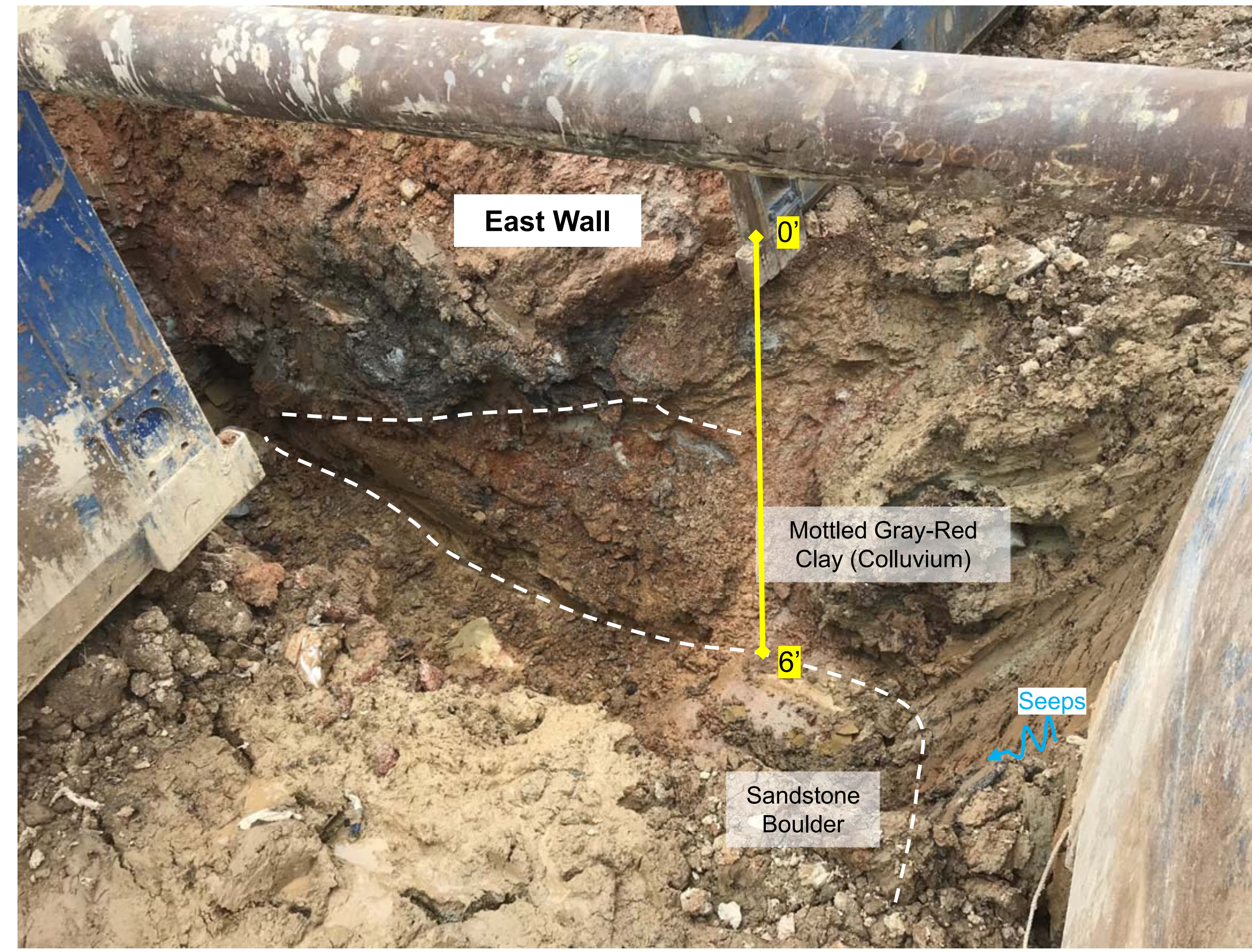
PREPARED BY: WCD	FIGURE TITLE: TP 6A PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-10

0 5 10 mm in ANSI B sized paper

Tet Pit 07: Photo logs of west wall (left) and east wall (right) showing sandstone (interpreted as boulders) exposed at the base of the excavation. The test pit was dug perpendicular to the excavation of Line 10.



Feature	Depth (ft)
Top of Sandstone Boulder	5 (from trench bottom)



Feature	Depth (ft)
Top of Sandstone Boulder	6 (from trench bottom)

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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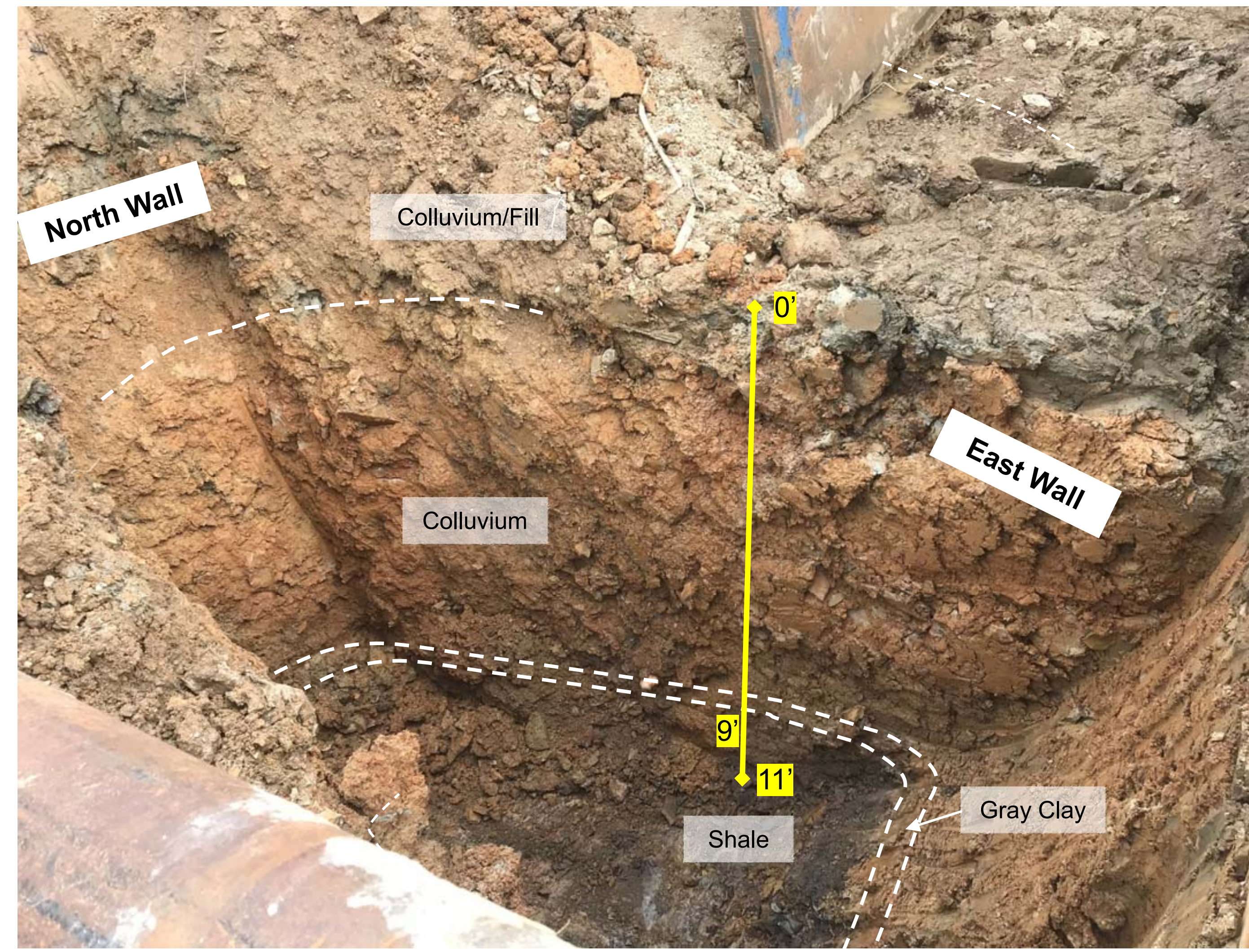
PREPARED BY: WCD	FIGURE TITLE: TP 07 PHOTO LOG			
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-11	

0 5 10 mm in ANSI B sized paper

Test Pit 08: Photo logs of the west wall (left) and east wall (right) showing fresh shale exposed at the base of the excavation. The test pit was dug perpendicular to the excavation of Line 10.



Feature	Depth from trench bottom (ft)
Top of Gray Clay	9
Shale (Bedrock) Contact	10
Bottom of Excavation	11

Feature	Depth from trench bottom (ft)
Shale (Bedrock) Contact	9
Bottom of Excavation	11

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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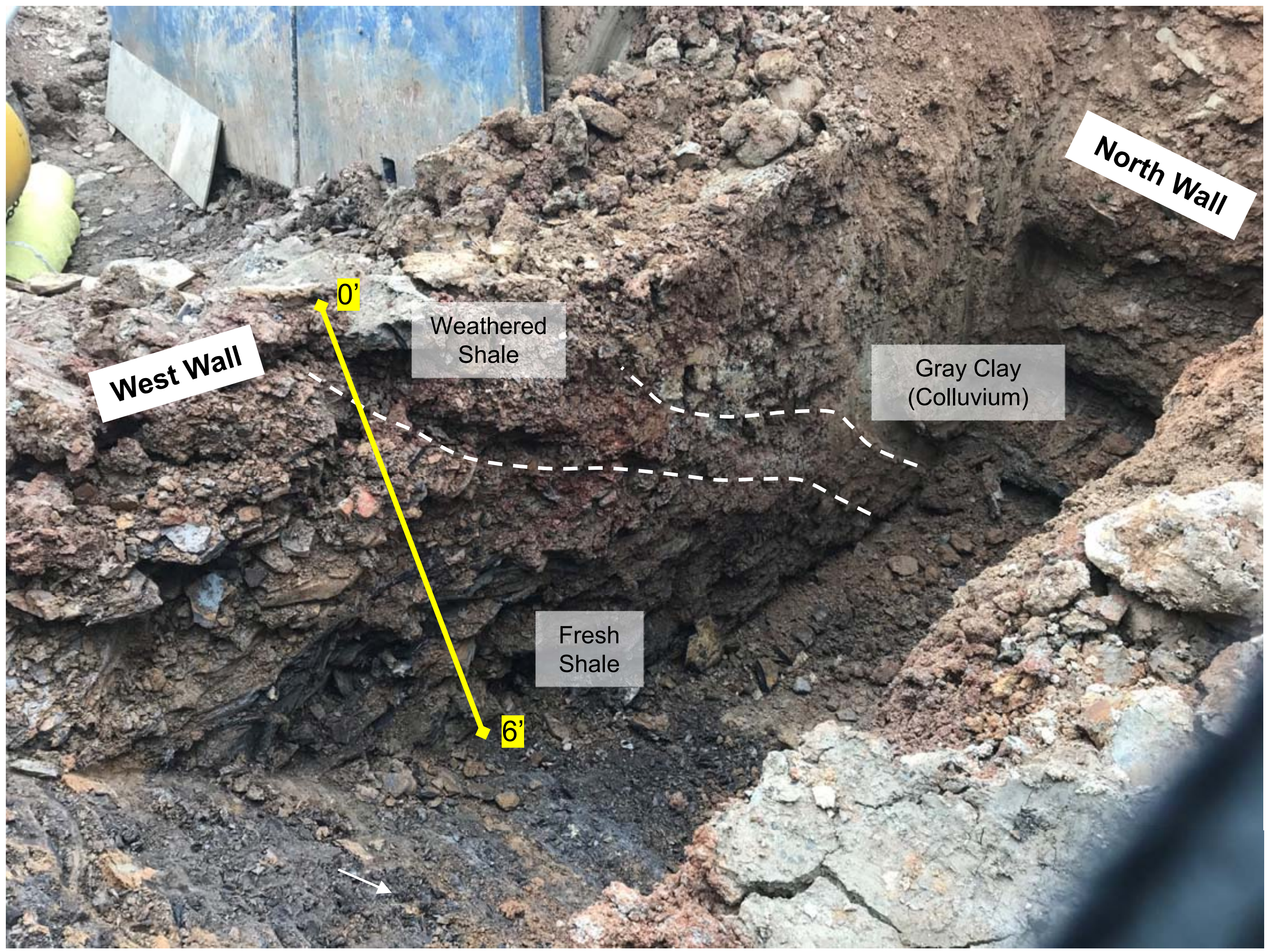
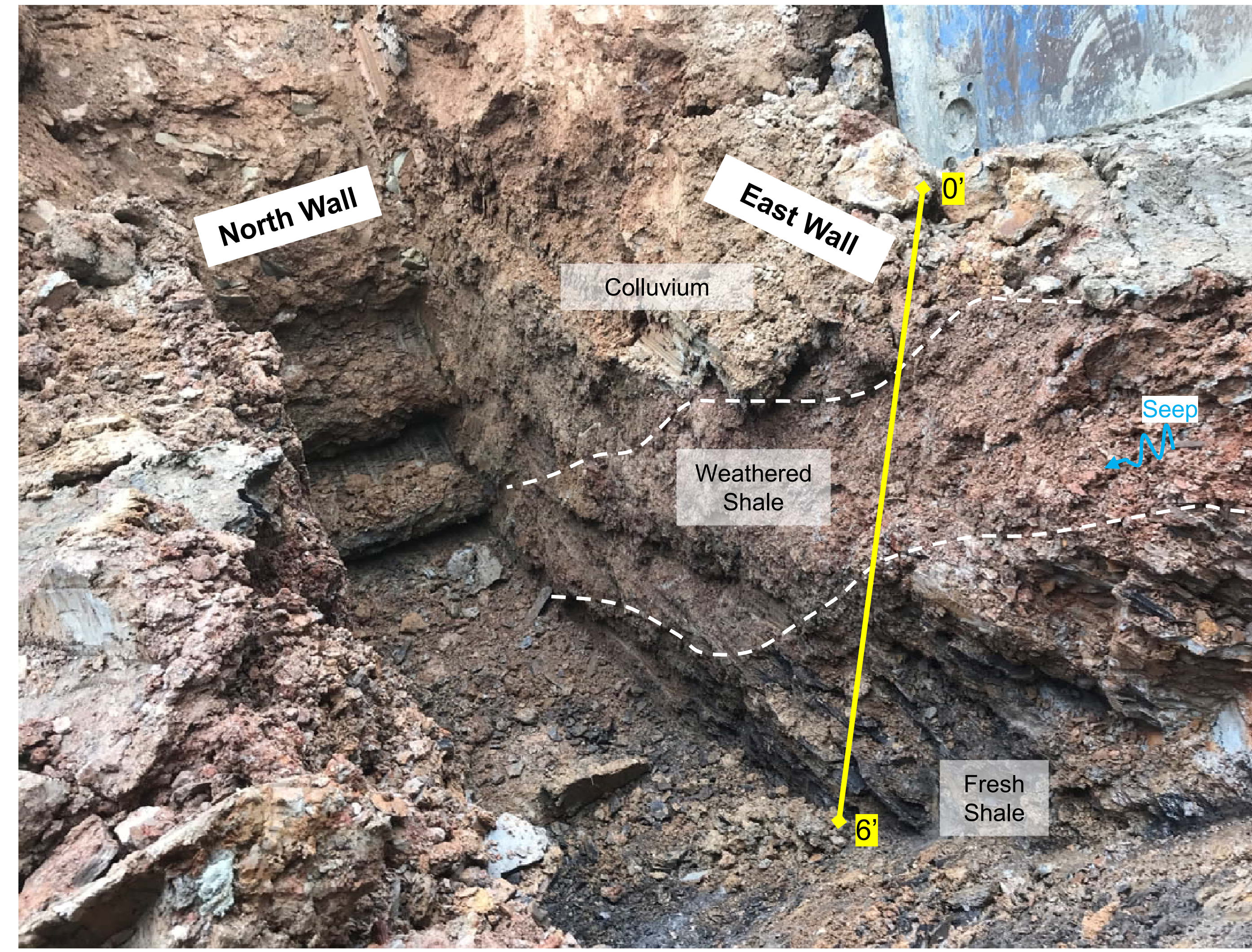
PREPARED BY: WCD	FIGURE TITLE: TP 08 PHOTO LOG			
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-12	

0 5 10 mm in ANSI B sized paper

Test Pit 09: Photo logs of the test pit's west wall (left) and east wall (right) showing fresh shale exposed at the base of the excavation. The depth of shale bedrock dives steeply to the north. The test pit was dug perpendicular to the excavation of Line 10.





Feature	Depth from trench bottom (ft)
Bottom of Excavation	6

Feature	Depth from trench bottom (ft)
Bottom of Excavation	6

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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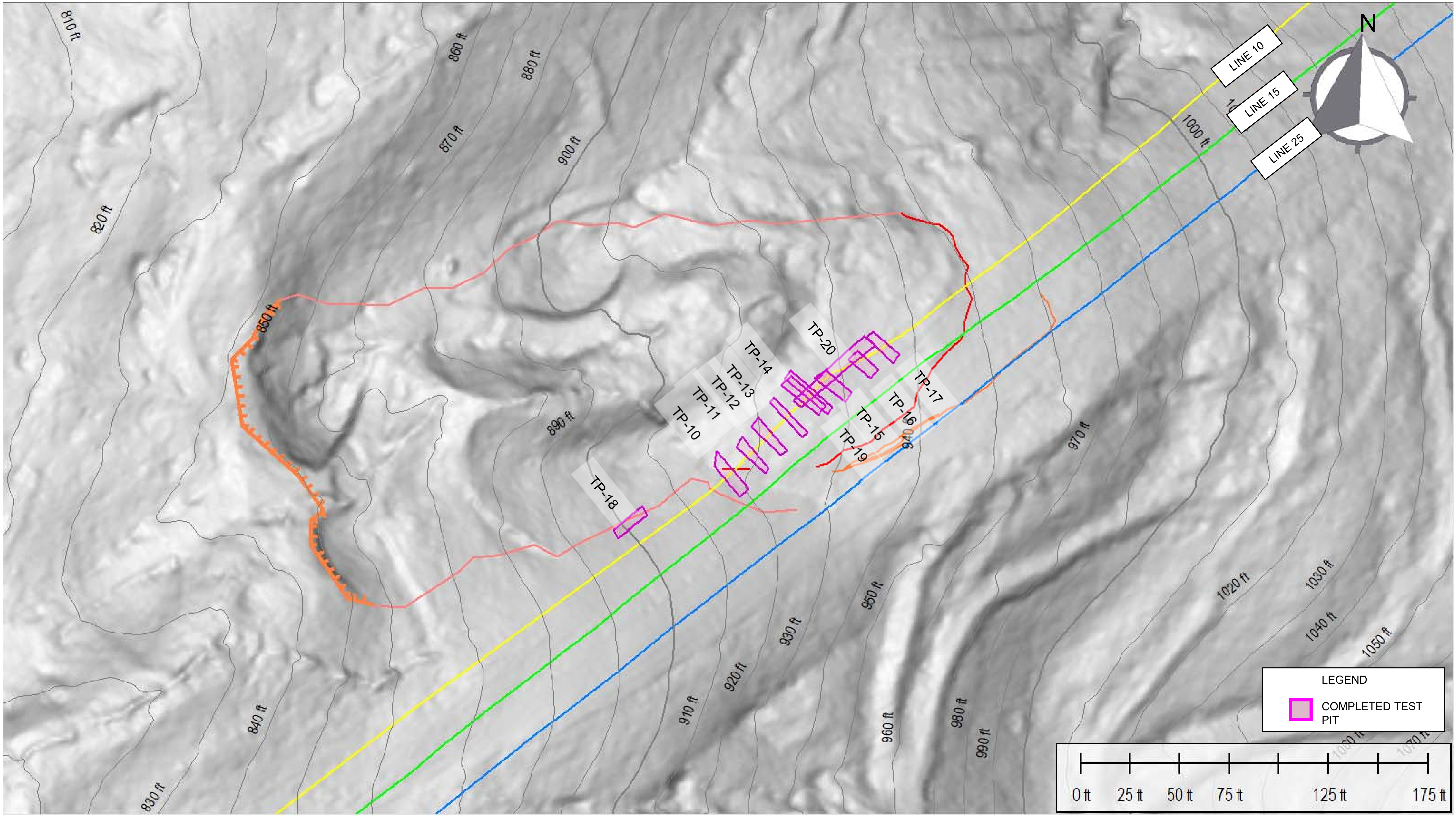
PREPARED BY: WCD	FIGURE TITLE: TP 09 PHOTO LOG			
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-13	

0 5 10 mm in ANSI B sized paper

04-2021



NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Test pits were excavated by Otis Eastern Service, LLC and logged by BGC.
3. All dimensions are in feet and are approximate.
4. Base image based on digital elevation model from November 2019 lidar data provided by TETLP. Surveyed pipeline centerlines and test pit locations provided by SGC Engineering LLC.
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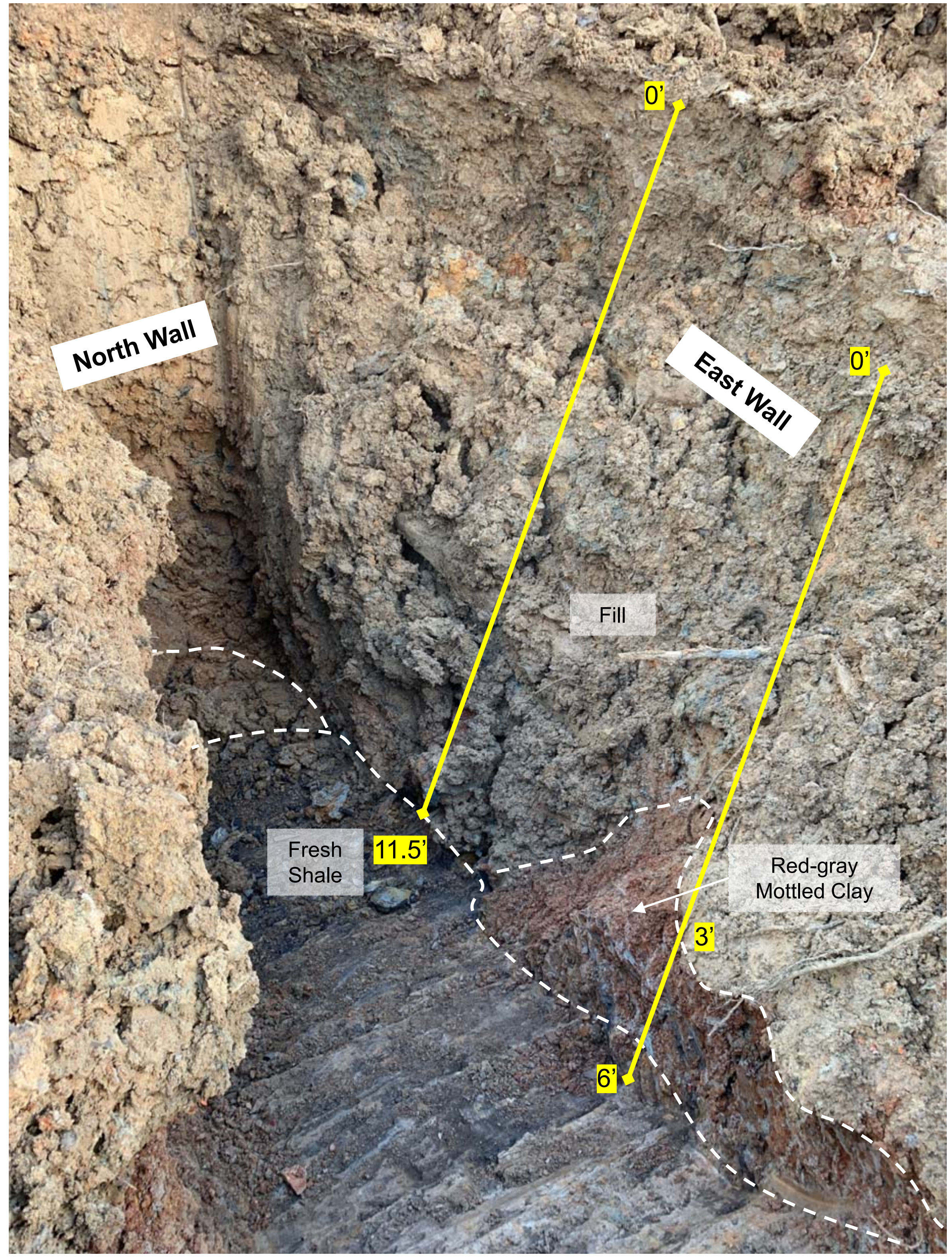
PREPARED BY:	FIGURE TITLE		
WCD	PLAN VIEW - TEST PITS 10 TO 20		
CHECKED BY:	CLIENT:		
TM	TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
CAD	AS SHOWN	1607024	E-14

0 5 10 mm in ANSI B sized paper

BGC ENGINEERING INC.

Test Pit 10: Photo log showing fresh shale exposed at the base of the excavation. The depth of the shale bedrock is measured at two locations along the east wall of the test pit.



Feature	Depth (ft)
Top of Red-Gray Mottled Clay	3
Bottom of Excavation/Shale (Bedrock) Contact	6 (to south) 11.5 (to north)

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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3. All dimensions are in feet and are approximate. Depths were measured using a measuring tape or estimated using the excavator bucket and arm.
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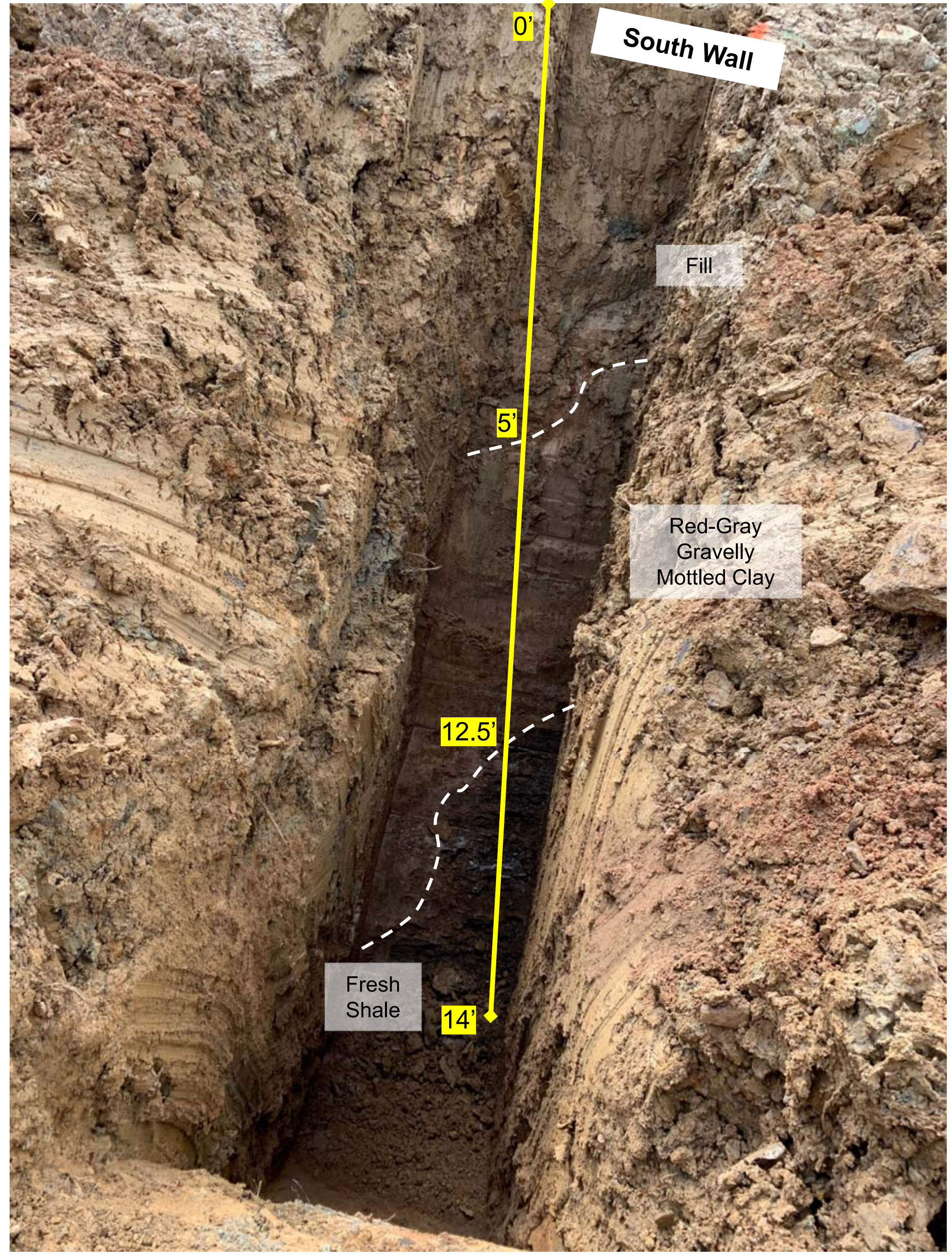
PREPARED BY: WCD	FIGURE TITLE: TP 10 PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-15

0 5 10 mm in ANSI B sized paper

Test Pit 11: Photo log showing fresh shale exposed at the base of the excavation. The top of shale bedrock dives steeply to the east.



Feature	Depth (ft)
Top of Red-Gray Mottled Clay	5
Shale (Bedrock) Contact	12.5
Bottom of Excavation	14

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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3. All dimensions are in feet and are approximate. Depths were measured using a measuring tape or estimated using the excavator bucket and arm.
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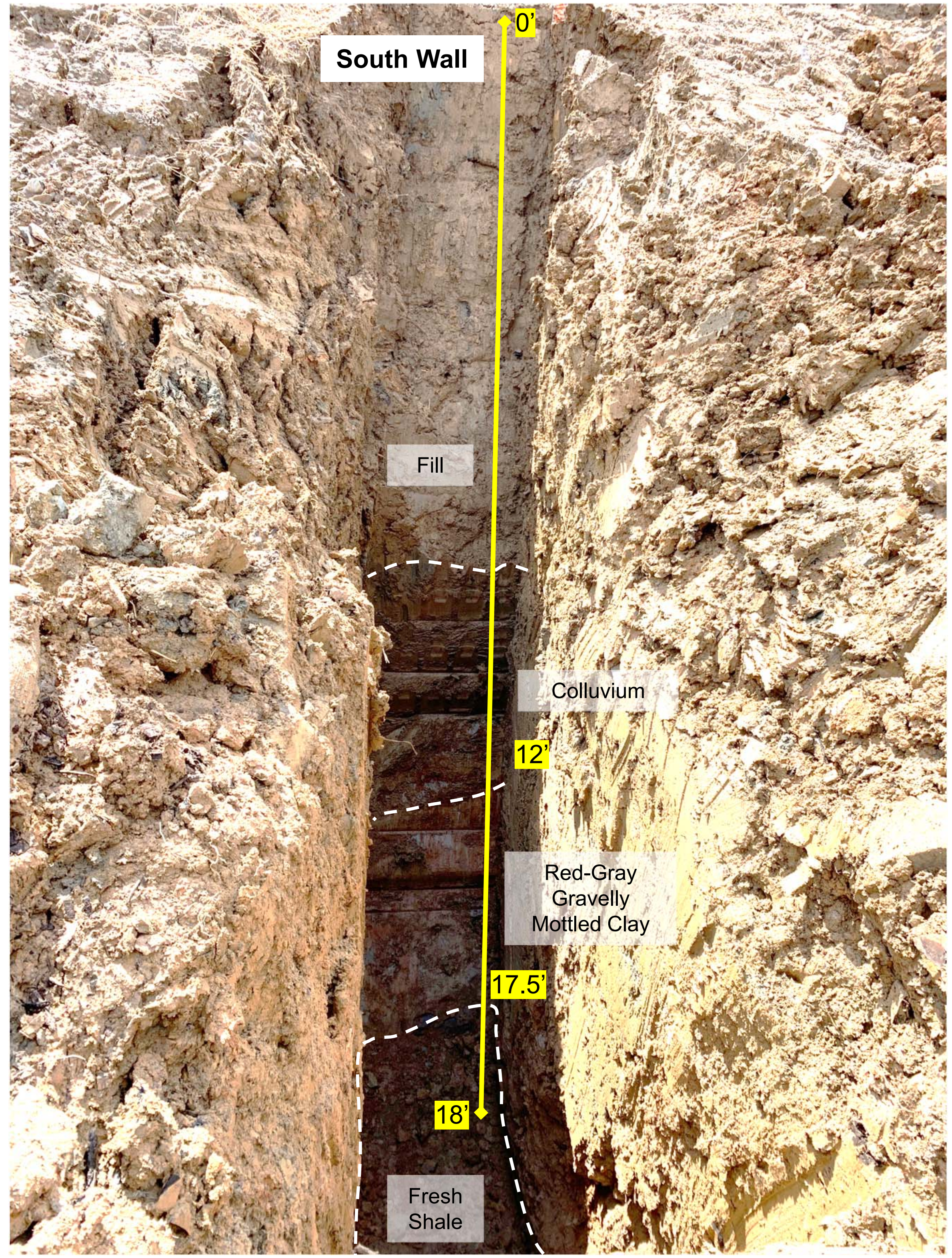
PREPARED BY: WCD	FIGURE TITLE: TP 11 PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-16

0 5 10 mm in ANSI B sized paper

Test Pit 12: Photo log showing fresh shale exposed at the base of the excavation.



Feature	Depth (ft)
Top of Red-Gray Mottled Clay	12
Shale (Bedrock) Contact	17.5
Bottom of Excavation	18

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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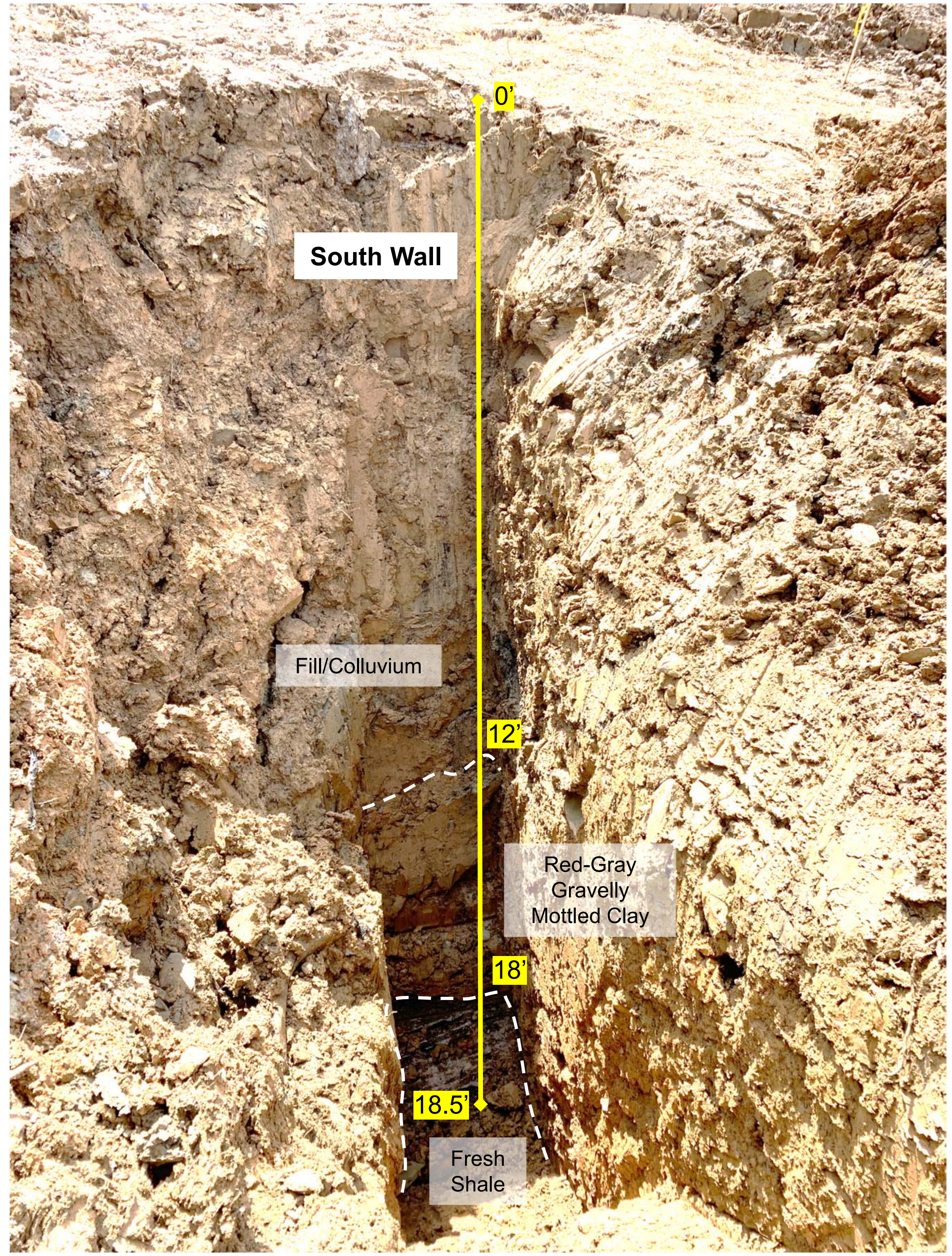
PREPARED BY: WCD	FIGURE TITLE: TP 12 PHOTO LOG			
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-17	

0 5 10 mm in ANSI B sized paper

Test Pit 13: Photo log showing fresh shale exposed at the base of the excavation. Depths were estimated due to unsafe conditions around the excavation.



Feature	Depth (ft)
Top of Red-Gray Mottled Clay	12
Shale (Bedrock) Contact	18
Bottom of Excavation	18.5

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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3. All dimensions are in feet and are approximate. Depths were measured using a measuring tape or estimated using the excavator bucket and arm.
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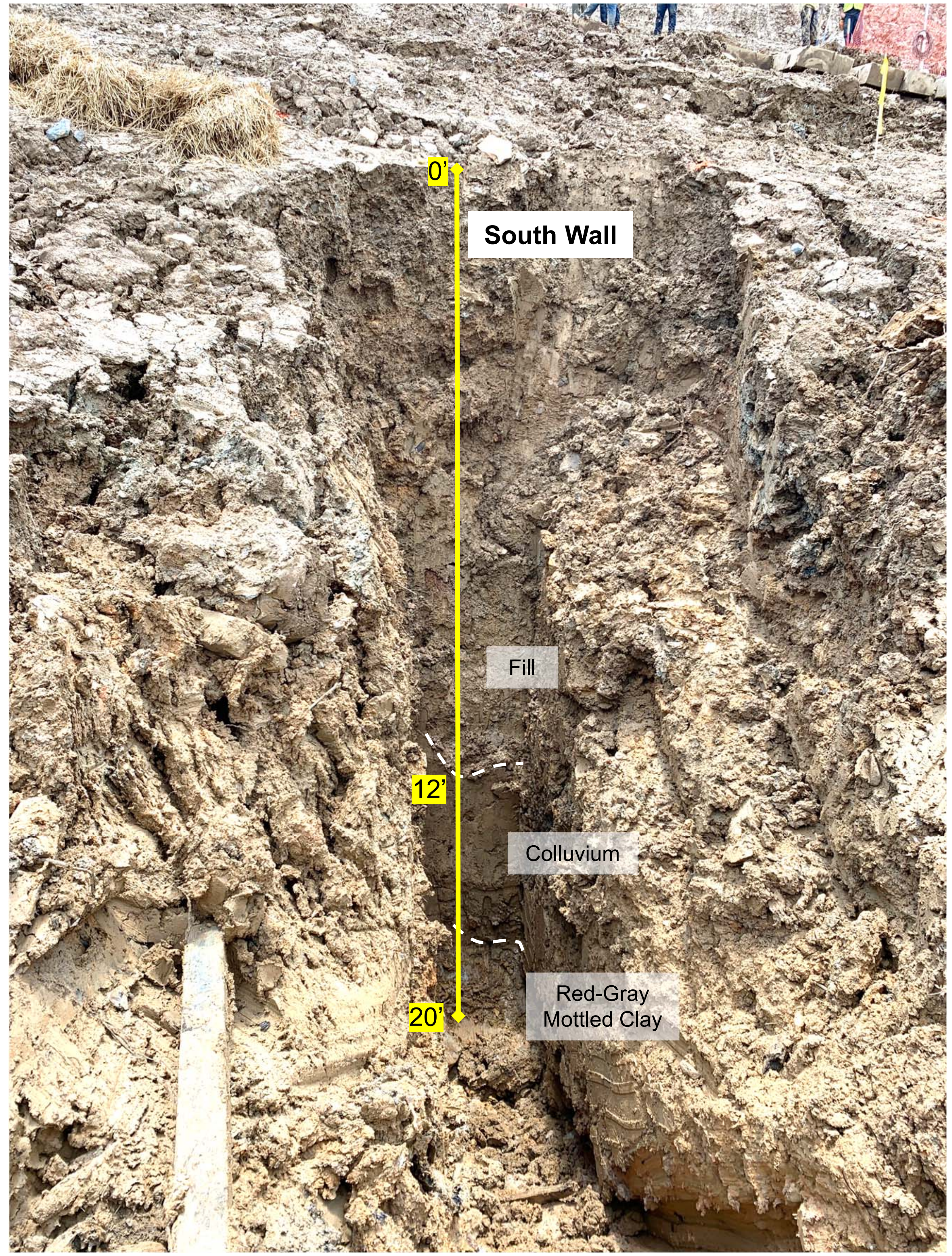
PREPARED BY: WCD	FIGURE TITLE: TP 13 PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-18

0 5 10 mm in ANSI B sized paper

Test Pit 14: Photo log showing red-gray mottled clay exposed at the base of the excavation. Depths were estimated due to unsafe conditions around the excavation.



Feature	Depth (ft)
Fill-Colluvium Contact	12
Bottom of Excavation	20

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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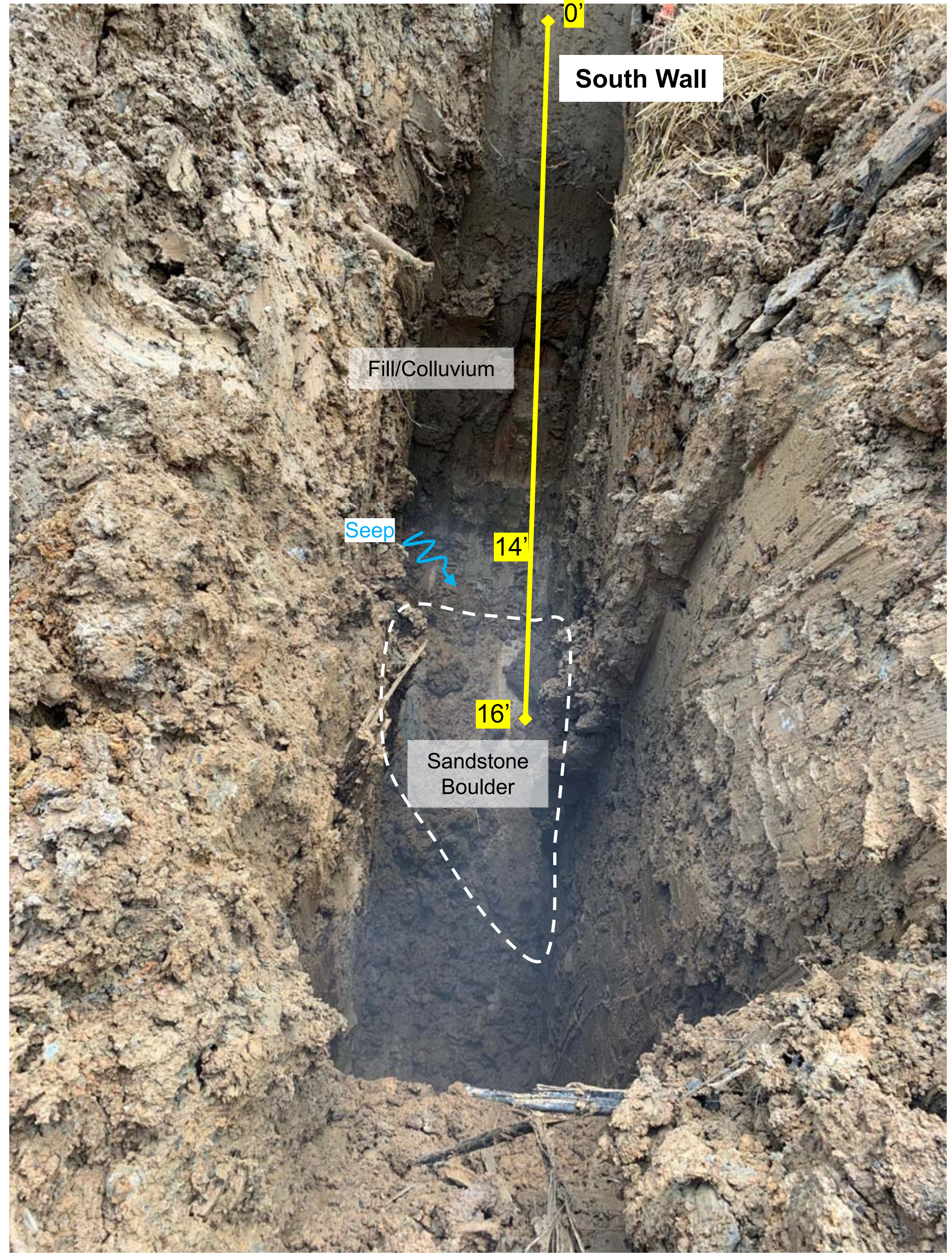
PREPARED BY: WCD	FIGURE TITLE: TP 14 PHOTO LOG			
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-19	

0 5 10 mm in ANSI B sized paper

Test Pit 15: Sandstone floors the bottom of excavation (interpreted as boulders). Test pit concluded upon refusal at the sandstone.



Feature	Depth (ft)
Seep	14
Bottom of Excavation/Top of Sandstone Boulder	16

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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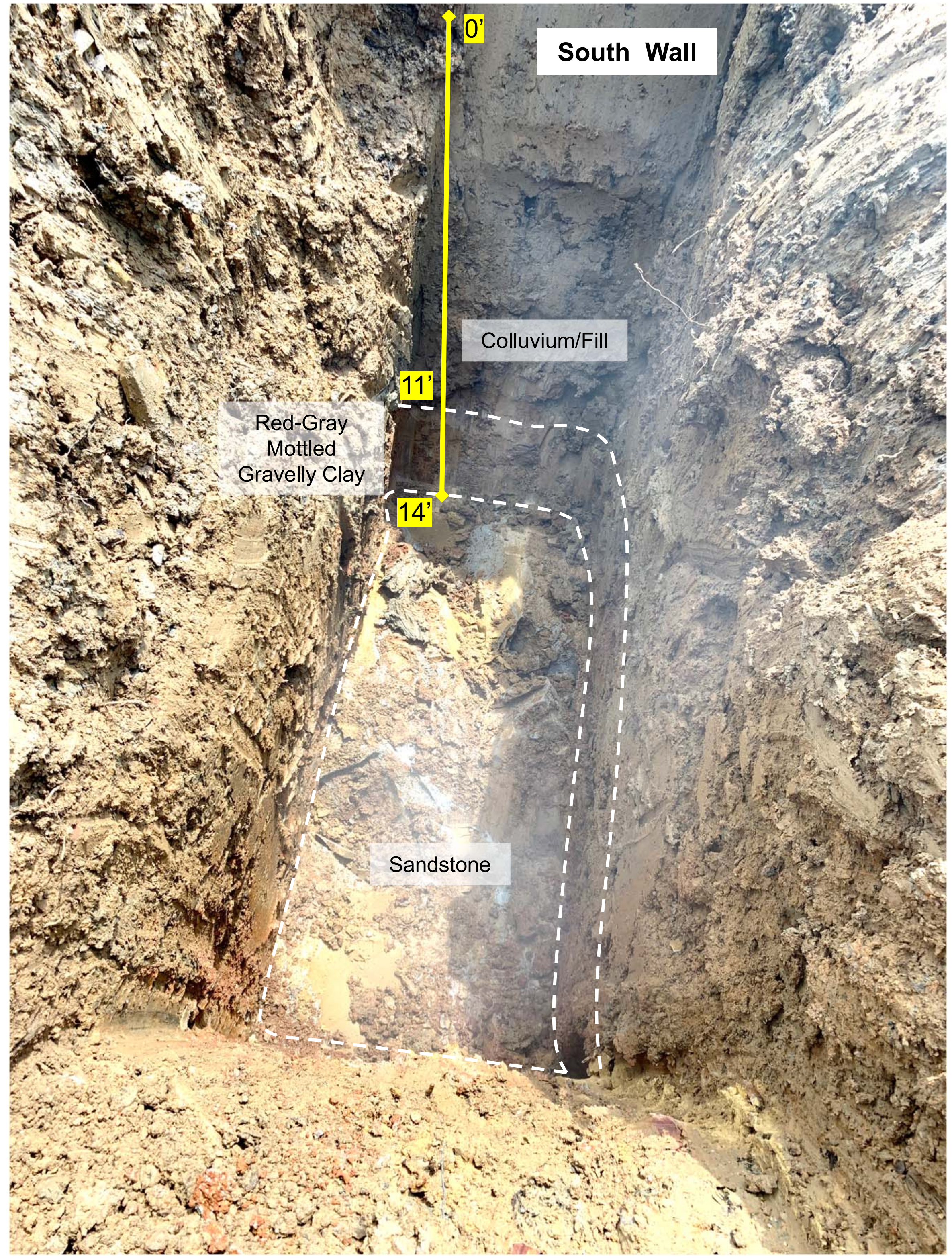
PREPARED BY:	FIGURE TITLE		
WCD	TP 15 PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-20

0 5 10 mm in ANSI B sized paper

Test Pit 16: Test pit concluded upon refusal at the sandstone (interpreted as boulders).



Feature	Depth (ft)
Top of Red-Gray Gravelly Clay	11
Bottom of Excavation/Top of Sandstone	14

NOTES:
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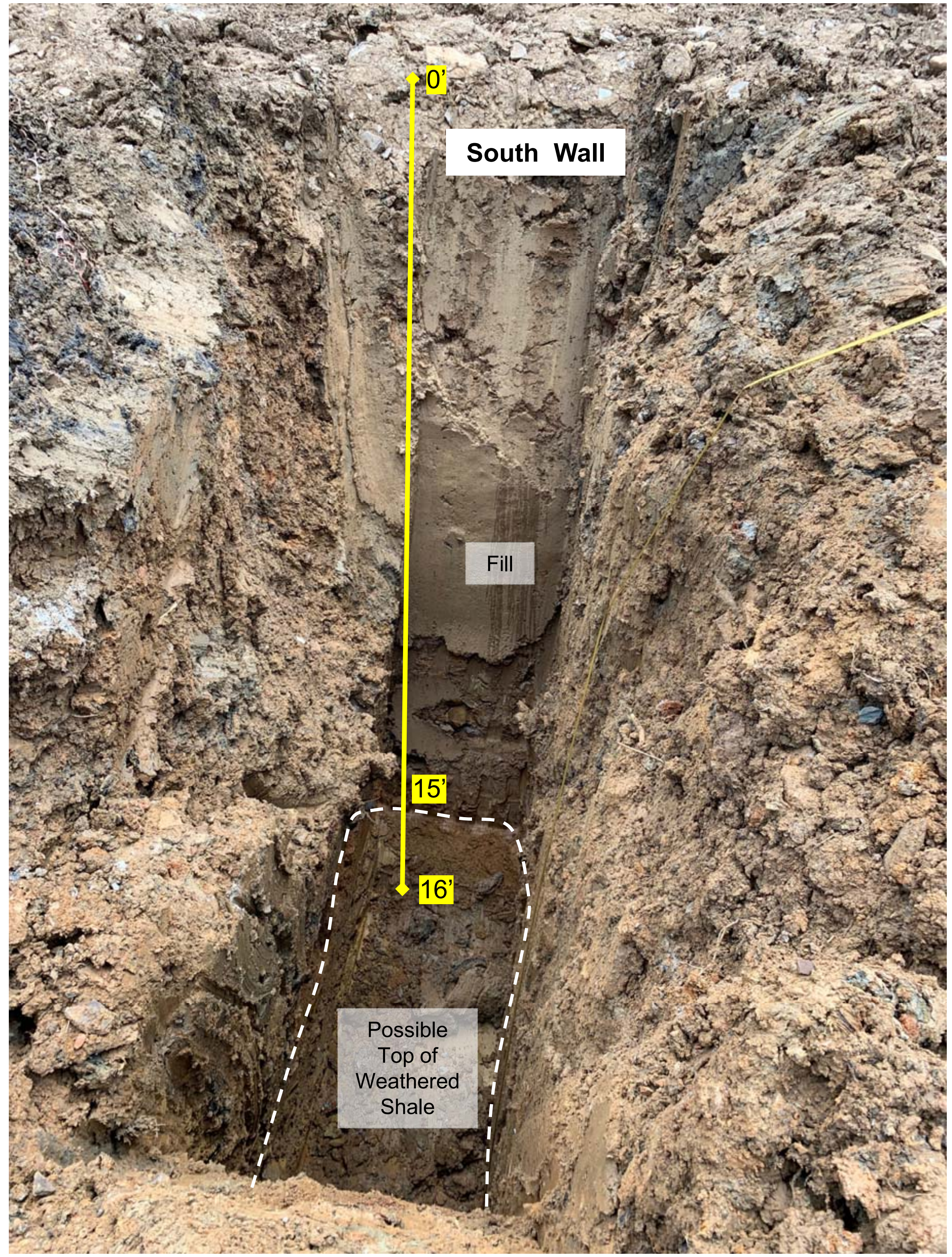
PREPARED BY: WCD	FIGURE TITLE: TP 16 PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-21

0 5 10 mm in ANSI B sized paper

Test Pit 17: The test pit was concluded at the total reach of the excavator. Due to collapsing side walls, the depth of the weathered shale was not able to be confirmed.



Feature	Depth (ft)
Possible Shale (Bedrock) Contact	15
Bottom of Excavation	16

NOTES:
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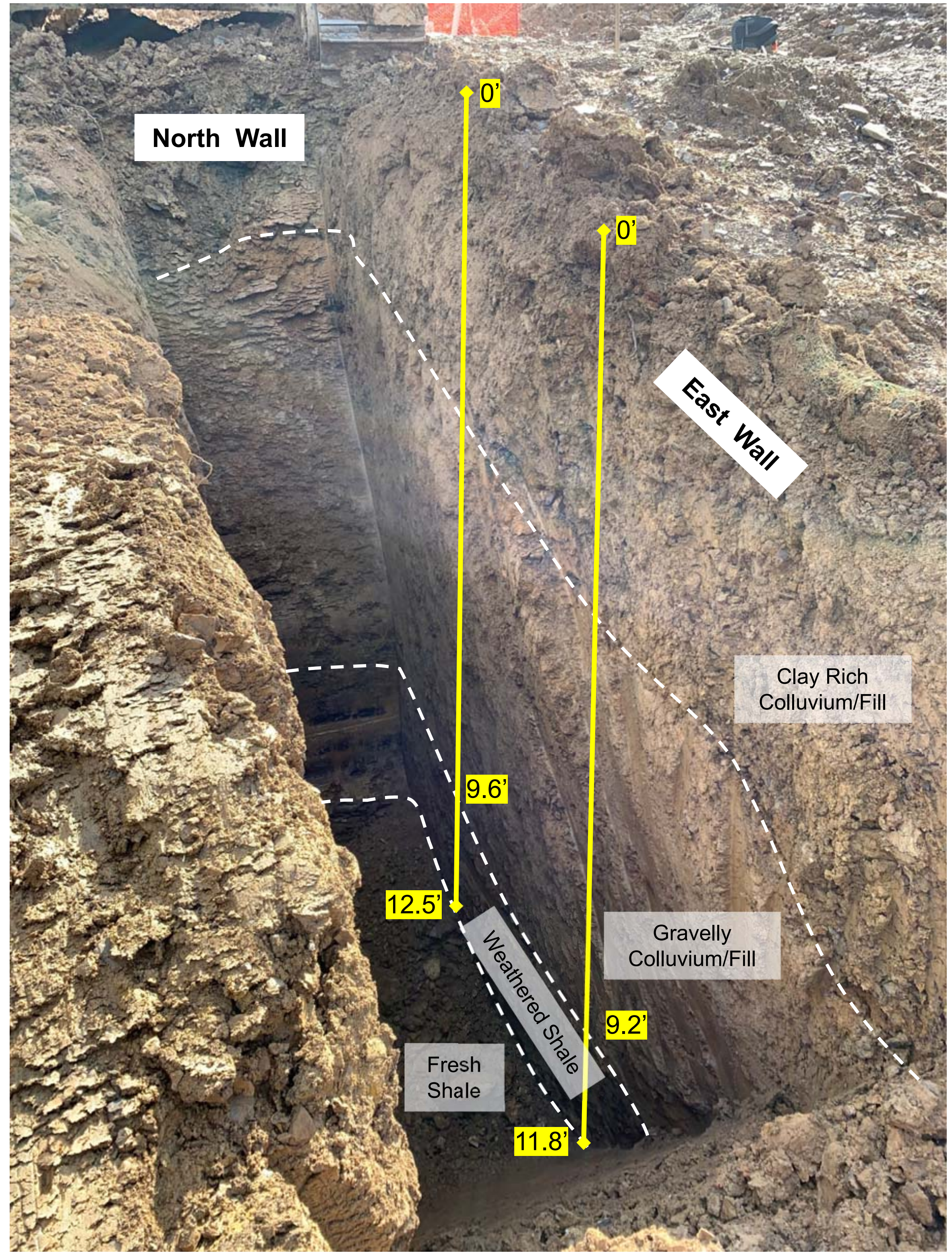
PREPARED BY: WCD	FIGURE TITLE: TP 17 PHOTO LOG			
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-22	

0 5 10 mm in ANSI B sized paper

Test Pit 18: Photo log showing fresh shale exposed at the base of the excavation.



Feature	Depth (ft)
Top of Weathered Shale	9.2 – 9.6
Bottom of Excavation/ Top of Fresh Shale	11.8 – 12.5

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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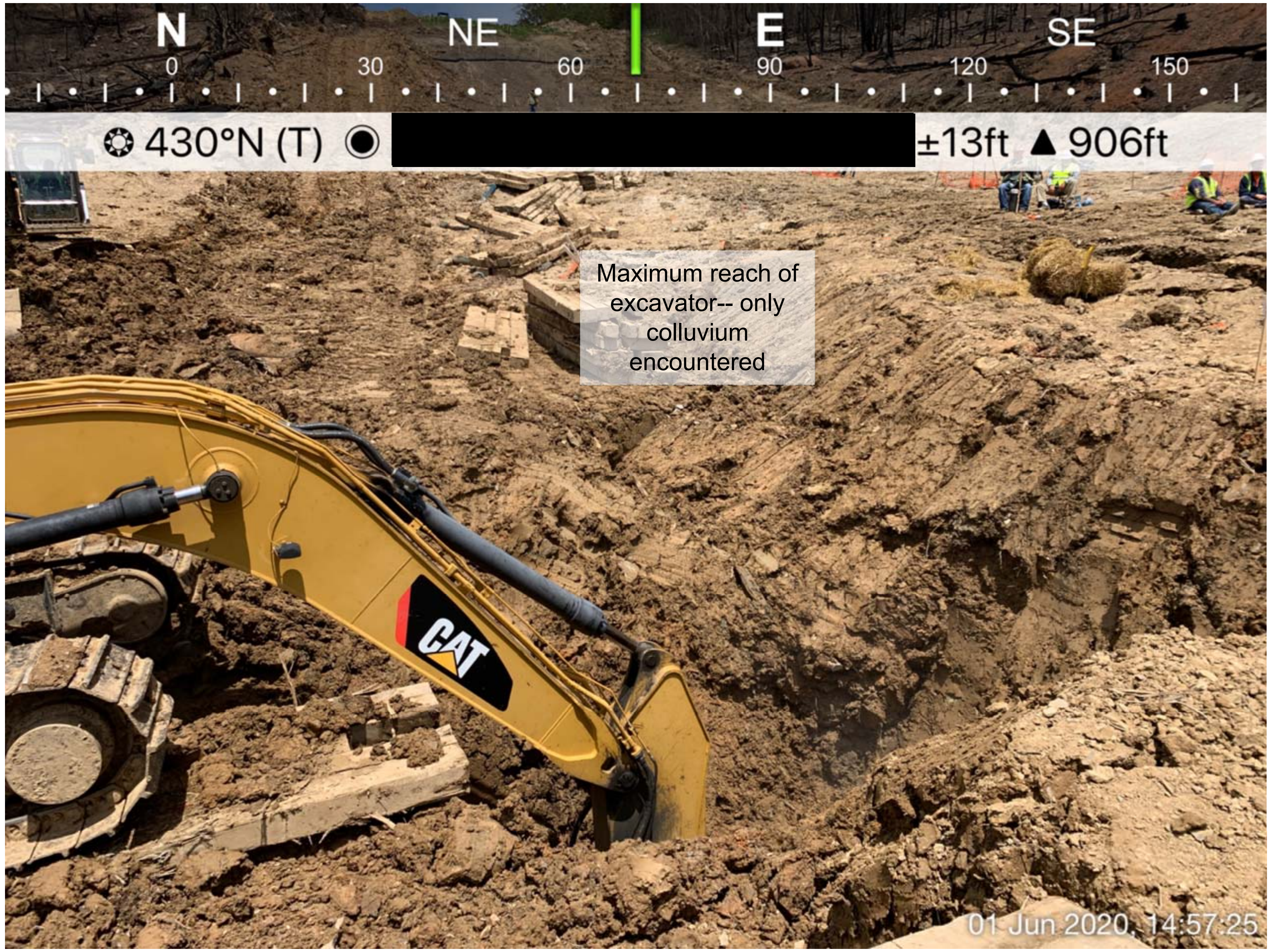
PREPARED BY: WCD	FIGURE TITLE: TP 18 PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-23

0 5 10 mm in ANSI B sized paper

Test Pit 19: Colluvium (right image) was exposed throughout the entire depth (33 ft) of the excavation. Left image shows the maximum reach of the excavator.



Feature	Depth (ft)
Bottom of Excavation	33

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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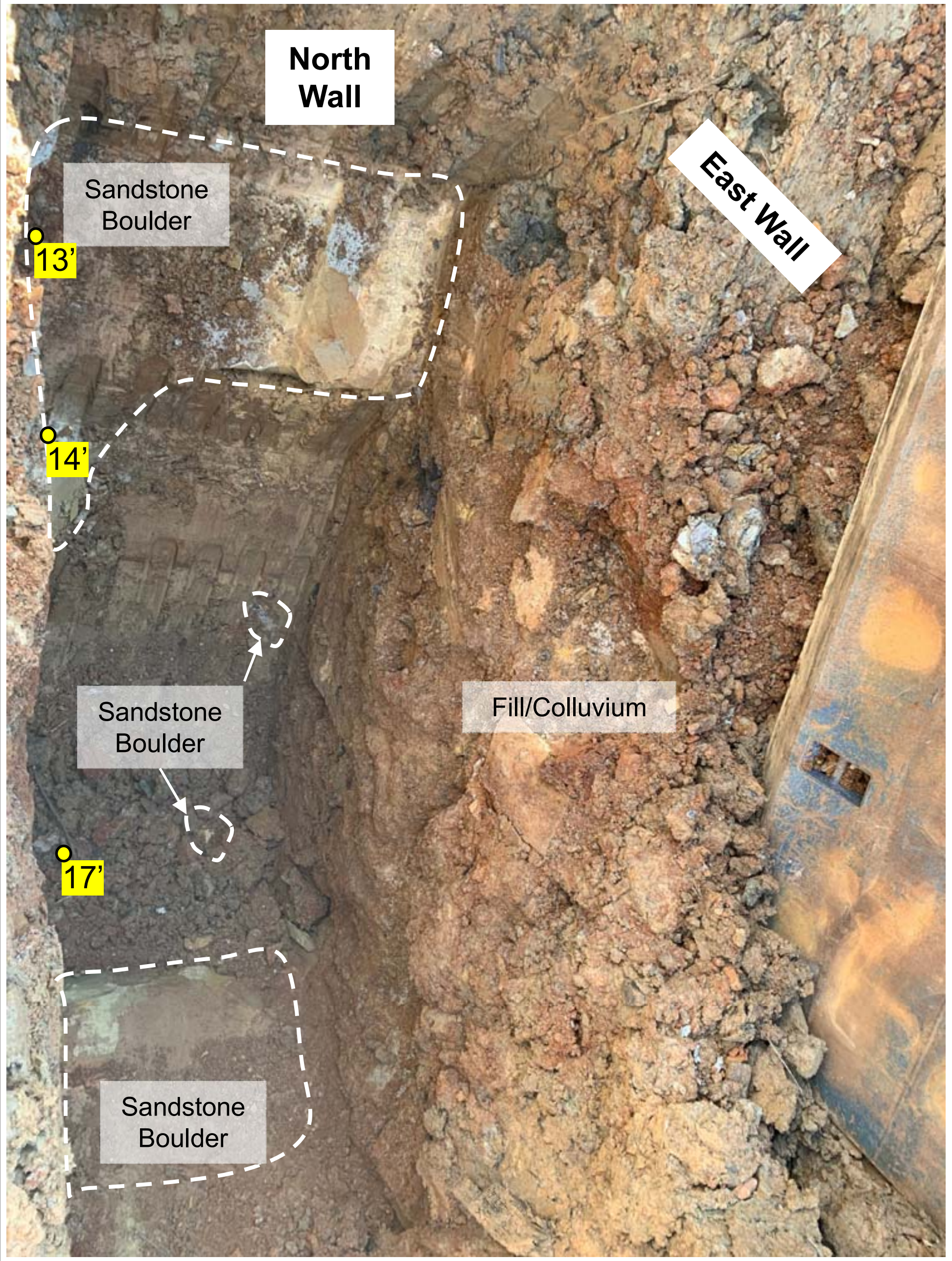
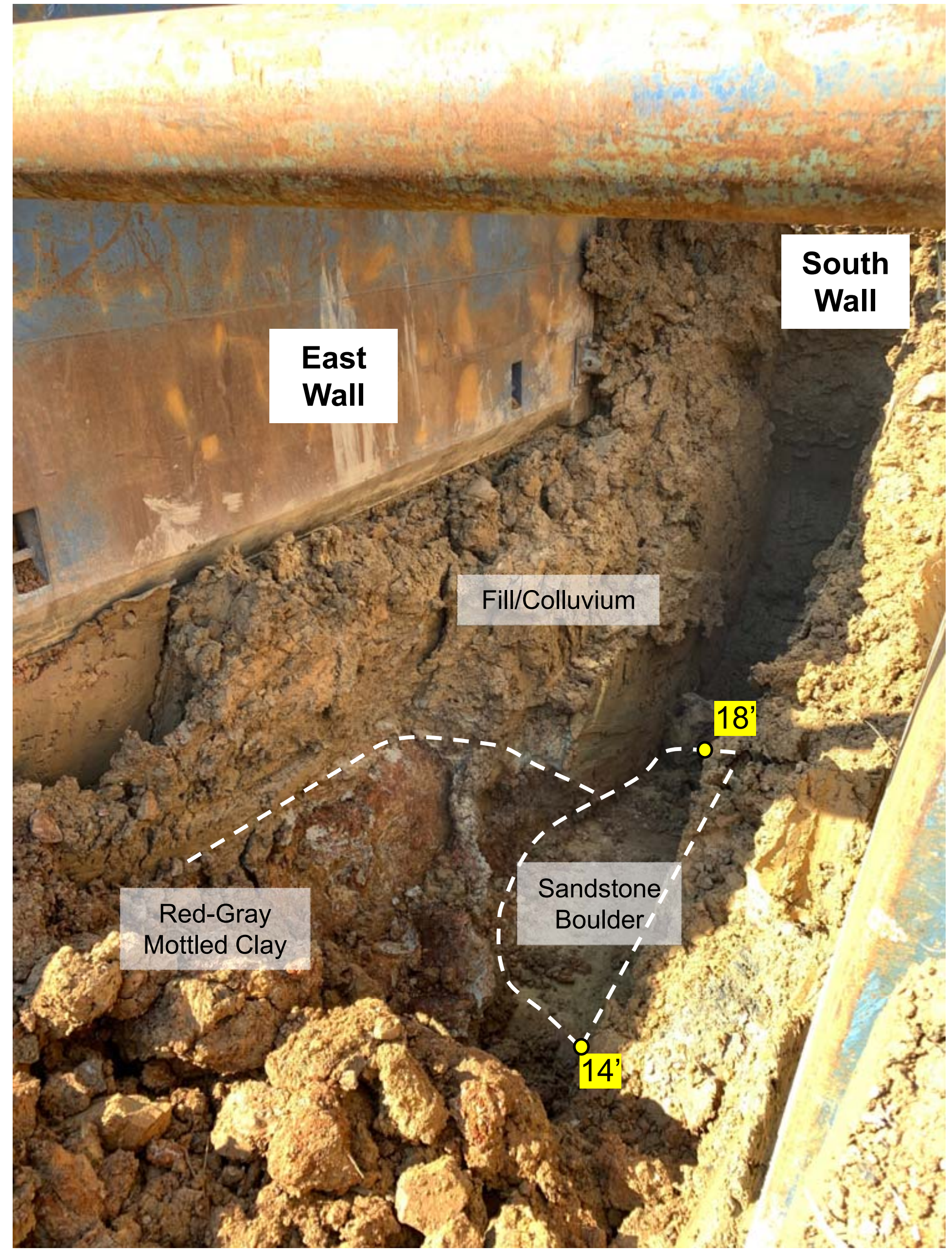
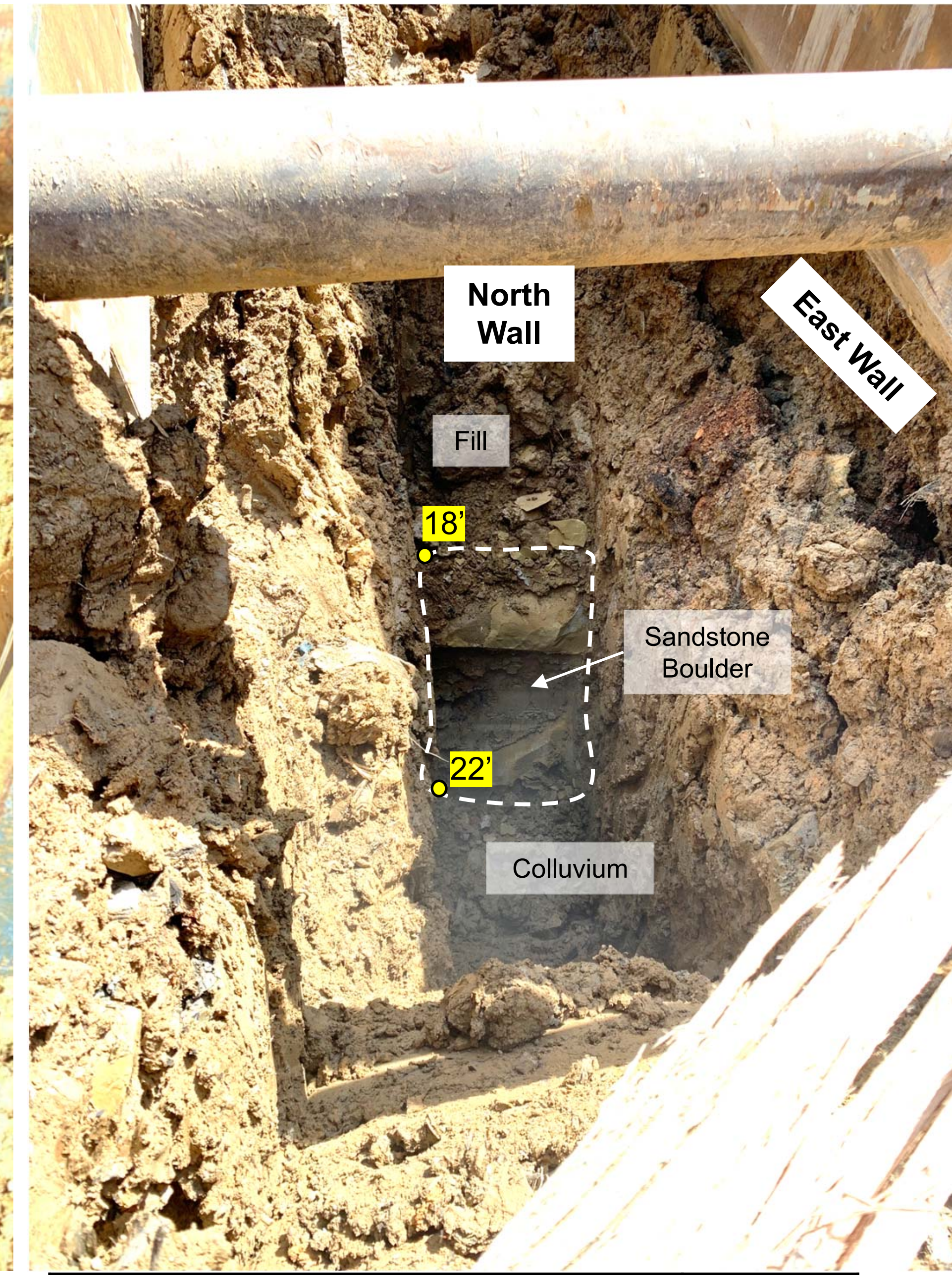
PREPARED BY: WCD	FIGURE TITLE: TP 19 PHOTO LOG			
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-24	

0 5 10 mm in ANSI B sized paper







Test Pit 20: Sandstone boulders within colluvium exposed throughout excavation. The progression of the excavation is shown from left (shallower) to right (deeper).

Feature	Depth (ft)
Top of Sandstone Boulder	18
Bottom of Excavation/Bottom of Sandstone Boulder	22

NOTES:
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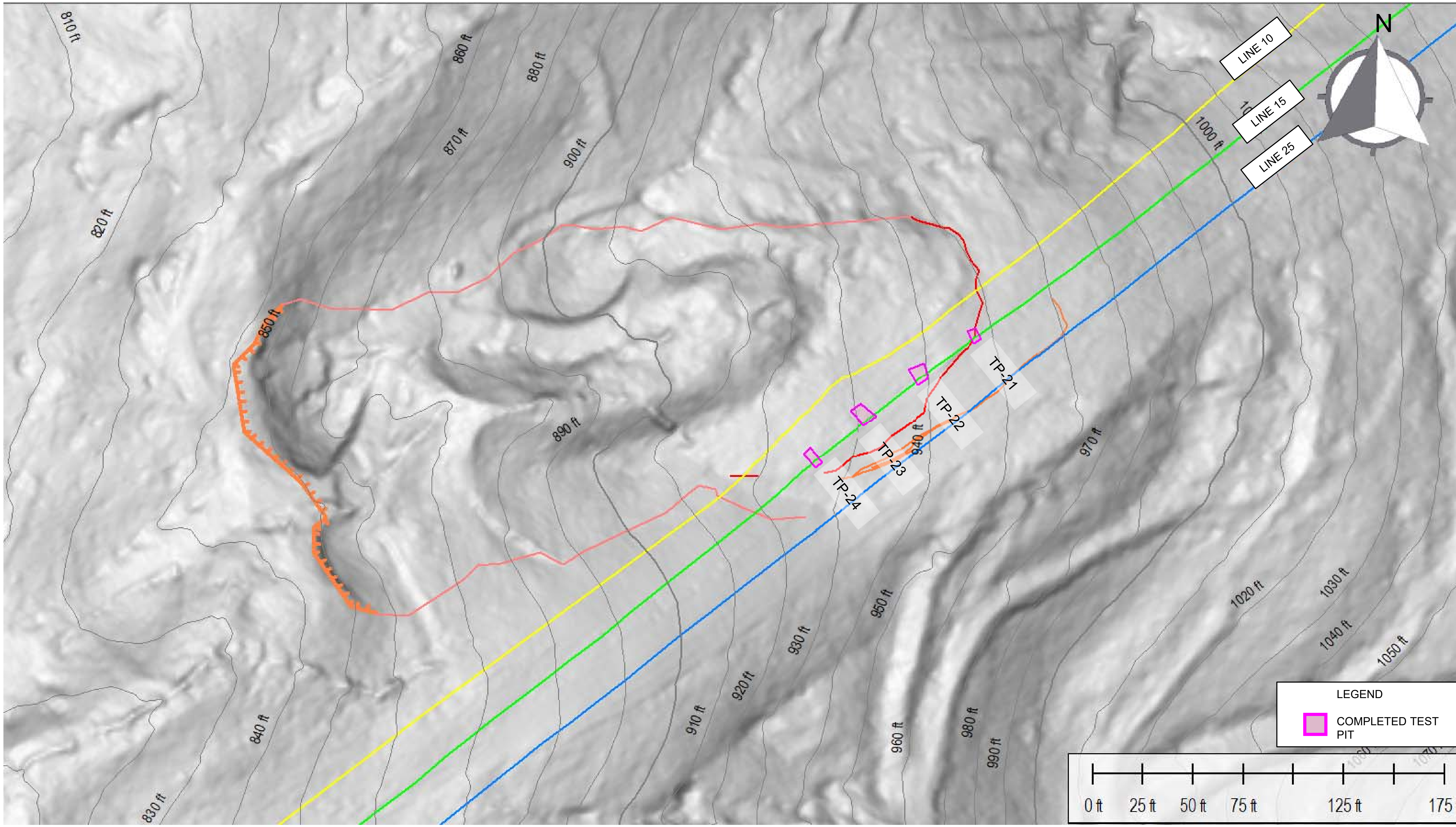
PREPARED BY: WCD	FIGURE TITLE: TP 20 PHOTO LOG			
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-25	

0 5 10 mm in ANSI B sized paper

04-2021



NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Test pits were excavated by Otis Eastern Service, LLC and logged by BGC.
3. All dimensions are in feet and are approximate.
4. Base image based on digital elevation model from November 2019 lidar data provided by TETLP. Surveyed pipeline centerlines and test pit locations provided by SGC Engineering LLC.
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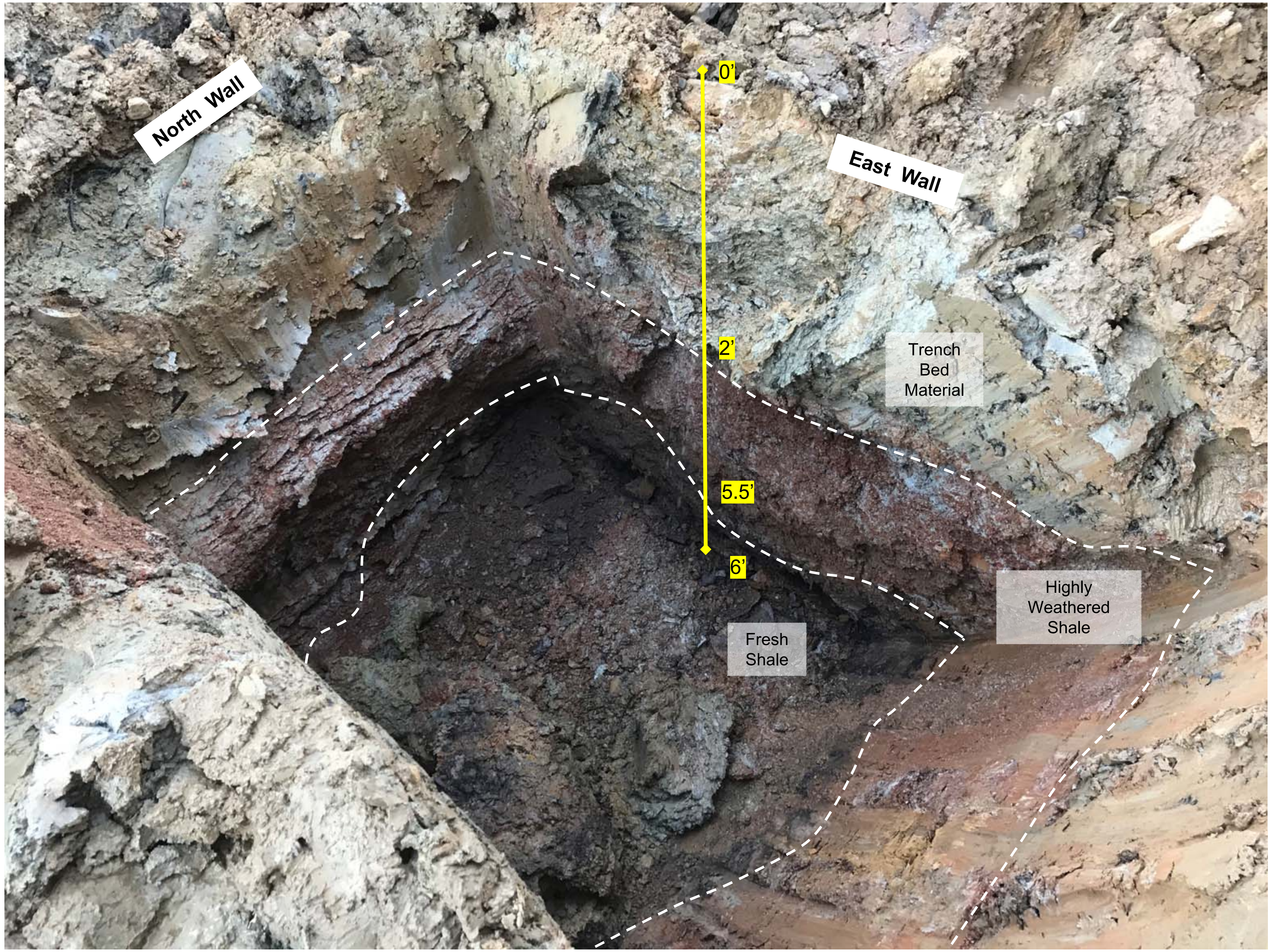
PREPARED BY: WCD	FIGURE TITLE: PLAN VIEW - TEST PITS 21 TO 24			
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-26	

0 5 10 mm in ANSI B sized paper

BGC ENGINEERING INC.

Test Pit 21: Photo log showing fresh shale exposed at the base of the excavation.



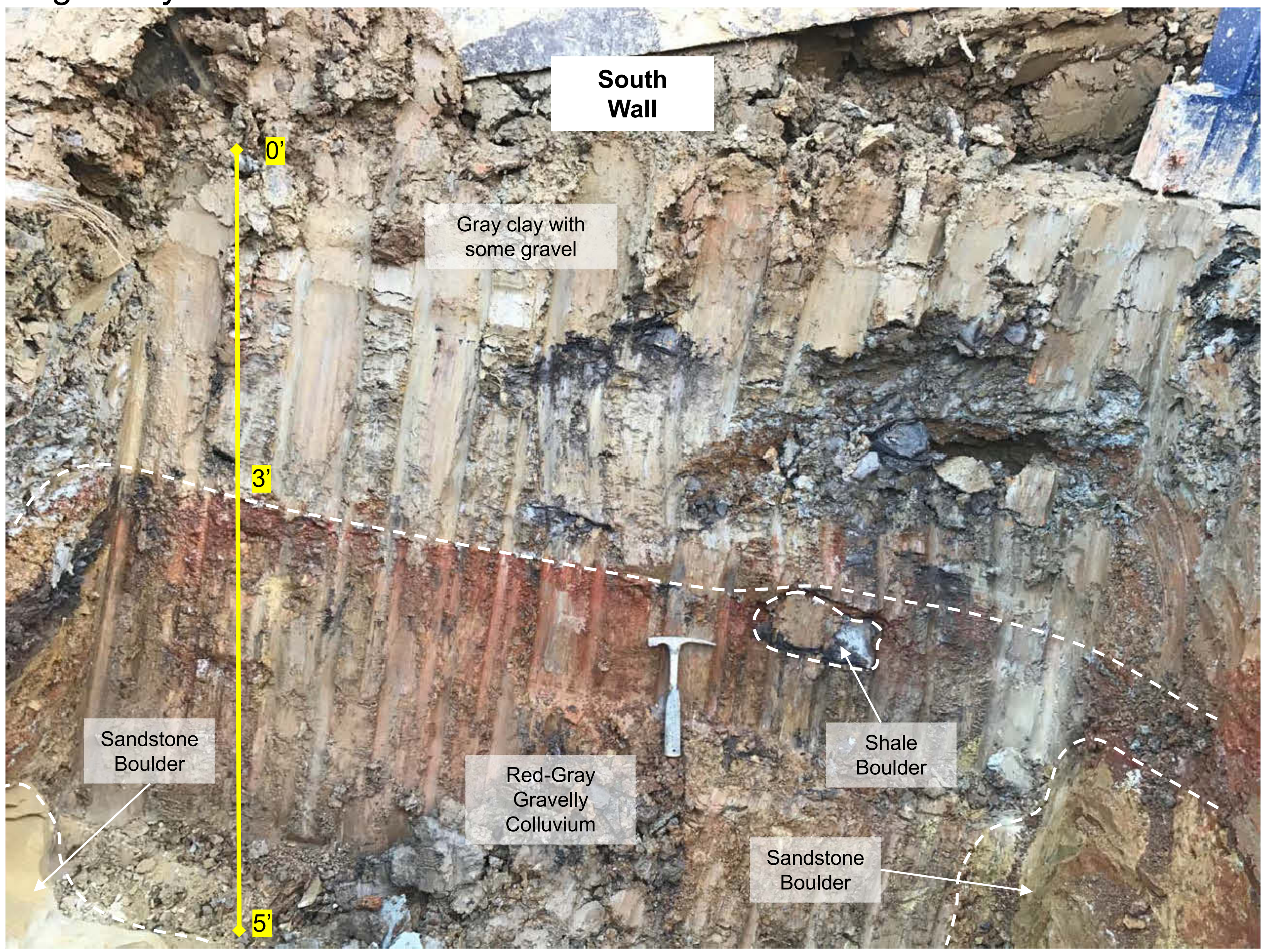
Feature	Depth (ft, from trench bottom)
Top of Weathered Shale	**2**
Top of Fresh Shale	**5.5**
Bottom of Excavation	6

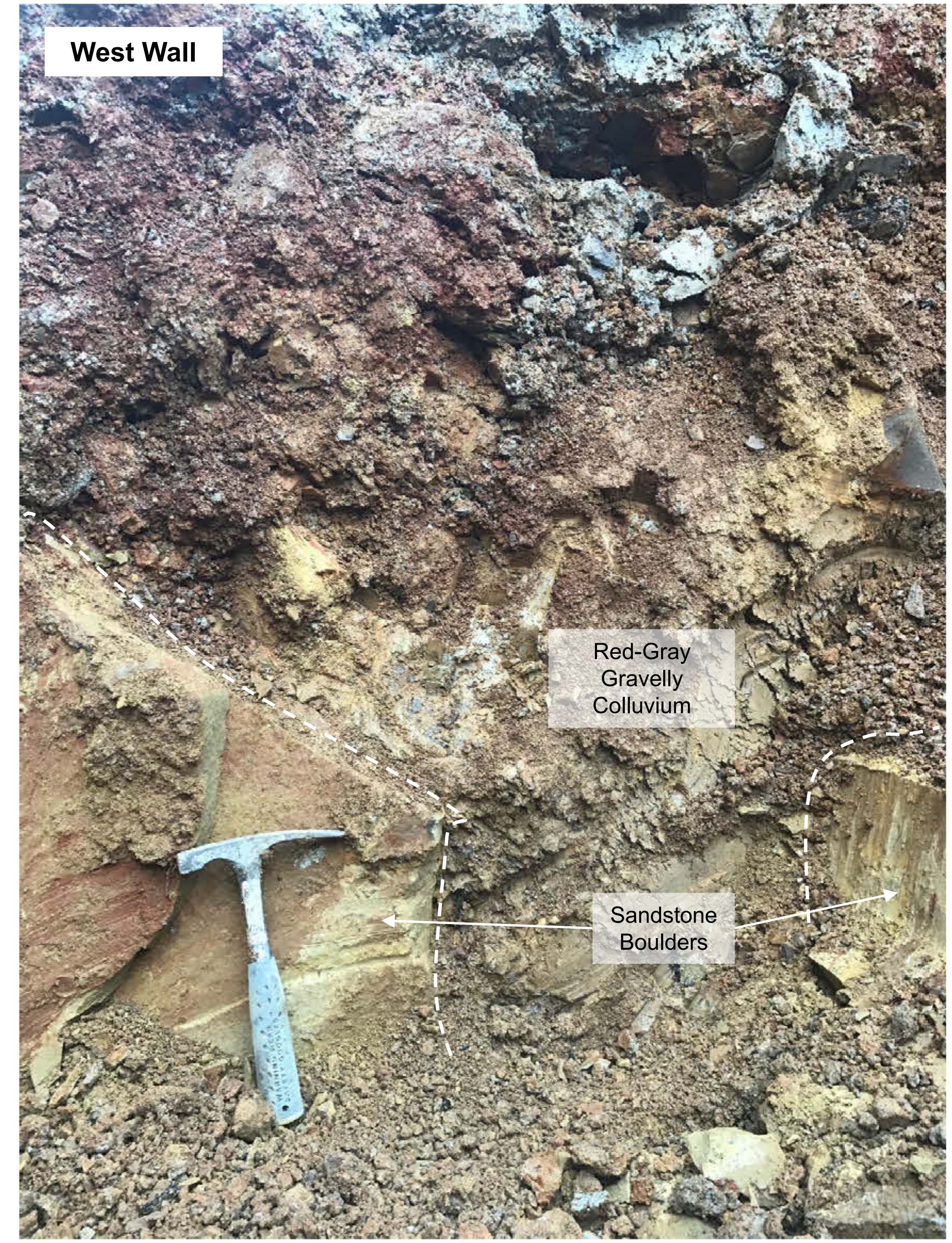
NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Test pits were excavated by Otis Eastern Service, LLC and logged by BGC.
3. All dimensions are in feet and are approximate. Depths were measured using a measuring tape or estimated using the excavator bucket and arm. TP-21 was excavated between trench boxes after the removal of Line 15; the elevation of the top of the test pit was approximately the bottom of Line 15.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: WCD	FIGURE TITLE: TP 21 PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-27

0 5 10 mm in ANSI B sized paper

Test Pit 22: Left photo shows clear contact between gray clay with some gravel and red to gray clay with abundant pebble to boulder sized shale and sandstone clasts. The right images shows two sandstone boulders suspended in gravelly colluvium at the base of the west wall of the excavation.





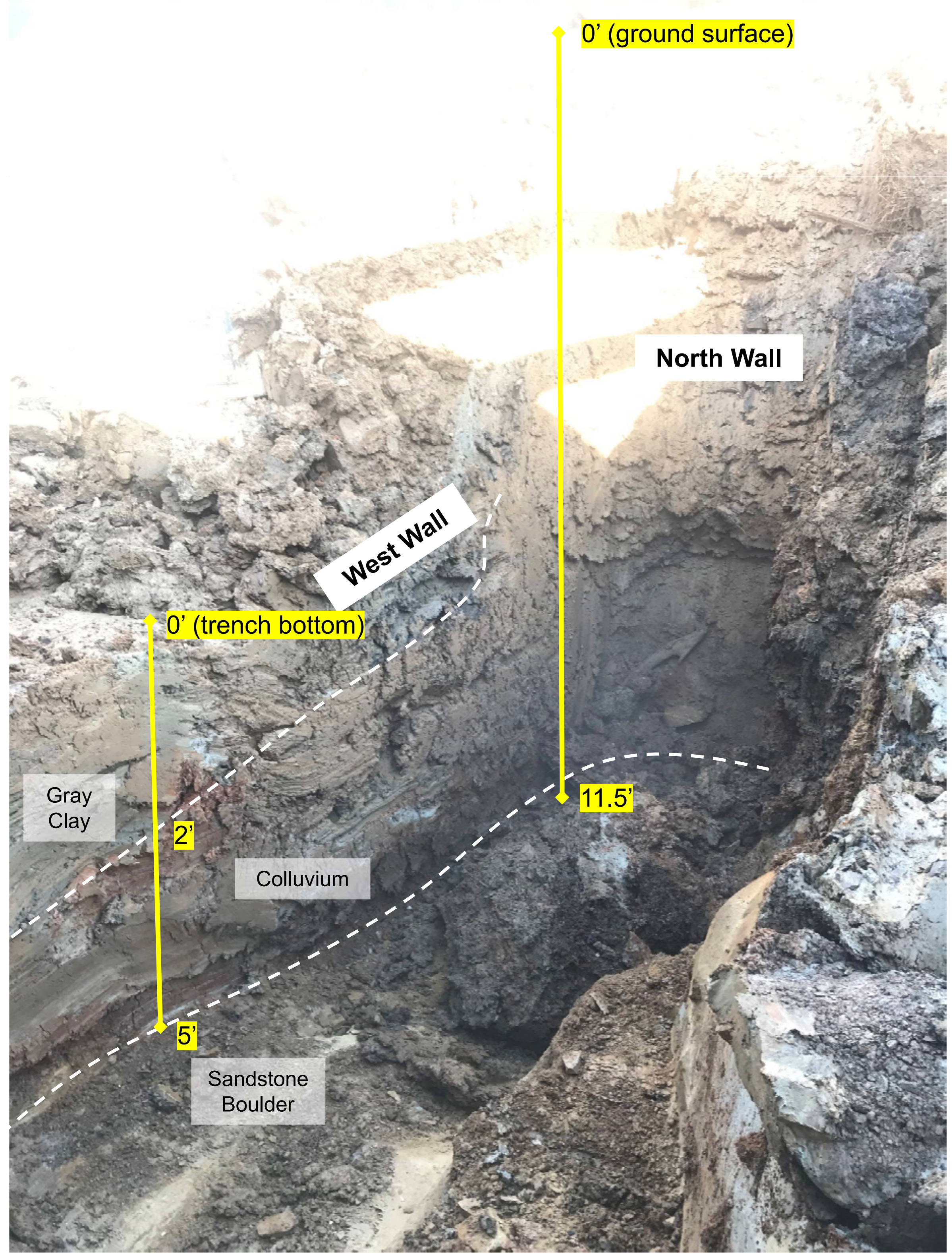
Feature	Depth (ft, from trench bottom)
Top of Red-Gray Gravelly Colluvium	**3**
Bottom of Excavation/top of Sandstone Boulders	5

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Test pits were excavated by Otis Eastern Service, LLC and logged by BGC.
3. All dimensions are in feet and are approximate. Depths were measured using a measuring tape or estimated using the excavator bucket and arm. TP-22 was excavated between trench boxes after the removal of Line 15; the elevation of the top of the test pit was approximately the bottom of Line 15.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY:	FIGURE TITLE		
WCD	TP 22 PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-28

0 5 10 mm in ANSI B sized paper

Test Pit 23: Sandstone floor for the entire bottom of excavation (interpreted as boulders). Refusal as the sandstone prevented further digging.



Feature	Depth (ft, from trench bottom)
Top of Colluvium	2
Bottom of Excavation/top of Sandstone Boulders	5 (11.5' from ground surface)

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Test pits were excavated by Otis Eastern Service, LLC and logged by BGC.
3. All dimensions are in feet and are approximate. Depths were measured using a measuring tape or estimated using the excavator bucket and arm. TP-23 was excavated between trench boxes after the removal of Line 15; the elevation of the top of the test pit was approximately the bottom of Line 15.
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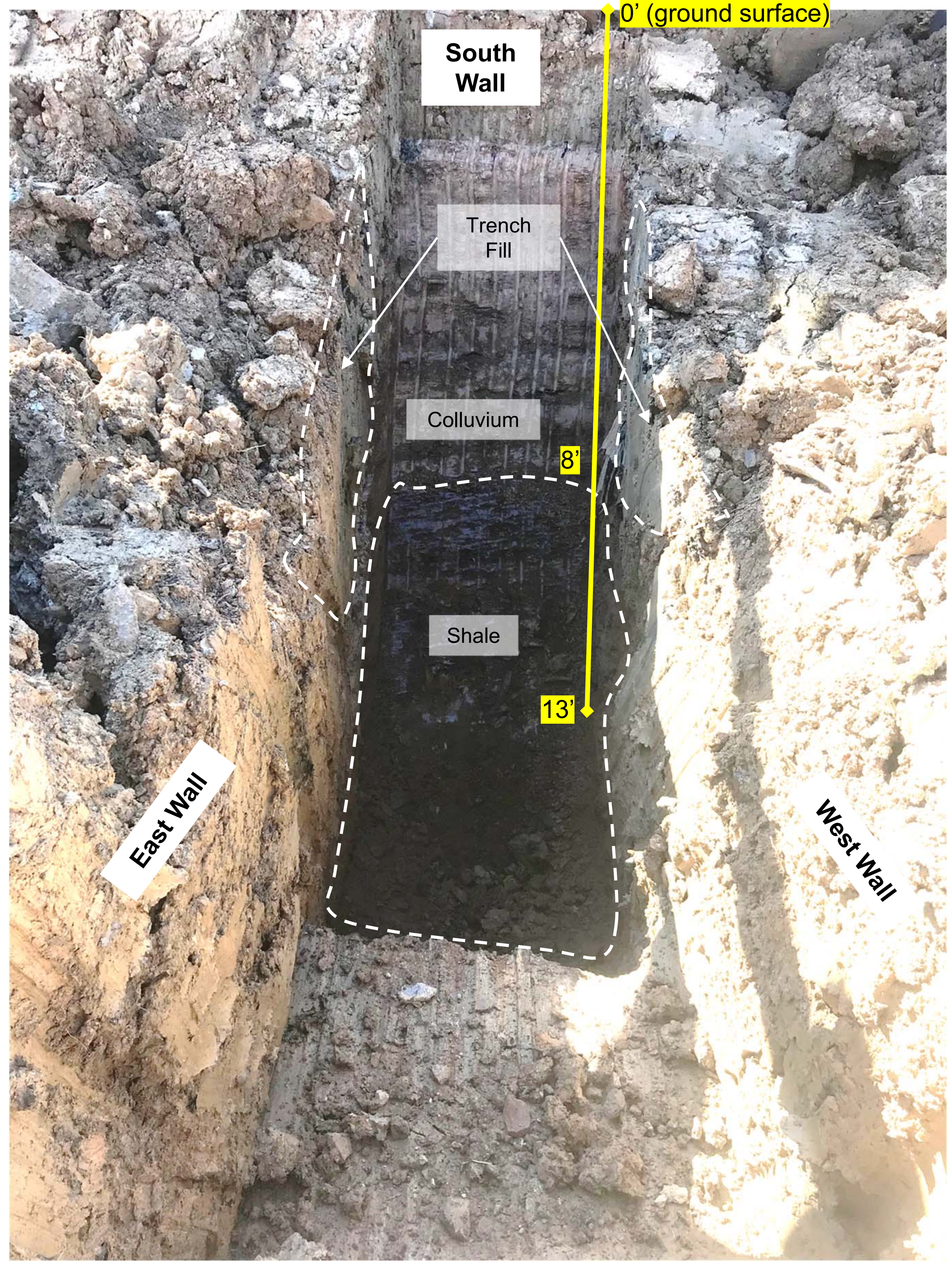
PREPARED BY: WCD	FIGURE TITLE: TP 23 PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-29

0 5 10 mm in ANSI B sized paper

Test Pit 24: Photo log looking south from the excavator. Shale-colluvium contact dives to the north and colluvium contains large sandstone boulders which caught on the excavator bucket near the end of digging.



Feature	Depth (ft, from ground surface)
Shale (Bedrock) Contact	8
Bottom of Excavation	13

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Test pits were excavated by Otis Eastern Service, LLC and logged by BGC.
3. All dimensions are in feet and are approximate. Depths were measured using a measuring tape or estimated using the excavator bucket and arm. TP-24 was excavated between trench boxes after the removal of Line 15; the elevation of the top of the test pit was approximately the bottom of Line 15.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: WCD	FIGURE TITLE: TP 24 PHOTO LOG		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: E-30

0 5 10 mm in ANSI B sized paper

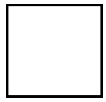
APPENDIX F
BOREHOLE LOGS

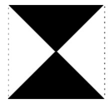
SYMBOLS AND TERMS

FOR SOIL DESCRIPTIONS ON LOGS

Project Name: May 4, 2020 Fleming County Incident Geotechnical Causation   Project Number: 1607.024

SAMPLE SYMBOLS


NO RECOVERY


SPT


CORE SAMPLE

CLASSIFICATION BY PARTICLE SIZE[1]

NAME	SIZE RANGE (mm) [2]	US STANDARD SIEVE SIZE Retained	US STANDARD SIEVE SIZE Passing
Boulders	>300	12 inch	-
Cobbles	75 - 300	3 inch	12 inch
Gravel:			
Coarse	19 - 75	0.75 inch	3 inch
Fine	5 - 19	No. 4	0.75 inch
Sand:			
Coarse	2 - 5	No. 10	No. 4
Medium	0.4 - 2	No. 40	No. 10
Fine	0.074 - 0.4	No. 200	No. 40
Fines (Silt or Clay)[3]	<0.074	-	No. 200

PROPORTION OF MINOR COMPONENTS BY WEIGHT

"and"	35% to 50%.
"y/ey"	20% to 35%
"Some"	10% to 20%
"Trace"	0% to 10%

PARTICLE SHAPE

Flat	Particles with width/thickness >3
Elongated	Particles with length/width >3
Flat and Elongated	Particles that meet both criteria

ANGULARITY

"Angular"	Particles have sharp edges and relatively planar sides with un-polished surfaces.
"Sub-angular"	Particles are similar to angular description but have some rounded edges.
"Sub-rounded"	Particles have nearly planar sides but have well rounded corners and edges.
"Rounded"	Particles have smoothly curved sides and no edges.

DENSITY OF GRANULAR SOILS

DESCRIPTION	SPT - "N"[4]	FIELD IDENTIFICATION
"Very Loose"	0-4	None
"Loose"	4-10	Easily penetrated by 13 mm rod by hand
"Compact"	10-30	Easily penetrated by 13 mm rod by hammer
"Dense"	30-50	Penetrated 0.3 m by 13 mm rod by hammer
"Very dense"	>50	Penetrated a ~cm by 13 mm rod by hammer

CONSISTENCY OF COHESIVE SOILS

DESCRIPTION	SPT- "N" [6,7]	UNDRAINED SHEAR STRENGTH - "S_u" kPa [5]	FIELD IDENTIFICATION
"Very soft"	<2	<12	Easily penetrated several cm by the fist.
"Soft"	2-4	12-25	Easily penetrated several cm by the thumb.
"Firm"	4-8	25-50	Can be penetrated several cm by the thumb with moderate ef-
"Stiff"	8-15	50-100	Readily indented by the thumb but penetrated only with great
"Very Stiff"	15-30	100-200	Readily indented by the thumb nail.
"Hard"	>30	>200	Indented with difficulty by the thumbnail.

(1) ASTM D2487-11, Unified Soil Classification System (USCS).
(2) Approximate metric conversion.
(3) Fines are classified as silt or clay on the basis of Atterberg limits (refer to Plasticity Chart).
(4) Standard Penetration Test (SPT) blow count uncorrected, after Terzaghi and Peck, 1948.
(5) Undrained shear strength can be estimated by vane (gives S_u), pocket penetrometer (gives unconfined compressive strength, i.e., 2 S_u), or unconfined compression test (gives 2 S_u).
(6) Approximate correlation with Standard Penetration Test blow counts, after Terzaghi and Peck, 1948.
(7) "R" represents sampler refusal during Standard Penetration Test.

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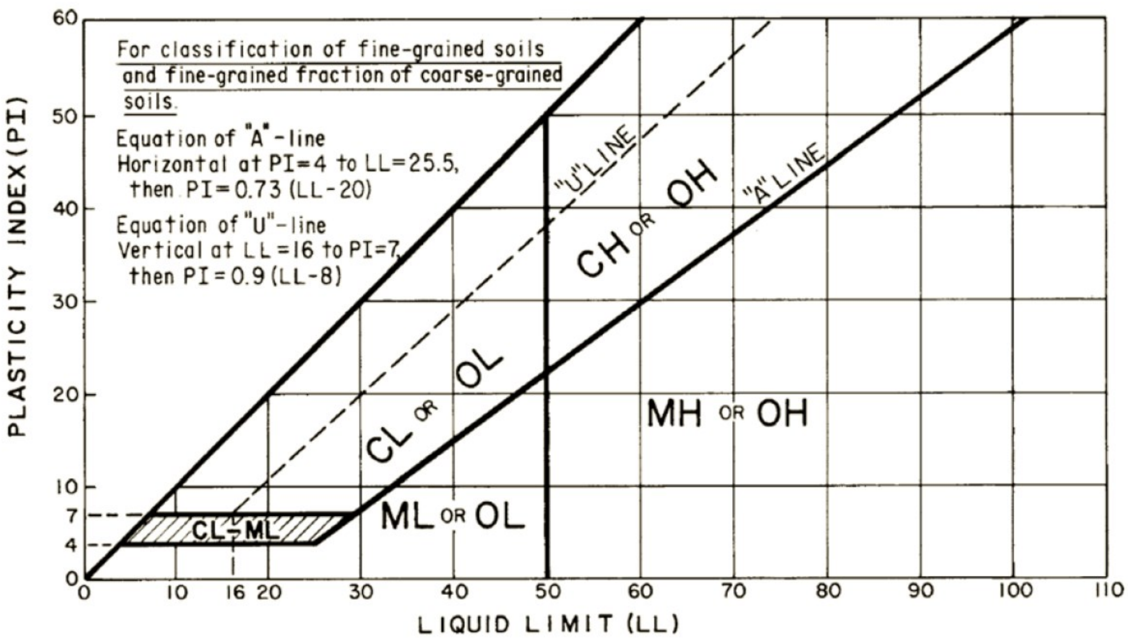
SYMBOLS AND TERMS

FOR SOIL DESCRIPTIONS ON LOGS

Project Name: May 4, 2020 Fleming County Incident Geotechnical Causation Project Number: 1607.024

PLASTICITY OF COHESIVE SOILS [9]			
DESCRIPTION	SILT	CLAY	CRITERIA
High	W_L[10] >50%	W_L >50%	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.
Low	W_L<50%	W_L<50%	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit.
Non-Plastic	NP	-	A 1/8 inch (3 mm) thread cannot be rolled at any water content.

PLASTICITY OF COHESIVE SOILS[10]



MOISTURE CONDITION [8]	
Description	Criteria
Dry	Absence of moisture
Moist	Damp but no visible water
Wet	Visible free water, usually soil is below water table

CEMENTATION [8]	
Description	Criteria
Weak	Crumbles or breaks with handling or little pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

DILATANCY[11]	
Description	Criteria
None	No visible change in the spec-men during shaking or squeezing
Slow	Water appears slowly on the surface of the specimen during shaking and dis-appears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

Notes:
(8) ASTM D2488-09a.
(9) This plasticity classification conforms to the Unified Soil Classification System (USCS) and to ASTM D-2487. Under ASTM and USCS, all clays with a liquid limit less than 50% are classified as low plasticity (CL).
(10) W_L = Liquid Limit (%)
(11) Test for dilatancy conducted by shaking and squeezing a moulded ball of soil that is 12 mm in diameter.
(12) Test for dry strength conducted on natural soil pieces or moulded balls about 25 mm in diameter that have been dried at less than 60°C.

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SYMBOLS AND TERMS

FOR SOIL DESCRIPTIONS ON LOGS

Project Name: May 4, 2020 Fleming County Incident Geotechnical Causation   Project Number: 1607.024

STRUCTURE	
Description	**Criteria**
Stratified	Alternating layers of varying material or colour with layers at least 6 mm thick; note thickness
Laminated	Alternating layers of varying material or colour with the layers less than 6 mm thick; note thickness
Fissured	Breaks along definite planes or fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	Same colour and appearance throughout
Heterogeneous	Colour and appearance vary throughout

IDENTIFICATION OF INORGANIC FINE-GRAINED SOILS FROM MANUAL TESTS		
Soil Symbol	**Dry Strength**	**Dilatancy**
ML	None to Low	Slow to Rapid
CL/CI	Medium to High	None to Slow
MH	Low to Medium	None to Slow
CH	High to Very High	None

DRY STRENGTH	
Description	**Criteria[12]**
None	The dry specimen crumbles into powder upon applying pressure or handling
Low	The dry specimen breaks into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface
Very High	The dry specimen cannot be broken between the thumb and a hard surface

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SYMBOLS AND TERMS

FOR GRAPHIC DESCRIPTIONS ON LOGS

Project Name: May 4, 2020 Fleming County Incident Geotechnical Causation   Project Number: 1607.024

Lithological Graphic Log Legend	
Bedrock	**Soil**
Shale	Clay

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SYMBOLS AND TERMS
FOR ROCK DESCRIPTIONS ON LOGS

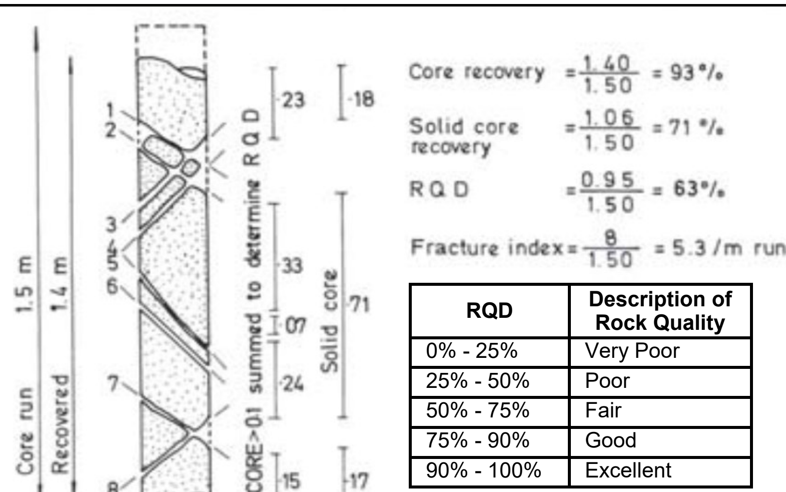
Project Name: May 4, 2020 Fleming County Incident Geotechnical Causation   Project Number: 1607.024

WEATHERING/ALTERATION [13]		
GRADE	**Description**	**Field Identification**
A/W 1	Fresh and Unweathered	No visible sign of rock material weathering
A/W 2	Slightly Weathered or Altered	Discolouration indicated weathering of rock material and discontinuity surfaces. All rock material may be discoloured by weathering and may be weaker than in its fresh condition.
A/W 3	Moderately Weathered or Altered	Less than 50% of rock material decomposed and/or disintegrated to soil. Fresh/ discoloured rock present as a continuous framework or corestones.
A/W 4	Highly Weathered or Altered	More than 50% rock material is decomposed or disintegrated to soil. Fresh/ Discoloured rock present as discontinuous framework or corestones.
A/W 5	Completely Weathered or Altered	All rock material decomposed and/or disintegrated to soil. Original mass structure still largely intact
A/W 6	Residual Soil	All rock material converted to soil; mass structure and material fabric destroyed.

HARDNESS CLASSIFICATION FOR ROCK [14]		
GRADE	**Description**	**Field Identification**
R6	Extremely Strong	Specimen can only be chipped with flat end of geological hammer
R5	Very Strong	Specimen requires many blows of flat end of geological hammer to fracture
R4	Strong	Specimen requires more than one blow of flat end of geological hammer to fracture
R3	Medium Strong	Cannot be scraped or peeled with pocket knife; can be fractured with single firm blow of flat end of the geologic hammer
R2	Weak	Can be peeled with pocket knife with difficulty; shallow indentation made by firm blow with point of geological hammer
R1	Very Weak	Crumbles under firm blow with point of geological hammer; can be peeled by a pocket knife
R0	Extremely Weak	Indented by thumbnail

JOINT CONDITION[15]	
Condition of Joints	**Rating**
Very rough surfaces. Not continuous. No separation. Hard joint wall rock.	25
Slightly rough surfaces. Separation <1mm. Hard joint wall rock.	20
Slightly rough surfaces. Separation <1mm. Soft joint wall rock.	12
Slickensided surfaces or gouge <5mm thick or joints open 1-5mm. Continuous joints.	6
Soft gouge >5mm thick or joints open >5mm. Continuous joints.	0

(13) After ISRM, 1981.
(14) ISRM, 1977
(15) Joint condition is a numerical index that summarizes the typical surface properties and infilling of discontinuities within an interval (Bieniawski, 1976).



RQD	Description of Rock Quality
0% - 25%	Very Poor
25% - 50%	Poor
50% - 75%	Fair
75% - 90%	Good
90% - 100%	Excellent

If strength grade ≤ R1, do not include in RQD.

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SYMBOLS AND TERMS

FOR ROCK DESCRIPTIONS ON LOGS

Project Name: May 4, 2020 Fleming County Incident Geotechnical Causation   Project Number: 1607.024

REFERENCES

American Society for Testing and Materials. Standard D2487-11: Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). West Conshohocken, PA.

American Society for Testing and Materials. Standard D2488-09a: Standard Practice for Description and Identification of Soils (Visual-Manual Procedure). West Conshohocken, PA.

Bieniawski, Z.T. 1976. Engineering classification of jointed rock masses. Trans South African Institute of Civil Engineers. 15, 335-344.

Canadian Geotechnical Society 2006. Canadian Foundation Engineering Manual 4th Edition. pp. 488.

International Society of Rock Mechanics (ISRM). 1977. International Society for Rock Mechanics Commission of Standardization of Laboratory and Field Tests: Suggested

Methods for the Quantitative Description of Discontinuities in Rock Masses. Committee on Field Tests, Document No. 4, pp. 319-368.

International Society of Rock Mechanics (ISRM). 1981. International Society for Rock Mechanics: Commission of Classification of Rocks and Rock Masses, Basic Geotechnical Description of Rock Masses. International Journal of Rock Mechanics, Mineral Science, and Geomechanics. Vol. 18, pp. 85-110.

Terzaghi, K., and Ralph B. Peck, 1948, Soil Mechanics in Engineering Practice, John Wiley and Sons, New York

Revision: May, 2015

Project: Fleming County Incident

DRILL HOLE # BH-01

Location : Fleming County Incident Site

Project No. : 1607024

Sampling Method : SPT	**Drill Designation** : CME-750	**Start Date** : 11 Jul 20
Co-ordinates : [redacted]	**Drilling Contractor** : GEOTILL	**Finish Date** : 11 Jul 20
Ground Elevation (ft) : 925	**Drill Method** : 4.25" HSA/NQ Core	**Final Depth of Hole (ft)** : 32.50
Datum : NAD 83 UTM Zone 17	**Core** : N/A	**Depth to Top of Rock (ft)** : 25.00
Dip (degrees from horizontal) : N/A	**Fluid** : Water	**Logged by** : WCD
Direction : N/A	**Casing** : N/A **Cased To (ft)** : N/A	**Reviewed by** : TM

Elevation (ft)	Depth (ft)	Sample Type	Sample No.	Symbol	Material Description	Instrument Details	SPT Blows per 6 inches	SPT N (blows/ft); Moisture Content W_P% W% W_L% (20 40 60 80)	Lab Tests and Comments
925 to 900	0 to 25.0				CLAY Gravelly, some sand, medium plasticity, stiff to very stiff, brown with occasional red and gray mottling, wetter than plastic limit, medium dry strength, no dilatency, subangular to angular gravel and cobbles composed of SHALE (moderately to completely weathered, extremely weak, gray to black, fissile) and SANDSTONE (moderately weathered, strong, gray to yellow-brown). [COLLUVIUM/FILL]				From 0.0 ft - Hollow Stem Auger Drilling
900 to 892.5	25.0 to 32.5	Core (28.0–32.5)			SHALE Highly to completely weathered, weak, gray to black, fine-grained, thinly bedded, highly carbonaceous. [OHIO SHALE] Between 25.0 to 28.0 ft - Harder for approximately 1 foot; black shale cuttings observed. Below 28.0 ft - moderately to slightly weathered, weak to medium strong, black, joints and bedding may be completely weathered to reddish-brown and gray clay.				From 28.0 ft - NQ Coring Core Run RQD = 82.4% UCS Test = 2930 psi
	32.5				End of borehole at 32.5 ft. Notes: 1) Drilling completed from surface to 32.5 ft using multiple methods noted in the comments. 2) No groundwater observed during drilling.				

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ENBRIDGE

Project: Fleming County Incident

DRILL HOLE # BH-02

Location : Fleming County Incident Site

Project No. : 1607024

Sampling Method : SPT
Co-ordinates : [redacted]
Ground Elevation (ft) : 925.6
Datum : NAD 83 UTM Zone 17
Dip (degrees from horizontal) : N/A
Direction : N/A

Drill Designation : CME-750
Drilling Contractor : GEOTILL
Drill Method : 4.25" HSA/NQ Core
Core : N/A
Fluid : Water
Casing : N/A **Cased To (ft)** : N/A

Start Date : 11 Jul 20
Finish Date : 11 Jul 20
Final Depth of Hole (ft) : 39.08
Depth to Top of Rock (ft) : 24.00
Logged by : WCD
Reviewed by : TM

Elevation (ft)	Depth (ft)	Sample Type	Sample No.	Symbol	Material Description	Instrument Details	SPT Blows per 6 inches	SPT N (blows/ft) / Moisture Content W_P% W% W_L% (20 40 60 80)	Lab Tests and Comments
925.6–902	0–24				CLAY Gravelly, some sand, medium plasticity, stiff to very stiff, brown with occasional red and gray mottling, wetter than plastic limit, medium dry strength, no dilatency, subangular to angular gravel to boulders composed of SHALE (moderately to completely weathered, extremely weak, gray to black, fissile) and SANDSTONE (moderately weathered, strong, gray to yellow-brown). [COLLUVIUM/FILL]				From 0.0 ft - Hollow Stem Auger Drilling
903–886.5	22–39.1	Core			SHALE Slightly weathered, weak to medium strong, black, fine-grained, thinly bedded, highly carbonaceous, completely weathered on some joints and bedding planes to reddish-brown and gray clay. [OHIO SHALE]				From 24.0 ft - NQ Coring UCS Test = 5610 psi Core Run RQD = 52.2% UCS Test = 2600 psi
	~33.1				From 33.1 ft - Core dropped during extraction from the core barrel. No RQD recorded.				Core Run RQD not collected - Core dropped during extraction.
	39.1				End of borehole at 39.1 ft.				

(Continued on next page)

Project: Fleming County Incident

DRILL HOLE # BH-02

Location : Fleming County Incident Site

Project No. : 1607024

Sampling Method : SPT
Co-ordinates : [redacted]
Ground Elevation (ft) : 925.6
Datum : NAD 83 UTM Zone 17
Dip (degrees from horizontal) : N/A
Direction : N/A

Drill Designation : CME-750
Drilling Contractor : GEOTILL
Drill Method : 4.25" HSA/NQ Core
Core : N/A
Fluid : Water
Casing : N/A **Cased To (ft)** : N/A

Start Date : 11 Jul 20
Finish Date : 11 Jul 20
Final Depth of Hole (ft) : 39.08
Depth to Top of Rock (ft) : 24.00
Logged by : WCD
Reviewed by : TM

Elevation (ft)	Depth (ft)	Sample Type	Sample No.	Symbol	Material Description	Instrument Details	SPT Blows per 6 inches	● SPT N (blows/ft) / Moisture Content W_P% W% W_L% (20 40 60 80)	Lab Tests and Comments
884, 882, 880, 878, 876, 874, 872, 870, 868, 866, 864, 862, 860, 858, 856, 854, 852, 850, 848, 846	40, 42, 44, 46, 48, 50, 52, 54, 56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80				Notes: 1) Drilling from surface to 39.1 ft using multiple methods noted in the comments. 2) No groundwater observed during drilling.				

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ENBRIDGE

Project: Fleming County Incident

DRILL HOLE # BH-03

Location : Fleming County Incident Site

Project No. : 1607024

Sampling Method : SPT
Co-ordinates : [redacted]
Ground Elevation (ft) : 925.6
Datum : NAD 83 UTM Zone 17
Dip (degrees from horizontal) : N/A
Direction : N/A

Drill Designation : CME-750
Drilling Contractor : GEOTILL
Drill Method : 4.25" HSA/NQ Core
Core : N/A
Fluid : Water
Casing : N/A **Cased To (ft)** : N/A

Start Date : 11 Jul 20
Finish Date : 11 Jul 20
Final Depth of Hole (ft) : 28.00
Depth to Top of Rock (ft) : 22.71
Logged by : WCD
Reviewed by : TM

Depth (ft)	Material Description	SPT Blows per 6 inches	Lab Tests and Comments
0	CLAY Gravelly, some sand, medium plasticity, stiff to very stiff, brown with occasional red and gray mottling, wetter than plastic limit, medium dry strength, no dilatency, subangular to angular gravel to boulders composed of SHALE (moderately to completely weathered, extremely weak, gray to black, fissile) and SANDSTONE (moderately weathered, strong, gray to yellow-brown). [COLLUVIUM/FILL]		From 0.0 ft - Hollow Stem Auger Drilling
22.5	At 22.5 ft - 2.5 inches of SANDSTONE, highly weathered, weak, yellowish-brown, fine-grained; observed as angular gravel.	13 64/5"	From 22 ft - Hollow Stem Auger Drilling - SPT Sampling From 23.0 ft - NQ Coring
	SHALE Moderately to completely weathered, weak to medium strong, gray to black, fine-grained, thinly bedded, highly carbonaceous, and jointed at fresh exposures, completely weathered shale is gray to reddish-brown clay with silt. [OHIO SHALE}		Core Run RQD = 9.2%
28.0	End of borehole at 28.0 ft.		

Elevation scale (ft): 924, 922, 920, 918, 916, 914, 912, 910, 908, 906, 904, 902, 900, 898, 896, 894, 892, 890, 888, 886
Depth scale (ft): 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40

Other column headings: Sample Type, Sample No., Symbol, Instrument Details; ● SPT N (blows/ft); Moderately Content: W_P% W% W_L% — 20 40 60 80

Notes:
1) Drilling from surface to 28.0 ft using multiple drilling methods noted in the comments.
2) No groundwater observed during drilling.

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ENBRIDGE

Project: Fleming County Incident

DRILL HOLE # BH-04

Location : Fleming County Incident Site

Project No. : 1607024

Sampling Method : SPT
Co-ordinates : [redacted]
Ground Elevation (ft) : 926.1
Datum : NAD 83 UTM Zone 17
Dip (degrees from horizontal) : N/A
Direction : N/A

Drill Designation : CME-750
Drilling Contractor : GEOTILL
Drill Method : 4.25" HSA/NQ Core
Core : N/A
Fluid : Water
Casing : N/A **Cased To (ft)** : N/A

Start Date : 11 Jul 20
Finish Date : 12 Jul 20
Final Depth of Hole (ft) : 28.42
Depth to Top of Rock (ft) : 23.08
Logged by : WCD
Reviewed by : TM

Elevation (ft)	Depth (ft)	Material Description	SPT Blows per 6 inches	SPT N (blows/ft)	Lab Tests and Comments
926	0	CLAY Gravelly, some sand, medium plasticity, stiff to very stiff, brown with occasional red and gray mottling, wetter than plastic limit, medium dry strength, no dilatency, subangular to angular gravel to boulders composed of SHALE (moderately to completely weathered, extremely weak, gray to black, fissile) and SANDSTONE (moderately weathered, strong, gray to yellow-brown). [COLLUVIUM/FILL]			From 0.0 ft - Hollow Stem Auger Drilling
907.1	19	From 19.0 to 20.0 ft - SANDSTONE, moderately weathered, medium strong, yellowish-brown to light gray, fine-grained, massive, quartzose. Observed as well graded gravel.	6 33 49 27 10 26 50/5"	● (≈80+)	From 19.0 ft - NQ Coring Core Run RQD = 100.0% From 20.0 ft - Hollow Stem Auger Drilling - SPT Sampling
903.0	23.08	SHALE Slightly weathered, weak to medium strong, black, fine-grained, thinly bedded, highly carbonaceous, completely weathered at some joints and bedding planes to a reddish-brown and gray clay. [OHIO SHALE] At 24.0 ft - Completely weathered shale as gray to reddish-brown clay. At 25.0 ft - Completely weathered shale as gray to reddish-brown clay.			from 23.4 ft - NQ Coring Core Run RQD = 51.0%
897.7	28.4	End of borehole at 28.4 ft.			

Notes:
1) Drilling completed from surface to 28.4 ft using multiple methods noted in the comments.
2) No groundwater observed during drilling.

Moisture Content: W_P% — W% — W_L% (20, 40, 60, 80)

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DRILL HOLE # BH-05

Project: Fleming County Incident

Location : Fleming County Incident Site

Project No. : 1607024

Sampling Method : SPT
Co-ordinates : [redacted]
Ground Elevation (ft) : 927.1
Datum : NAD 83 UTM Zone 17
Dip (degrees from horizontal) : N/A
Direction : N/A

Drill Designation : CME-750
Drilling Contractor : GEOTILL
Drill Method : 4.25" HSA/NQ Core
Core : N/A
Fluid : Water
Casing : N/A **Cased To (ft)** : N/A

Start Date : 12 Jul 20
Finish Date : 12 Jul 20
Final Depth of Hole (ft) : 30.00
Depth to Top of Rock (ft) : 23.42
Logged by : WCD
Reviewed by : TM

Depth (ft)	Material Description	SPT Blows per 6 inches	Lab Tests and Comments
0	CLAY Gravelly, some sand, medium plasticity, stiff to very stiff, gray to reddish-brown, wetter than plastic limit, medium dry strength, no dilatency, subangular to angular gravel to boulders composed of SHALE (moderately to completely weathered, extremely weak, gray to black, fissile) and SANDSTONE (moderately weathered, strong, gray to yellow-brown). [COLLUVIUM/FILL]		From 0.0 ft - Hollow Stem Auger Drilling
18	From 18.9 to 19.3 ft - Sandstone clast. From 20.4 to 20.6 ft - Sandstone clast. From 21.4 to 21.8 ft - Sandstone clast. From 22.8 to 23.0 ft - Sandstone clast.	19, 27, 14, 17, 20, 14, 18, 32, 14, 46, 50/5", 26, 50/4"	From 18.0 ft - Hollow Stem Auger Drilling - SPT Sampling
23.4	SHALE Highly weathered, weak, gray, fine-grained, thinly bedded, fissile. [OHIO SHALE] From 24.2 ft to 24.3 ft - Sandstone clasts. Below 25.0 ft - Moderately to slightly weathered, weak to medium strong, black.		From 25.0 ft - NQ Coring Core Run RQD = 54.5%
30	End of borehole at 30.0 ft. Notes: 1) Drilling completed from surface to 30.0 ft using multiple drilling methods noted in the comments. 2) No groundwater observed during drilling.		

Elevation (ft): 926 to 888; Depth (ft): 0 to 40

SPT N (blows/ft); Moisture Content W_P% W% W_L% (20, 40, 60, 80)

ENBRIDGE (SOILONLY) - US FEET ENBRIDGE_SOIL&ROCK.GDL BGC.GDT ENBRIDGE.GLB 2/22/21

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ENBRIDGE

DRILL HOLE # BH-06

Project: Fleming County Incident

Location : Fleming County Incident Site

Project No. : 1607024

Sampling Method : SPT
Co-ordinates : [redacted]
Ground Elevation (ft) : 933.6
Datum : NAD 83 UTM Zone 17
Dip (degrees from horizontal) : N/A
Direction : N/A

Drill Designation : CME-750
Drilling Contractor : GEOTILL
Drill Method : 4.25" HSA/NQ Core
Core : N/A
Fluid : Water
Casing : N/A **Cased To (ft)** : N/A

Start Date : 13 Jul 20
Finish Date : 13 Jul 20
Final Depth of Hole (ft) : 22.92
Depth to Top of Rock (ft) : 16.00
Logged by : WCD
Reviewed by : TM

Elevation (ft)	Depth (ft)	Material Description	SPT Blows per 6 inches	Lab Tests and Comments
933.6	0	CLAY Gravelly, some sand, medium plasticity, stiff to very stiff, gray to reddish-brown, wetter than plastic limit, medium dry strength, no dilatency, subangular to angular gravel to boulders composed of SHALE (moderately to completely weathered, extremely weak, gray to black, fissile) and SANDSTONE (moderately weathered, strong, gray to yellow-brown). [COLLUVIUM/FILL]		From 0.0 ft - Hollow Stem Auger Drilling
	9.0	From 9.0 to 9.4 ft - Yellowish-brown sandstone boulder. From 9.5 ft to 10.0 ft - Material lost during drilling.		From 9.0 ft - NQ Coring Core Run RQD = 100.0%
	10.0		4 6 12 17 9 11 9 8 4 7 8 12 11 15 21 50/5"	From 10.0 ft - Hollow Stem Auger Drilling - SPT Sampling
	16.0	SHALE Highly weathered, weak, gray, fine-grained, thinly bedded, fissile. [OHIO SHALE] From 17.6 ft - Moderately to slightly weatered, weak to medium strong, black.		From 17.9 ft - NQ Coring Core Run RQD = 74.0%
	22.9	End of borehole at 22.9 ft.		

Notes:
1) Drilling completed from surface to 22.9 ft using multiple drilling methods noted in the comments.
2) No groundwater observed during drilling.

SPT N (blows/ft); Moisture Content W_P% W% W_L%; 20 40 60 80

DRILL HOLE # BH-07

Project: Fleming County Incident

Location : Fleming County Incident Site

Project No. : 1607024

Sampling Method : SPT
Co-ordinates : [redacted]
Ground Elevation (ft) : 927.3
Datum : NAD 83 UTM Zone 17
Dip (degrees from horizontal) : N/A
Direction : N/A

Drill Designation : CME-750
Drilling Contractor : GEOTILL
Drill Method : 4.25" HSA/NQ Core
Core : N/A
Fluid : Water
Casing : N/A **Cased To (ft)** : N/A

Start Date : 13 Jul 20
Finish Date : 13 Jul 20
Final Depth of Hole (ft) : 25.42
Depth to Top of Rock (ft) : 20.25
Logged by : WCD
Reviewed by : TM

Depth (ft)	Material Description	SPT Blows per 6 inches	Lab Tests and Comments
0	CLAY Gravelly, some sand, medium plasticity, stiff to very stiff, gray to reddish-brown, wetter than plastic limit, medium dry strength, no dilatency, subangular to angular gravel to boulders composed of SHALE (moderately to completely weathered, extremely weak, gray to black, fissile) and SANDSTONE (moderately weathered, strong, gray to yellow-brown). [COLLUVIUM/FILL]		From 0.0 ft - Hollow Stem Auger Drilling
19.0	At 19.0 ft - Harder material.	8 12 50/5"	From 19.0 ft - Hollow Stem Auger Drilling - SPT Sampling From 20.4 ft - NQ Coring
20.25	SHALE Highly weathered,weak, gray, fine-grained, thinly bedded. [OHIO SHALE] Below 20.4 ft - Slightly weathered, medium strong, black.		UCS Test = 5740 psi Core Run RQD = 81.6%
25.4	End of borehole at 25.4 ft. Notes: 1) Drilling completed from surface to 25.4 ft using multiple drilling methods as noted in the comments. 2) No groundwater observed during drilling.		

Column headings: Elevation (ft) | Depth (ft) | Sample Type | Sample No. | Symbol | Material Description | Instrument Details | SPT Blows per 6 inches | SPT N (blows/ft); Moisture Content W_P% W% W_L% (20 40 60 80) | Lab Tests and Comments

Elevation scale: 926 to 888; Depth scale: 0 to 40.

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Project: Fleming County Incident

DRILL HOLE # BH-08

Location : Fleming County Incident Site

Project No. : 1607024

Sampling Method : SPT
Co-ordinates : [redacted]
Ground Elevation (ft) : 929.3
Datum : NAD 83 UTM Zone 17
Dip (degrees from horizontal) : N/A
Direction : N/A

Drill Designation : CME-750
Drilling Contractor : GEOTILL
Drill Method : 4.25" HSA/NQ Core
Core : N/A
Fluid : Water
Casing : N/A **Cased To (ft)** : N/A

Start Date : 12 Jul 20
Finish Date : 12 Jul 20
Final Depth of Hole (ft) : 28.00 → 32.67
Depth to Top of Rock (ft) : 28.00
Logged by : WCD
Reviewed by : TM

Elevation (ft)	Depth (ft)	Sample Type	Sample No.	Symbol	Material Description	Instrument Details	SPT Blows per 6 inches	SPT N (blows/ft) / Moisture Content W_P% W% W_L% (20 40 60 80)	Lab Tests and Comments
929.3–901.3	0–28				CLAY Gravelly, some sand, medium plasticity, stiff to very stiff, gray to reddish-brown, wetter than plastic limit, medium dry strength, no dilatency, subangular to angular gravel to boulders composed of SHALE (moderately to completely weathered, extremely weak, gray to black, fissile) and SANDSTONE (moderately weathered, strong, gray to yellow-brown). [COLLUVIUM/FILL]				From 0.0 ft - Hollow Stem Auger Drilling
901.3–896.6	28–32.7	Core			SHALE Slightly weathered, weak, black, fine-grained, thinly bedded, fissile with some rubbly areas. [OHIO SHALE] At 28.0 ft - Harder material.				From 28.0 ft - NQ Coring Core Run RQD = 23.0%
					End of borehole at 32.7 ft. Notes: 1) Drilling completed from surface to 32.7 ft using multiple drilling methods noted in the comments. 2) No groundwater observed during drilling.				

Elevation scale: 928, 926, 924, 922, 920, 918, 916, 914, 912, 910, 908, 906, 904, 902, 900, 898, 896, 894, 892, 890
Depth scale: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40

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ENBRIDGE

Project: Fleming County Incident

DRILL HOLE # BH-09

Location : Fleming County Incident Site

Project No. : 1607024

Sampling Method : SPT
Co-ordinates : [redacted]
Ground Elevation (ft) : 931.4
Datum : NAD 83 UTM Zone 17
Dip (degrees from horizontal) : N/A
Direction : N/A

Drill Designation : CME-750
Drilling Contractor : GEOTILL
Drill Method : 4.25" HSA/NQ Core
Core : N/A
Fluid : Water
Casing : N/A **Cased To (ft)** : N/A

Start Date : 12 Jul 20
Finish Date : 12 Jul 20
Final Depth of Hole (ft) : 33.00
Depth to Top of Rock (ft) : 28.00
Logged by : WCD
Reviewed by : TM

Elevation (ft)	Depth (ft)	Sample Type	Sample No.	Symbol	Material Description	Instrument Details	SPT Blows per 6 inches	● SPT N (blows/ft); Moisture Content W_P% W% W_L% (20 40 60 80)	Lab Tests and Comments
931.4	0				CLAY Gravelly, some sand, medium plasticity, stiff to very stiff, gray to reddish-brown, wetter than plastic limit, medium dry strength, no dilatency, subangular to angular gravel to boulders composed of SHALE (moderately to completely weathered, extremely weak, gray to black, fissile) and SANDSTONE (moderately weathered, strong, gray to yellow-brown). [COLLUVIUM/FILL]				From 0.0 ft - Hollow Stem Auger Drilling
	12.5	Core			From 12.5 to 13.8 ft - SANDSTONE, moderately weathered, medium strong, yellowish-brown to light gray, fine-grained, massive, quartzose				From 12.5 ft - NQ Coring Core Run RQD = 100.0%
	16.0	Core			From 16.0 to 16.5 ft - SANDSTONE, moderately weathered, medium strong, yellowish-brown to light gray, fine-grained, massive, quartzose				Core Run RQD = 100.0% from 16.5 ft - Hollow Stem Auger Drilling - SPT Sampling
903.4	28.0	Core			SHALE Slightly weathered, weak, black, fine-grained, thinly bedded, fissile. [OHIO SHALE] At 28.0 ft - Harder drilling.				From 28.0 ft - NQ Coring Core Run RQD = 35.9% UCS Test = 6010 psi
898.4	33.0				End of borehole at 33.0 ft. Notes: 1) Drilling completed from surface to 33.0 ft using multiple drilling methods noted in the comments. 2) No groundwater observed during drilling.				

Project: Fleming County Incident

DRILL HOLE # BH-10

Location : Fleming County Incident Site

Project No. : 1607024

Sampling Method : SPT	***Drill Designation*** : CME-750	***Start Date*** : 13 Jul 20
Co-ordinates : [redacted]	***Drilling Contractor*** : GEOTILL	***Finish Date*** : 13 Jul 20
Ground Elevation (ft) : 931.1	***Drill Method*** : 4.25" HSA/NQ Core	***Final Depth of Hole (ft)*** : 21.67
Datum : NAD 83 UTM Zone 17	***Core*** : N/A	***Depth to Top of Rock (ft)*** : 15.58
Dip (degrees from horizontal) : N/A	***Fluid*** : Water	***Logged by*** : WCD
Direction : N/A	***Casing*** : N/A ***Cased To (ft)*** : N/A	***Reviewed by*** : TM

Elevation (ft)	Depth (ft)	Sample Type	Sample No.	Symbol	Material Description	Instrument Details	SPT Blows per 6 inches	SPT N (blows/ft) / Moisture Content (W_P% W% W_L%; 20 40 60 80)	Lab Tests and Comments
931.1–915.5	0–15.6	Core (11.4–13.4), SPT (13.4–15.6)		Hatched	CLAY Gravelly, some sand, medium plasticity, stiff to very stiff, gray to reddish-brown, wetter than plastic limit, medium dry strength, no dilatency, subangular to angular gravel to boulders composed of SHALE (moderately to completely weathered, extremely weak, gray to black, fissile) and SANDSTONE (moderately weathered, strong, gray to yellow-brown). [COLLUVIUM/FILL] From 11.4 to 11.8 ft - Sandstone clast. From 13.2 to 13.7 ft - Sandstone clast.		5 5 7 13 37 40/5"	●	From 0.0 ft - Hollow Stem Auger Drilling From 11.4 ft - NQ Coring Core Run: Mix of colluvium and sandstone, no RQD reported. From 13.4 ft - Hollow Stem Auger Drilling - SPT Sampling
915.5–909.4	15.6–21.7	SPT, Core (17.0–21.7)		Hatched	SHALE Moderately weathered, weak, black, fine-grained, thinly bedded, fissile. [OHIO SHALE] From 16.3 to 17.0 ft - Material not recovered.				From 16.3 ft - Hollow Stem Auger Drilling From 17.0 ft - NQ Coring UCS Test = 360 psi Core Run RQD = 17.0%
	21.7				End of borehole at 21.7 ft. Notes: 1) Drilling completed from surface to 21.7 ft using multiple drilling methods noted in the comments. 2) No groundwater observed during drilling.				

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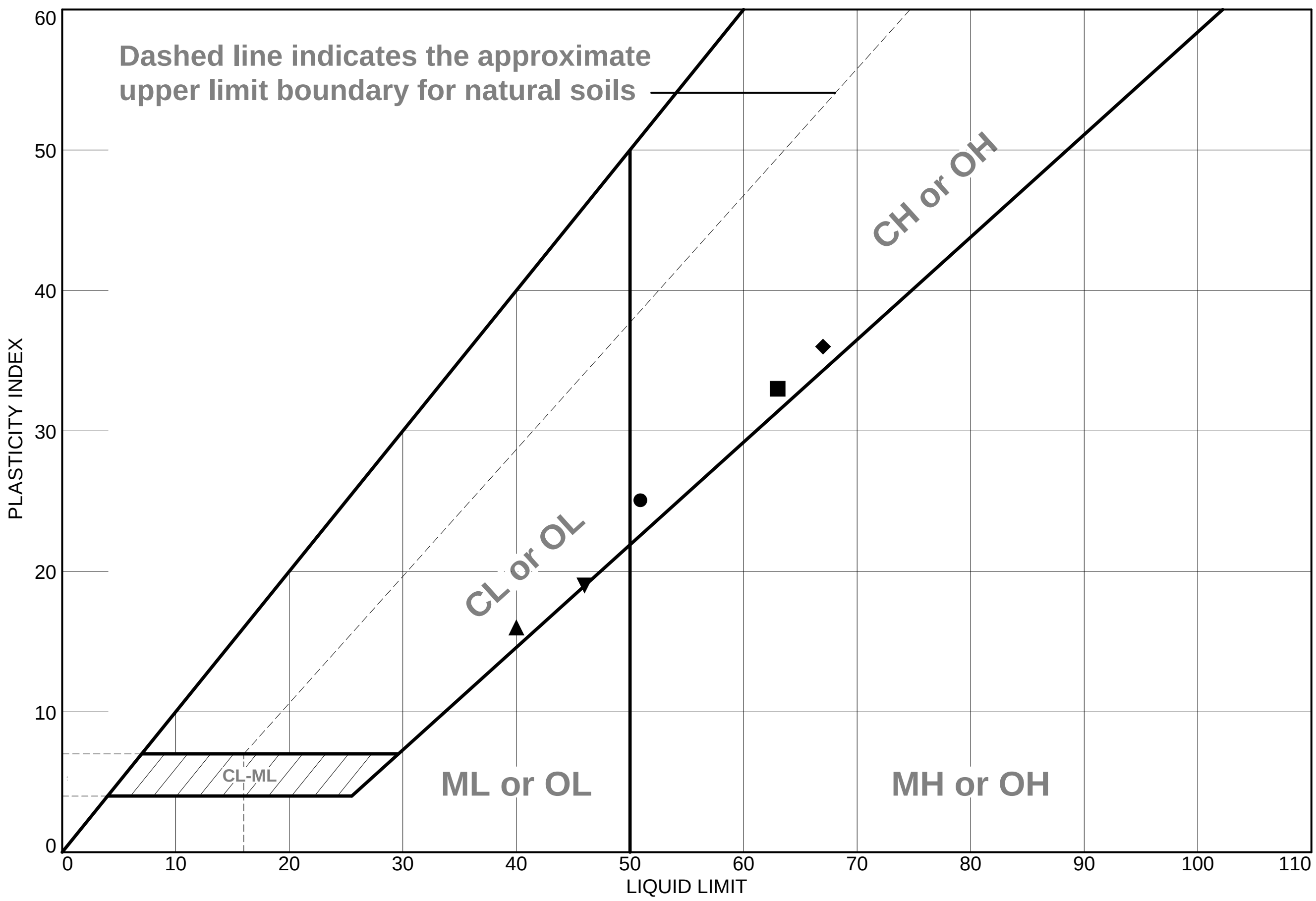
ENBRIDGE

Table F-1 Shape Accel Array and Slope Inclinometer Borehole Summary

Borehole ID	Northing UTM Zone 17 (ft)	Easting UTM Zone 17 (ft)	Ground Elevation (ft)	Total Inclinometer Casing Depth (ft)	Bottom Inclinometer Casing Elevation	Depth of Bedrock (ft)	Bedrock Elevation (ft)	Top of Casing Elevation (ft)	Total Casing Length (ft)	Inclinometer Casing Diameter (in)	SAA Extension Rod Length (ft)	X+ (A0) Azimuth (degrees)	Slip Plane Elevation (ft)	Date Drilling Completed	Location Description	Notes
SAA-01	[redacted]	[redacted]	937.3	48.3	889.0	28	909.3	939.222	50.2	3.34	3.44	281	n/a	2020-08-27	Downslope of bridge center	2 VWPs installed alongside casing: 2021562 @ 23.0 ft from casing bottom; 2021558 @ 31.0 ft from casing
SAA-02	[redacted]	[redacted]	928.7	48.1	880.6	28	900.7	930.801	50.2	3.34	3.44	278	908.5	2020-08-25	Downslope of southwest bridge abutment	2 VWPs installed alongside casing: 2021561 @ 23.0 ft from casing bottom; 2021564 @ 33.0 ft from casing
SAA-03	[redacted]	[redacted]	897.1	41.6	855.5	35.5	861.6	898.737	43.25	3.34	6.07	245	877.9	2020-07-27	Slide mass, center north	
SAA-04	[redacted]	[redacted]	891.8	38.0	853.9	17	874.8	894.106	40.2	3.34	3.28	246	884.3	2020-07-29	Slide mass, center south	
SAA-05	[redacted]	[redacted]	869.4	48.3	821.1	43	826.4	871.325	50.2	3.34	3.41	233	851.5	2020-08-02	Slide mass, bottom bench	
SAA-06	[redacted]	[redacted]	925.2	48.8	876.5	31	894.2	926.675	50.2	3.34	3.44	268	907.7	2002-07-30	Slide mass, near head	SAA-06 was decomissioned on 8/27/20 and the instrument was installed in SAA-01
SAA-07	[redacted]	[redacted]	945.7	28.7	917.0	14	931.7	947.196	30.2	3.34	1.48	259	n/a	2020-08-27	Downslope of northeast bridge abutment	
SAA-08	[redacted]	[redacted]	934.9	17.9	917.0	8	926.9	937.205	20.2	3.34	1.28	261	n/a	2020-08-19	Uplsope of southwest bridge abutment	
SAA-09	[redacted]	[redacted]	949.6	17.4	932.2	8.25	941.4	952.394	20.2	3.34	1.28	287	n/a	2020-08-20	Uplsope of northeast bridge abutment	
SAA-10	[redacted]	[redacted]	979.4	18.9	960.5	10	969.4	980.728	20.2	3.34	1.18	263	n/a	2020-08-21	Southeast of Line 25, upslope of bridge	
SAA-11	[redacted]	[redacted]	974.9	19.1	955.8	7	967.9	975.968	20.2	3.34	1.08	247	n/a	2020-08-28	Northwest of Line 10, upslope of bridge	
SAA-12	[redacted]	[redacted]	931.1	17.6	913.5	10.5	920.6	933.704	20.2	3.34	1.28	301	n/a	2020-08-19	Between Line 15 and 25, southwest of southwest bridge abutment	
SAA-13	[redacted]	[redacted]	957.9	28.7	929.2	11.5	946.4	959.37	30.2	3.34	1.35	252	n/a	2020-08-28	Northwest of Line 10, upslope of bridge	
INC-14	[redacted]	[redacted]	834.6	44.3	790.3	42	792.6	836.898	46.6	2.75	n/a	235	818.9	2020-09-04	Downslope of landslide toe	
INC-15	[redacted]	[redacted]	828.7	29.6	799.1	19.5	809.2	831.3	32.25	2.75	n/a	276	819.3	2020-09-03	Downslope of landslide toe	
BH-16	[redacted]	[redacted]	839.5	34.8	804.8	29	810.5	n/a	n/a	n/a	n/a	n/a	n/a	2020-09-02	Downslope of landslide toe	
BH-17	[redacted]	[redacted]	843.8	40.5	803.3	36	807.8	n/a	n/a	n/a	n/a	n/a	n/a	2020-09-03	Downslope of landslide toe	
BH-18	[redacted]	[redacted]	840.0	30.3	809.7	23	817.0	n/a	n/a	n/a	n/a	n/a	n/a	2020-09-03	Downslope of landslide toe	

APPENDIX G
SOIL LABORATORY TESTING RESULTS

LIQUID AND PLASTIC LIMITS TEST REPORT



	Material Description	Sampled	Tested	Technician	LL	PL	PI	%<#40	USCS
●	Gravelly Fat Clay (CH)	5/12/20	6/6/20	B. DAVENPORT	51	26	25	66.0	CH
■	Gravelly Fat Clay (CH)	5/12/20	6/6/20	B. DAVENPORT	63	30	33	58.6	CH
▲	Lean Clay with Gravel (CL)	5/12/20	6/6/20	B. DAVENPORT	40	24	16	73.1	CL
◆	Fat Clay (CH)	5/12/20	6/6/20	B. DAVENPORT	67	31	36	91.7	CH
▼	Lean Clay with Sand (CL)	5/12/20	6/6/20	B. DAVENPORT	46	27	19	83.5	CL

Project No. 17052 **Client:** CODY DUCKWORTH

Project: FLEMING COUNTY INCIDENT

○ **Location:** BGC - 01 **Sample Number:** 21781

□ **Location:** BGC - 02 **Sample Number:** 21782

△ **Location:** BGC - 03 **Sample Number:** 21783

◇ **Location:** BGC - 04 **Sample Number:** 21784

▽ **Location:** BGC - 05 **Sample Number:** 21785

L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

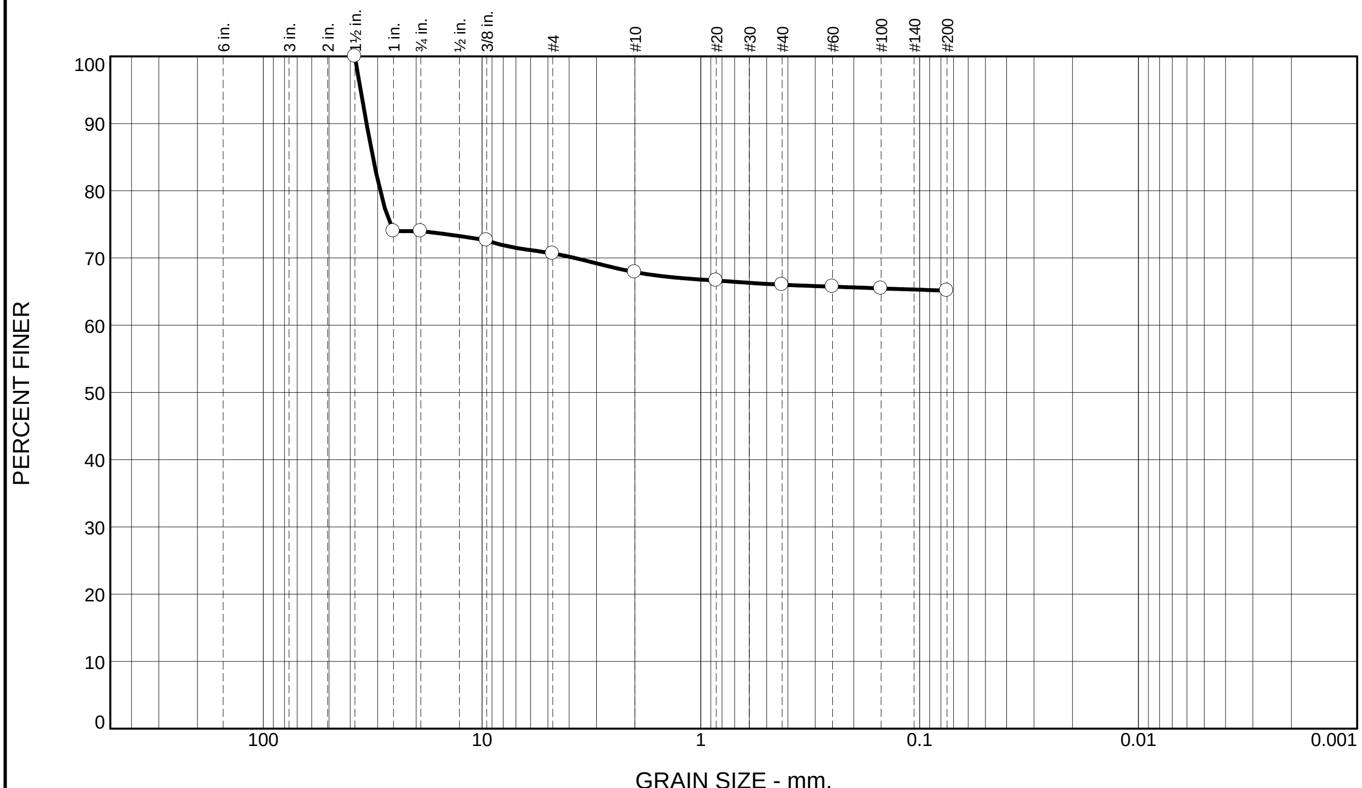
Checked by: S. MORTIMER

Title: GEOTECHNICAL ENGINEER

Figure

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	26.0	3.3	2.8	1.9	0.8	65.2	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5"	100.0		
1"	74.0		
3/4"	74.0		
3/8"	72.6		
#4	70.7		
#10	67.9		
#20	66.6		
#40	66.0		
#60	65.7		
#100	65.5		
#200	65.2		

* (no specification provided)

Material Description

Gravelly Fat Clay (CH)

Atterberg Limits

PL= 26 LL= 51 PI= 25

Classification

USCS= CH AASHTO= A-7-6(15)

Remarks

Location: BGC - 01
Sample Number: 21781

Date: 5/12/20

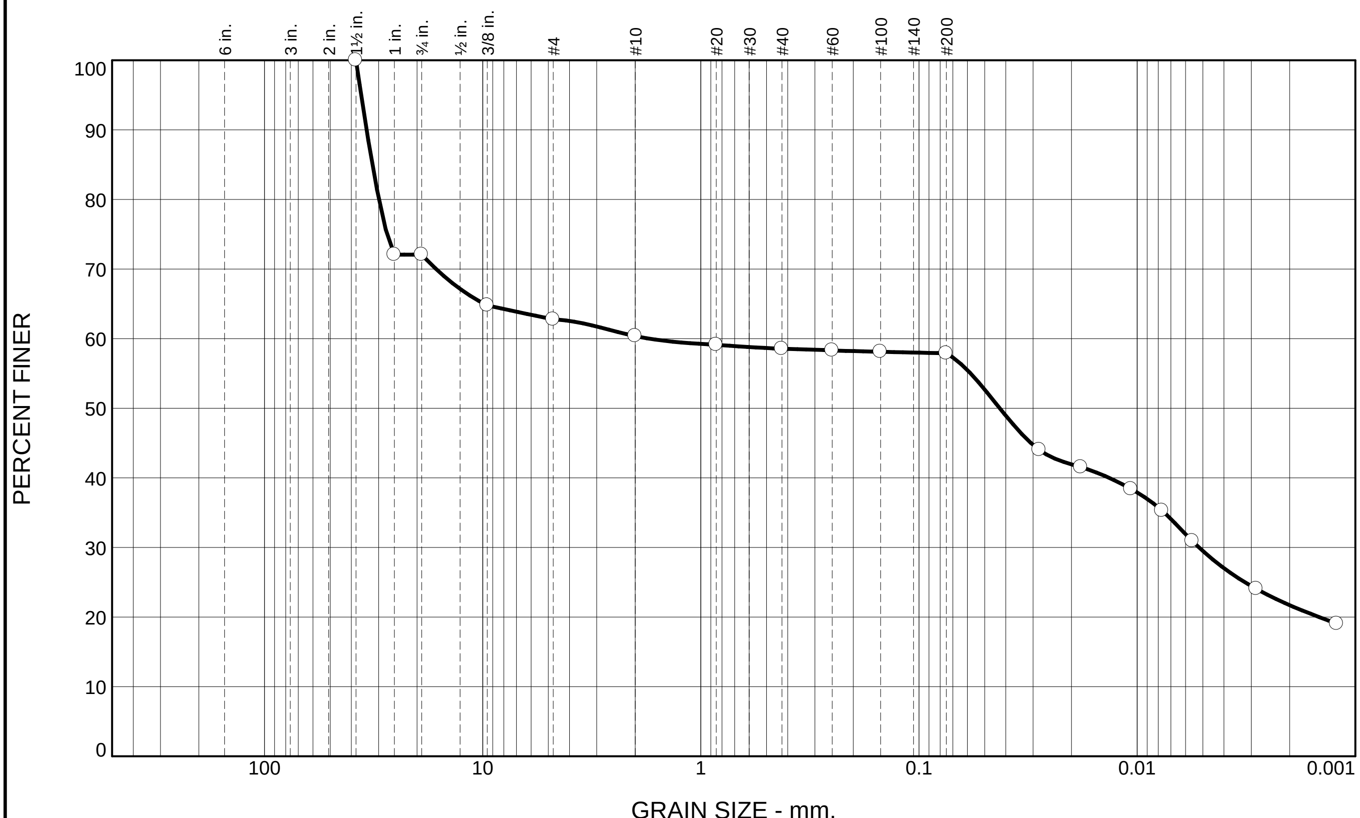
L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

Client: CODY DUCKWORTH
Project: FLEMING COUNTY INCIDENT

Project No: 17052 **Figure**

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	27.9	9.3	2.4	1.8	0.7	28.4	29.5

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5"	100.0		
1"	72.1		
3/4"	72.1		
3/8"	64.8		
#4	62.8		
#10	60.4		
#20	59.1		
#40	58.6		
#60	58.3		
#100	58.1		
#200	57.9		

* (no specification provided)

Material Description

Gravelly Fat Clay (CH)

Atterberg Limits

PL= 30 LL= 63 PI= 33

Classification

USCS= CH AASHTO= A-7-5(17)

Remarks

Location: BGC - 02
Sample Number: 21782

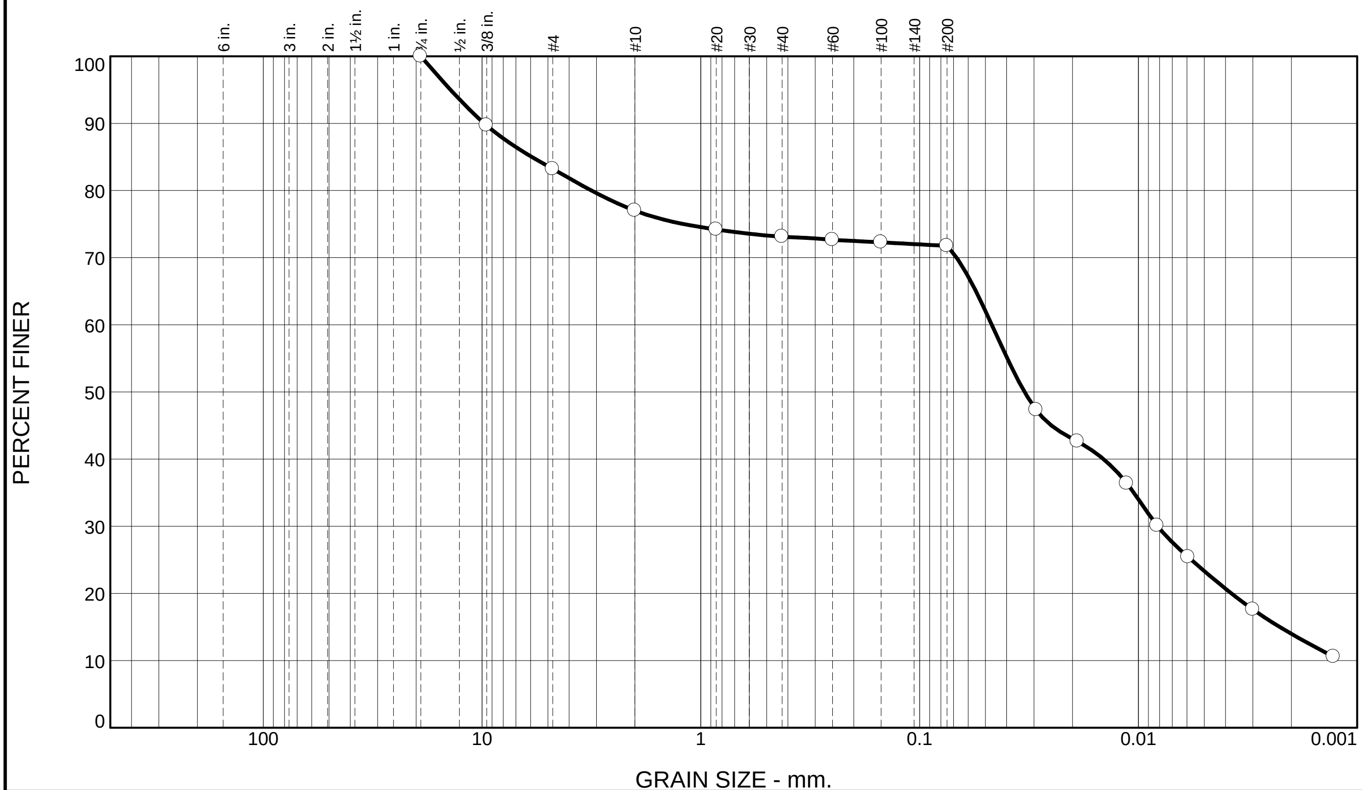
Date: 5/12/20

L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

Client: CODY DUCKWORTH
Project: FLEMING COUNTY INCIDENT

Project No: 17052 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	16.8	6.2	3.9	1.3	48.5	23.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/4"	100.0		
3/8"	89.7		
#4	83.2		
#10	77.0		
#20	74.2		
#40	73.1		
#60	72.6		
#100	72.3		
#200	71.8		

* (no specification provided)

Material Description

Lean Clay with Gravel (CL)

Atterberg Limits

PL= 24 LL= 40 PI= 16

Classification

USCS= CL AASHTO= A-6(11)

Remarks

Location: BGC - 03
Sample Number: 21783

Date: 5/12/20

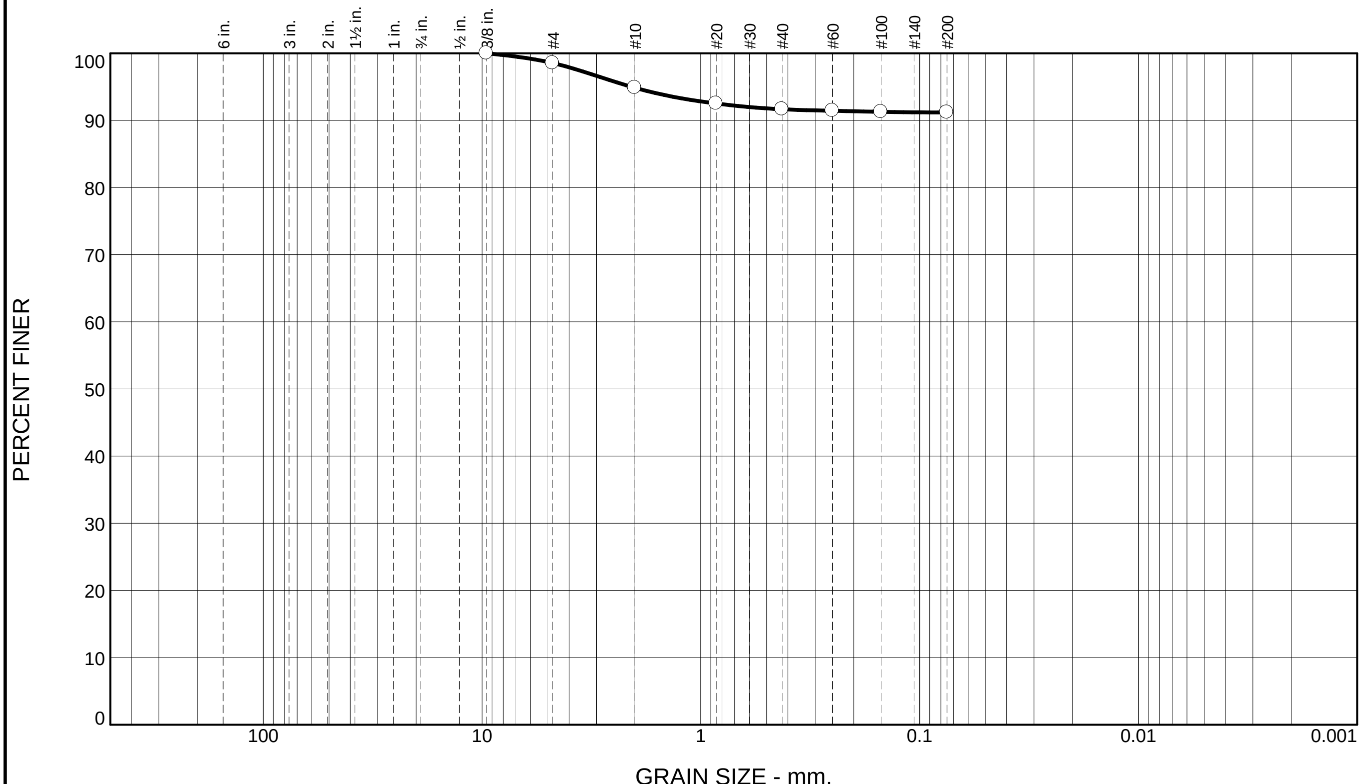
L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

Client: CODY DUCKWORTH
Project: FLEMING COUNTY INCIDENT

Project No: 17052 **Figure**

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.5	3.6	3.2	0.5	91.2	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/8"	100.0		
#4	98.5		
#10	94.9		
#20	92.5		
#40	91.7		
#60	91.4		
#100	91.3		
#200	91.2		

* (no specification provided)

Material Description

Fat Clay (CH)

Atterberg Limits

PL= 31 LL= 67 PI= 36

Classification

USCS= CH AASHTO= A-7-5(39)

Remarks

Location: BGC - 04
Sample Number: 21784

Date: 5/12/20

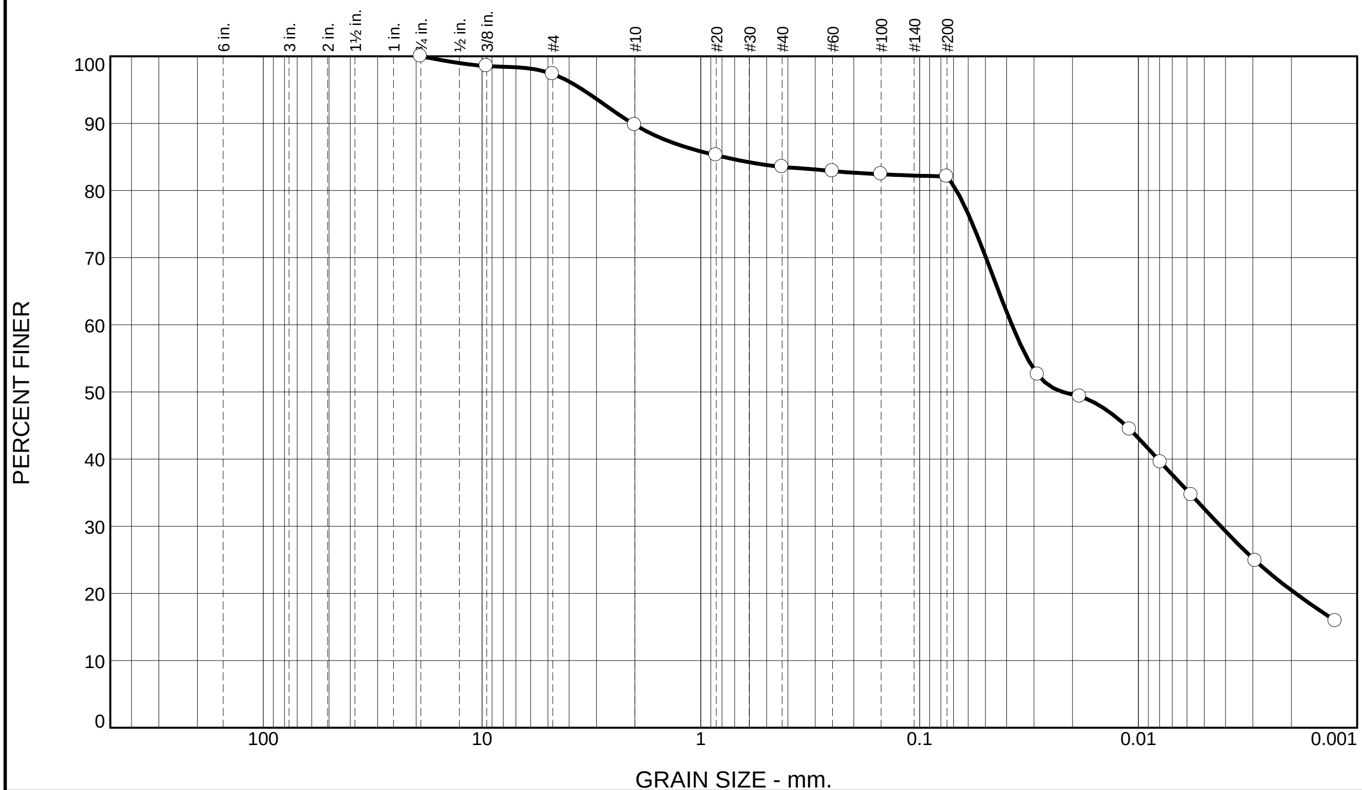
L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

Client: CODY DUCKWORTH
Project: FLEMING COUNTY INCIDENT

Project No: 17052 **Figure**

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	2.6	7.6	6.3	1.4	49.5	32.6

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/4"	100.0		
3/8"	98.5		
#4	97.4		
#10	89.8		
#20	85.3		
#40	83.5		
#60	82.9		
#100	82.4		
#200	82.1		

* (no specification provided)

Material Description

Lean Clay with Sand (CL)

Atterberg Limits

PL= 27 LL= 46 PI= 19

Classification

USCS= CL AASHTO= A-7-6(17)

Remarks

Location: BGC - 05
Sample Number: 21785

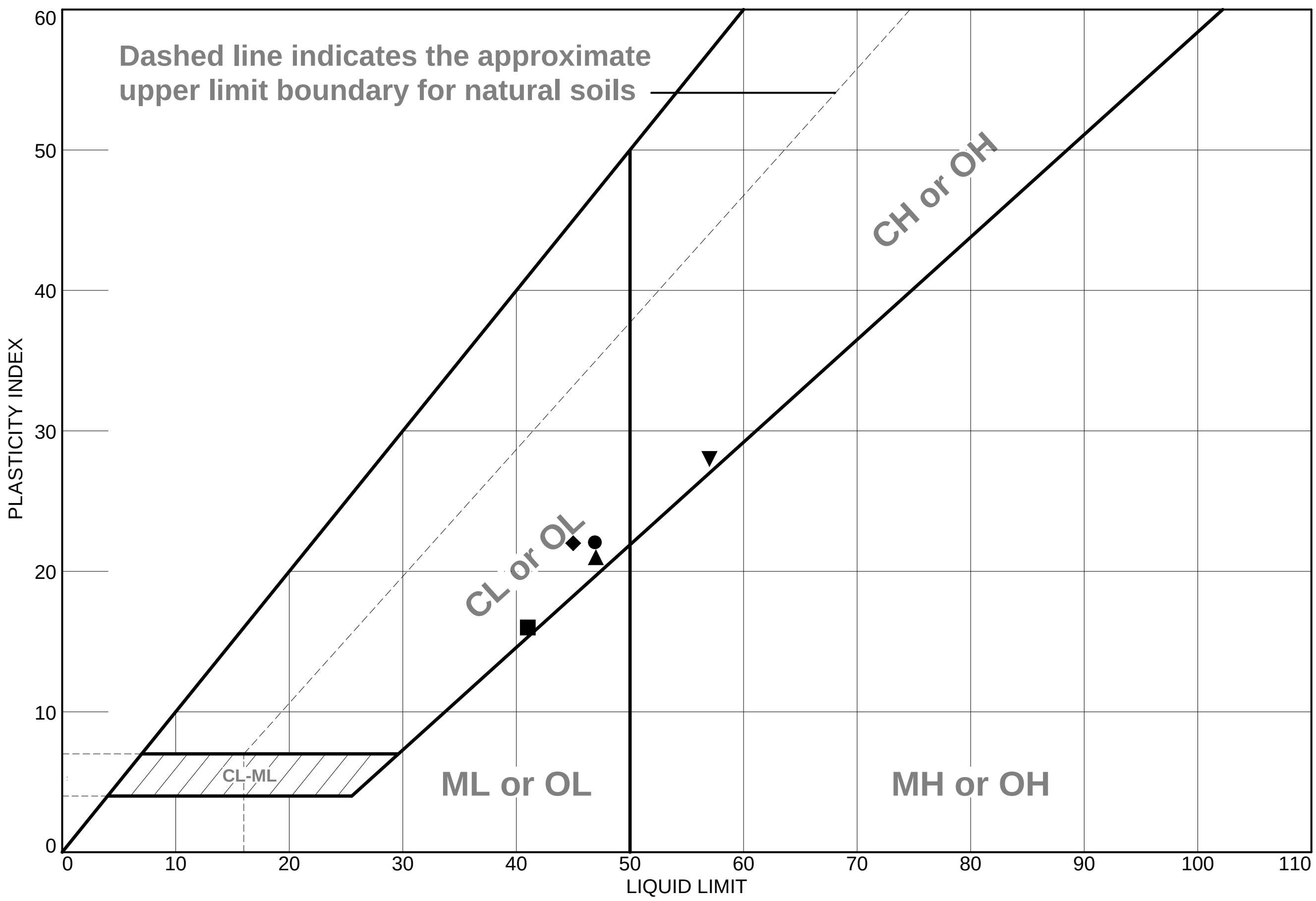
Date: 5/12/20

L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

Client: CODY DUCKWORTH
Project: FLEMING COUNTY INCIDENT
Project No: 17052 **Figure**

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

LIQUID AND PLASTIC LIMITS TEST REPORT



	Material Description	Sampled	Tested	Technician	LL	PL	PI	%<#40	USCS
●	Lean Clay with Sand (CL)	5/12/20	6/5/20	B. DAVENPORT	47	25	22	80.7	CL
■	Sandy Lean Clay (CL)	5/12/20	6/5/20	B. DAVENPORT	41	25	16	71.4	CL
▲	Lean Clay with Sand	5/12/20	6/5/20	B. DAVENPORT	47	26	21	85.6	CL
◆	Gravelly Lean Clay (CL)	5/12/20	6/5/20	B. DAVENPORT	45	23	22	69.6	CL
▼	Fat Clay (CH)	5/12/20	6/5/20	B. DAVENPORT	57	29	28	89.2	CH

Project No. 17052 **Client:** CODY DUCKWORTH

Project: FLEMING COUNTY INCIDENT

○ **Location:** BGC - 07 **Sample Number:** 21786
□ **Location:** BGC - 08 **Sample Number:** 21787
△ **Location:** BGC - 09 **Sample Number:** 21788
◇ **Location:** BGC - 10 **Sample Number:** 21789
▽ **Location:** BGC - 11 **Sample Number:** 21790

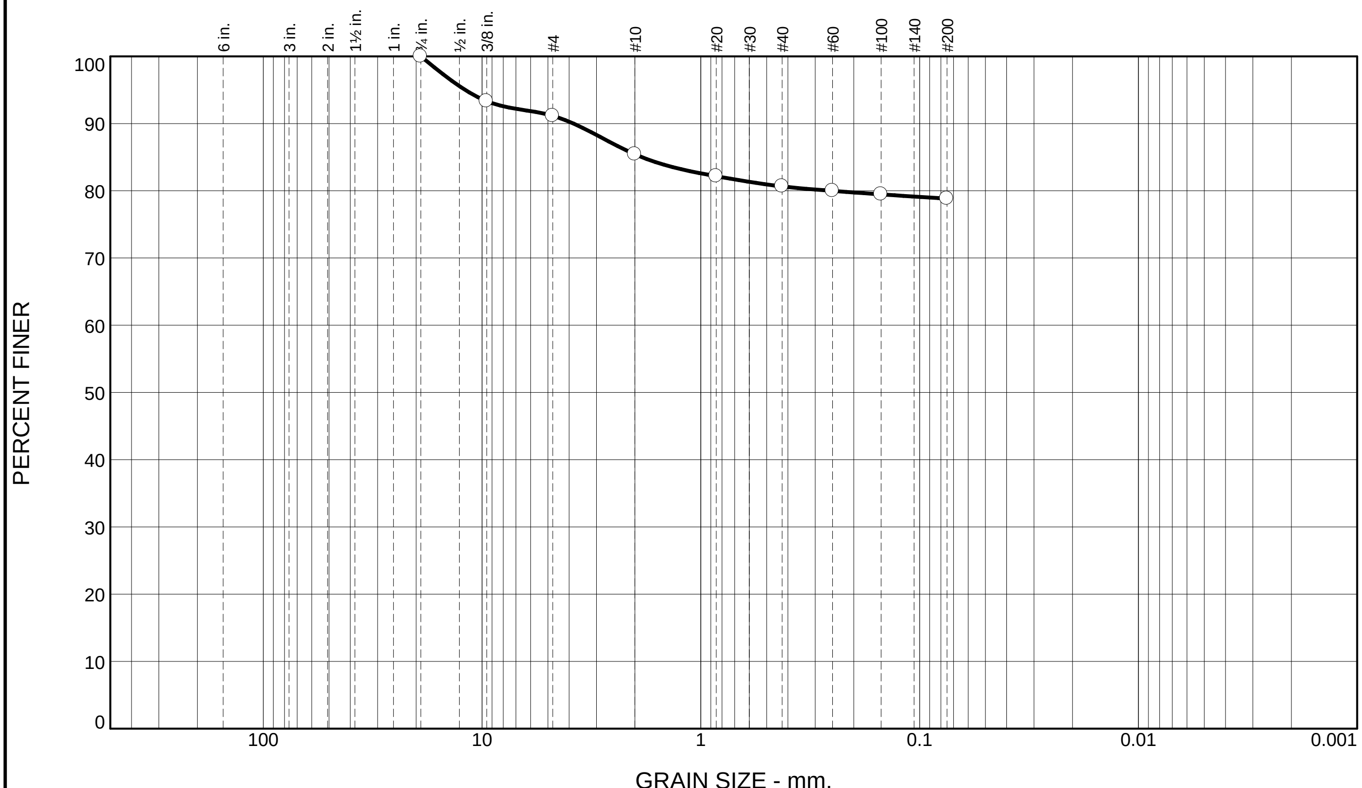
L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

Checked by: S. MORTIMER
Title: GEOTECHNICAL ENGINEER

Figure

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	8.9	5.7	4.7	1.9	78.8	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/4"	100.0		
3/8"	93.3		
#4	91.1		
#10	85.4		
#20	82.2		
#40	80.7		
#60	80.0		
#100	79.5		
#200	78.8		

* (no specification provided)

Material Description

Lean Clay with Sand (CL)

Atterberg Limits

PL= 25 LL= 47 PI= 22

Classification

USCS= CL AASHTO= A-7-6(18)

Remarks

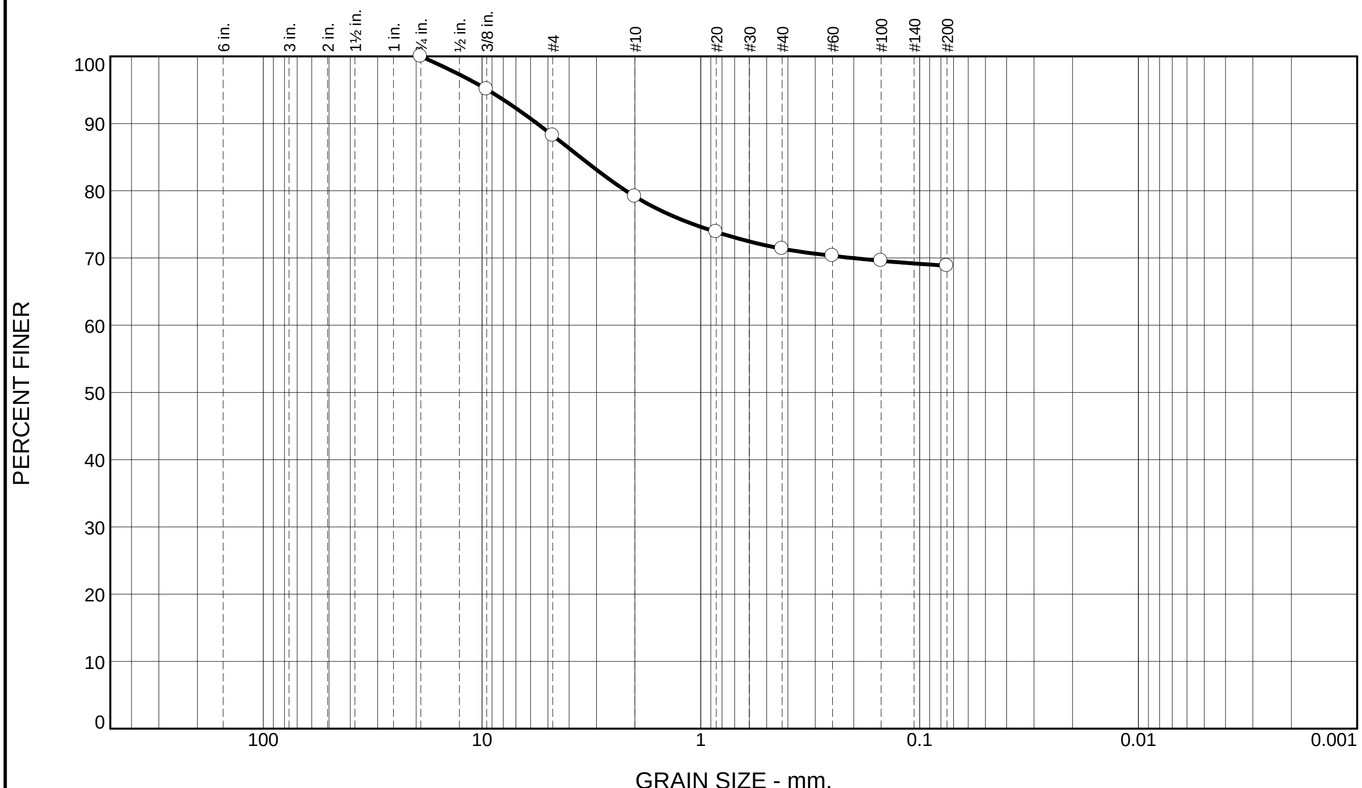
Location: BGC - 07
Sample Number: 21786
Date: 5/12/20

L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

Client: CODY DUCKWORTH
Project: FLEMING COUNTY INCIDENT
Project No: 17052 **Figure**

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	11.8	9.1	7.7	2.5	68.9	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/4"	100.0		
3/8"	95.1		
#4	88.2		
#10	79.1		
#20	73.9		
#40	71.4		
#60	70.3		
#100	69.6		
#200	68.9		

* (no specification provided)

Material Description

Sandy Lean Clay (CL)

Atterberg Limits

PL= 25 LL= 41 PI= 16

Classification

USCS= CL AASHTO= A-7-6(10)

Remarks

Location: BGC - 08
Sample Number: 21787

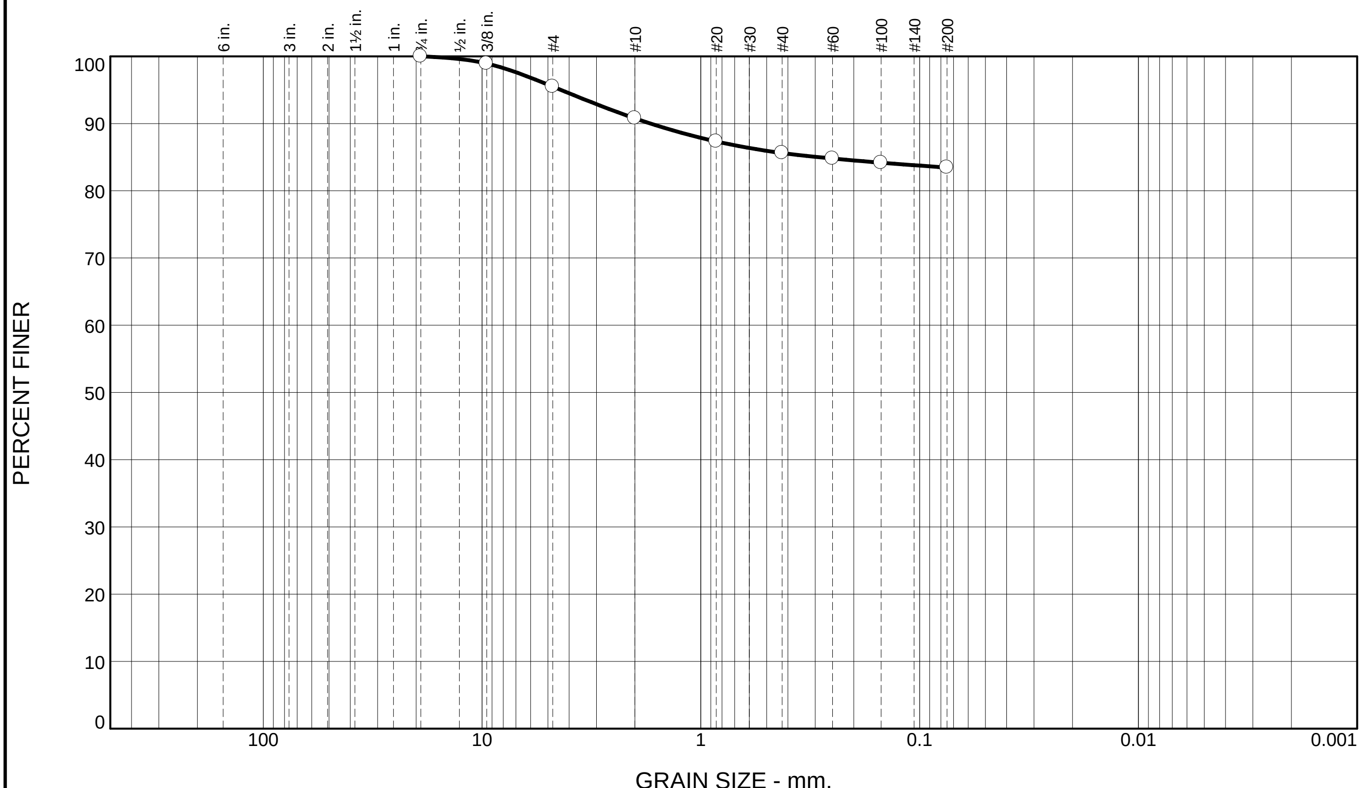
Date: 5/12/20

L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

Client: CODY DUCKWORTH
Project: FLEMING COUNTY INCIDENT
Project No: 17052 **Figure**

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	4.5	4.7	5.2	2.1	83.5	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/4"	100.0		
3/8"	98.9		
#4	95.5		
#10	90.8		
#20	87.3		
#40	85.6		
#60	84.8		
#100	84.2		
#200	83.5		

* (no specification provided)

Material Description

Lean Clay with Sand

Atterberg Limits

PL= 26 LL= 47 PI= 21

Classification

USCS= CL AASHTO= A-7-6(19)

Remarks

Location: BGC - 09
Sample Number: 21788

Date: 5/12/20

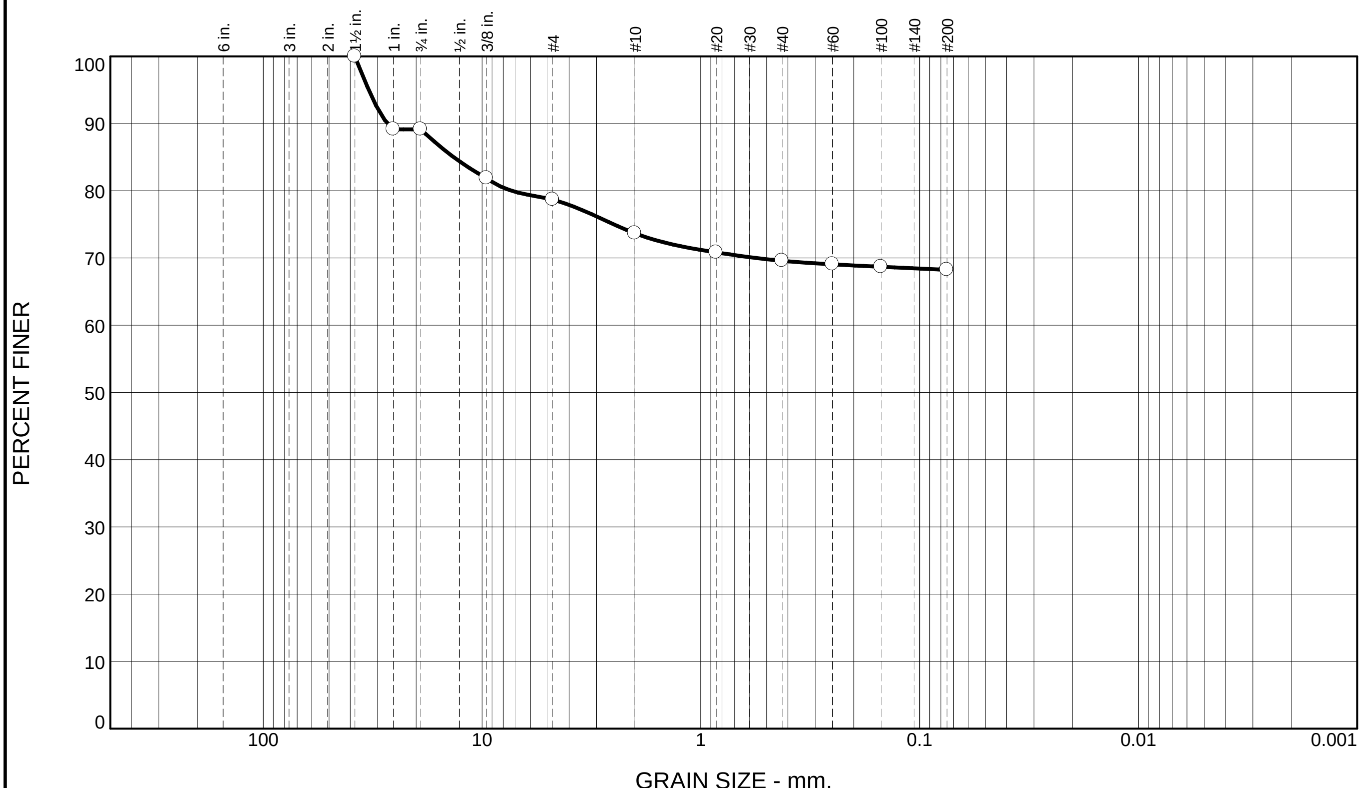
L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

Client: CODY DUCKWORTH
Project: FLEMING COUNTY INCIDENT

Project No: 17052 **Figure**

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	10.9	10.4	5.0	4.1	1.4	68.2	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5"	100.0		
1"	89.1		
3/4"	89.1		
3/8"	81.9		
#4	78.7		
#10	73.7		
#20	70.8		
#40	69.6		
#60	69.1		
#100	68.7		
#200	68.2		

* (no specification provided)

Material Description

Gravelly Lean Clay (CL)

Atterberg Limits

PL= 23 LL= 45 PI= 22

Classification

USCS= CL AASHTO= A-7-6(14)

Remarks

Location: BGC - 10
Sample Number: 21789

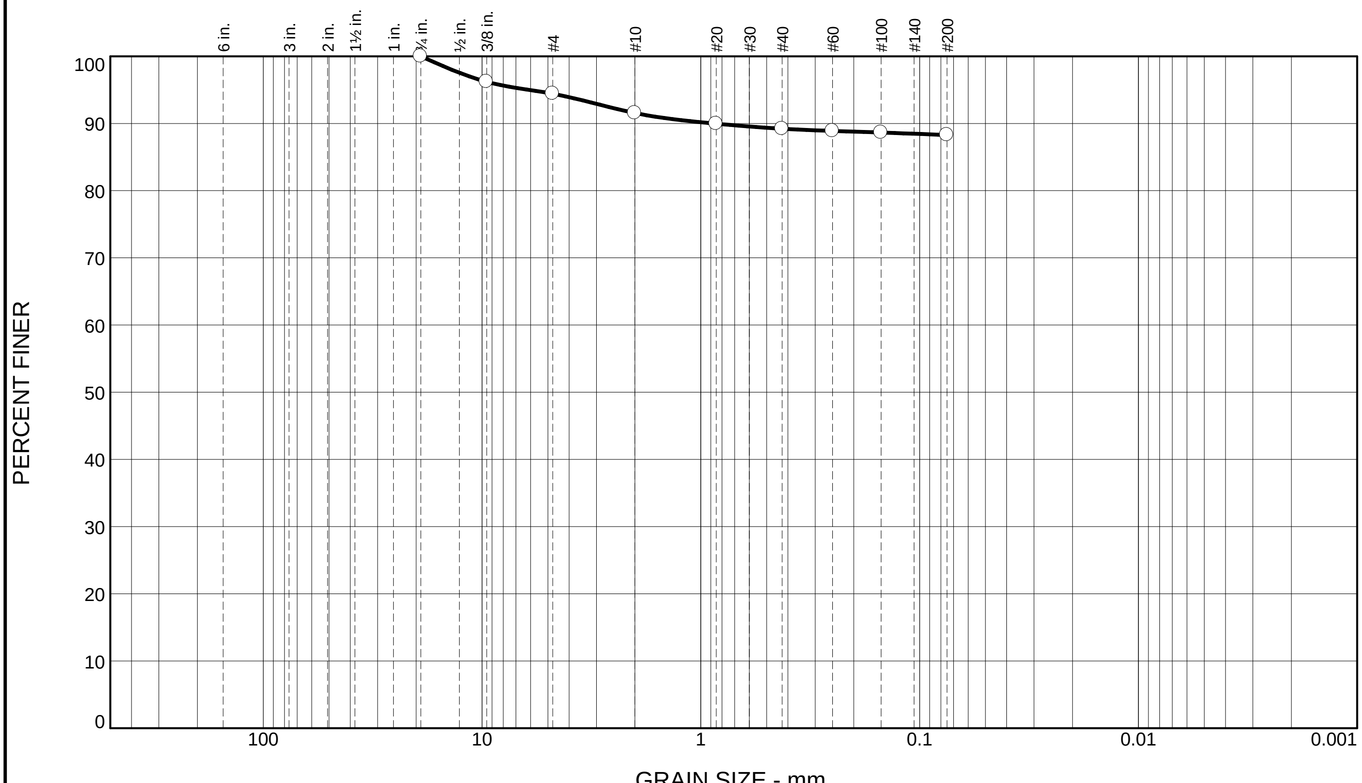
Date: 5/12/20

L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

Client: CODY DUCKWORTH
Project: FLEMING COUNTY INCIDENT
Project No: 17052 **Figure**

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	5.6	2.8	2.4	0.9	88.3	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/4"	100.0		
3/8"	96.2		
#4	94.4		
#10	91.6		
#20	90.0		
#40	89.2		
#60	88.9		
#100	88.6		
#200	88.3		

* (no specification provided)

Material Description

Fat Clay (CH)

Atterberg Limits

PL= 29 LL= 57 PI= 28

Classification

USCS= CH AASHTO= A-7-6(28)

Remarks

Location: BGC - 11
Sample Number: 21790

Date: 5/12/20

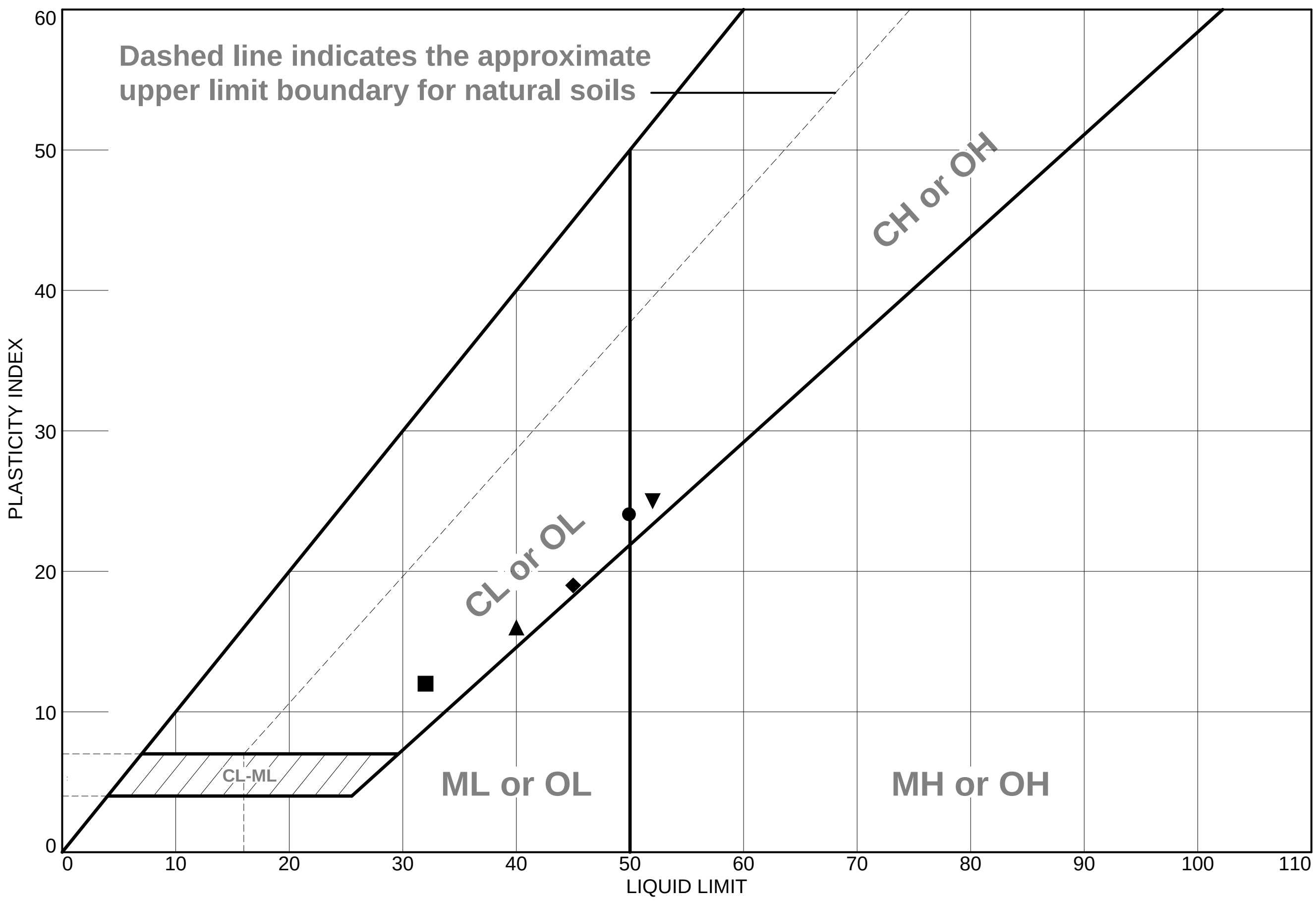
L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

Client: CODY DUCKWORTH
Project: FLEMING COUNTY INCIDENT

Project No: 17052 **Figure**

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

LIQUID AND PLASTIC LIMITS TEST REPORT



	Material Description	Sampled	Tested	Technician	LL	PL	PI	%<#40	USCS
●	Fat Clay with Gravel (CH)	5/12/20	6/8/20	B. DAVENPORT	50	26	24	78.3	CH
■	Clayey Gravel (GC)	5/12/20	6/8/20	B. DAVENPORT	32	20	12	49.3	GC
▲	Gravelley Lean Clay (CL)	5/12/20	6/9/20	B. DAVENPORT	40	24	16	67.9	CL
◆	Gravelly Lean Clay (CL)	5/12/20	6/9/20	B. DAVENPORT	45	26	19	58.6	CL
▼	Clayey Gravel (GC)	5/12/20	6/9/20	B. DAVENPORT	52	27	25	32.7	GC

Project No. 17052 **Client:** CODY DUCKWORTH

Project: FLEMING COUNTY INCIDENT

○ **Location:** TP07 - 01 **Sample Number:** 21791
□ **Location:** TP08 - 01 **Sample Number:** 21792
△ **Location:** TP09 - 01 **Sample Number:** 21793
◇ **Location:** BGC - 25 - 01 **Sample Number:** 21794
▽ **Location:** BGC - 25 - 02 **Sample Number:** 21795

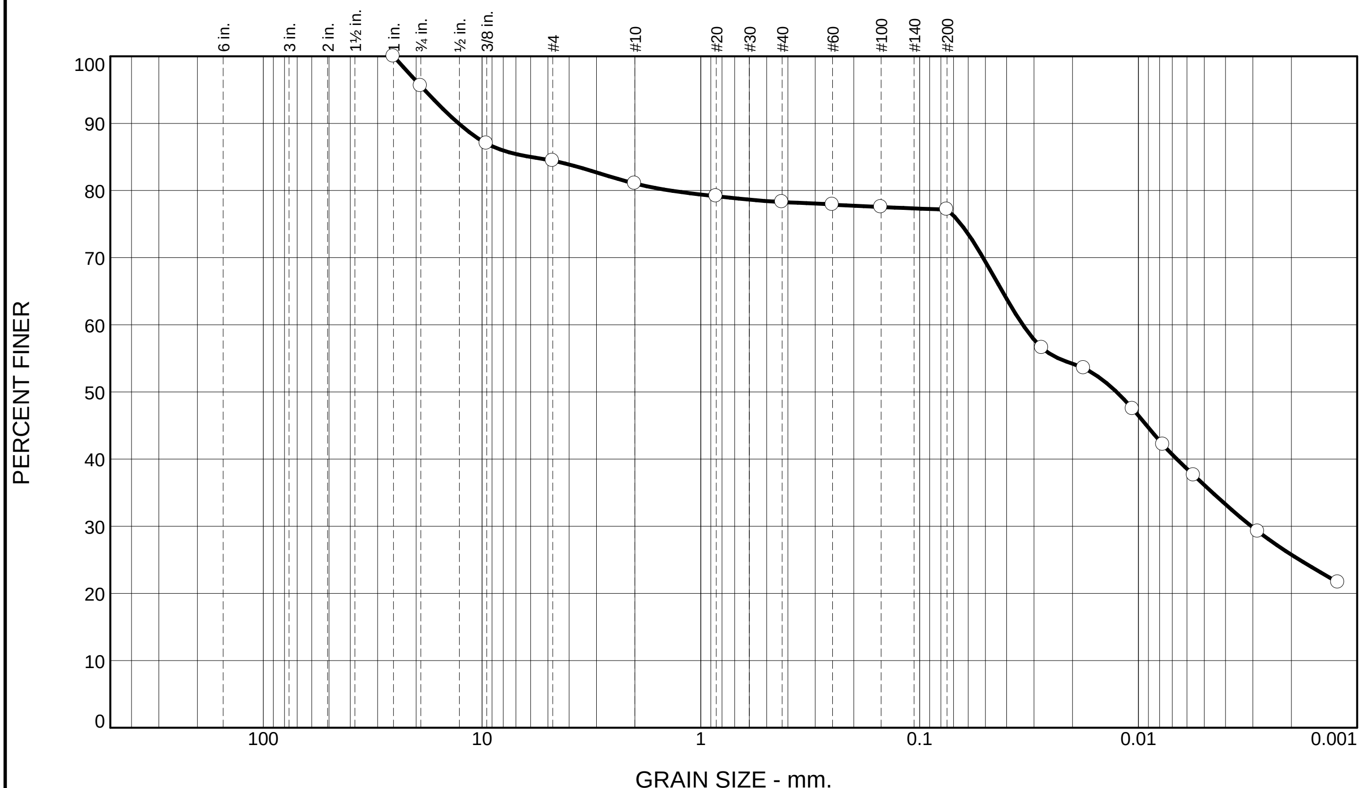
L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

Checked by: S. MORTIMER
Title: GEOTECHNICAL ENGINEER

Figure

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	4.4	11.2	3.4	2.7	1.1	41.0	36.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1"	100.0		
3/4"	95.6		
3/8"	87.0		
#4	84.4		
#10	81.0		
#20	79.2		
#40	78.3		
#60	77.9		
#100	77.5		
#200	77.2		

* (no specification provided)

Material Description

Fat Clay with Gravel (CH)

Atterberg Limits

PL= 26 LL= 50 PI= 24

Classification

USCS= CH AASHTO= A-7-6(19)

Remarks

Location: TP07 - 01
Sample Number: 21791

Date: 5/12/20

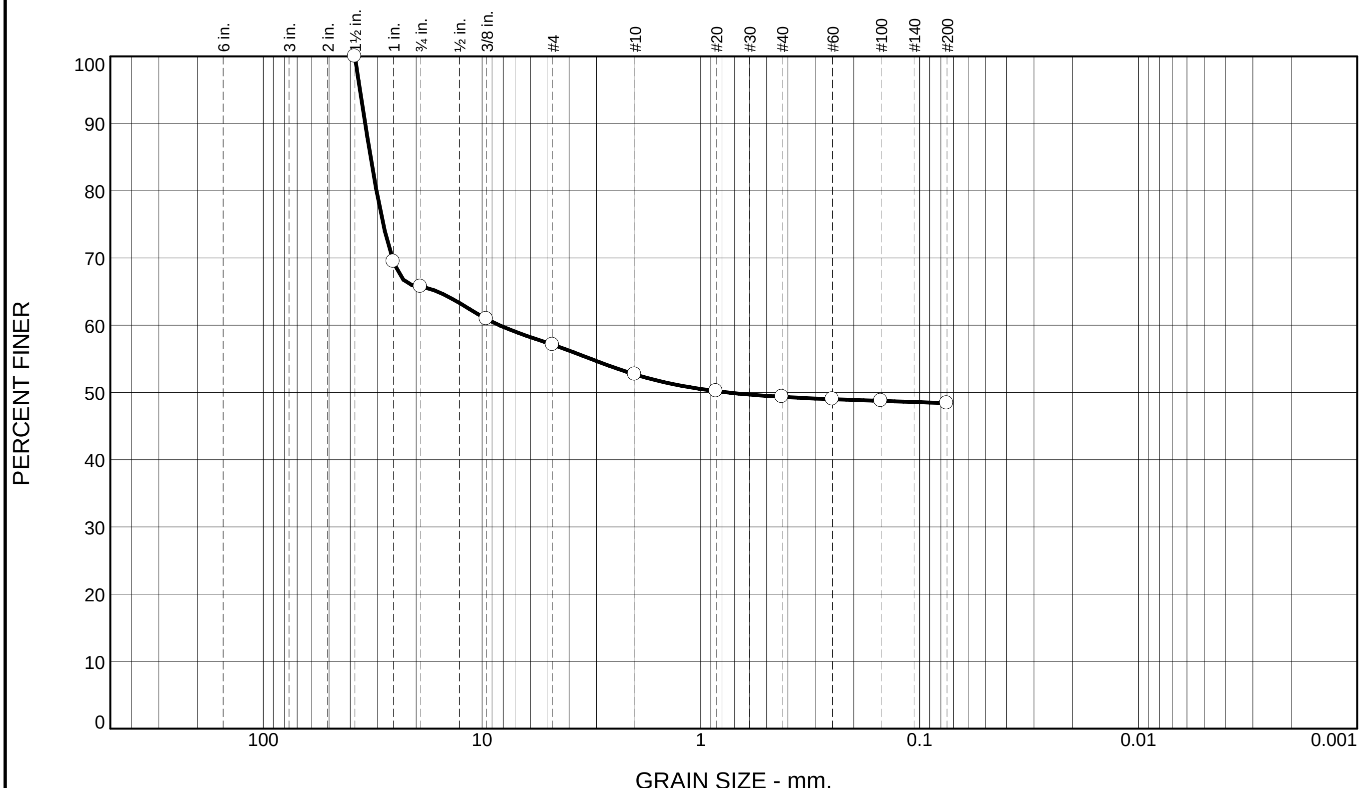
L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

Client: CODY DUCKWORTH
Project: FLEMING COUNTY INCIDENT

Project No: 17052 **Figure**

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	34.3	8.6	4.4	3.4	0.9	48.4	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5"	100.0		
1"	69.5		
3/4"	65.7		
3/8"	60.9		
#4	57.1		
#10	52.7		
#20	50.2		
#40	49.3		
#60	49.0		
#100	48.8		
#200	48.4		

* (no specification provided)

Material Description

Clayey Gravel (GC)

Atterberg Limits

PL= 20 LL= 32 PI= 12

Classification

USCS= GC AASHTO= A-6(3)

Remarks

Location: TP08 - 01
Sample Number: 21792

Date: 5/12/20

L.E. Gregg Associates, Inc.

2456 Fortune Dr, Ste 155, Lexington, KY 40509

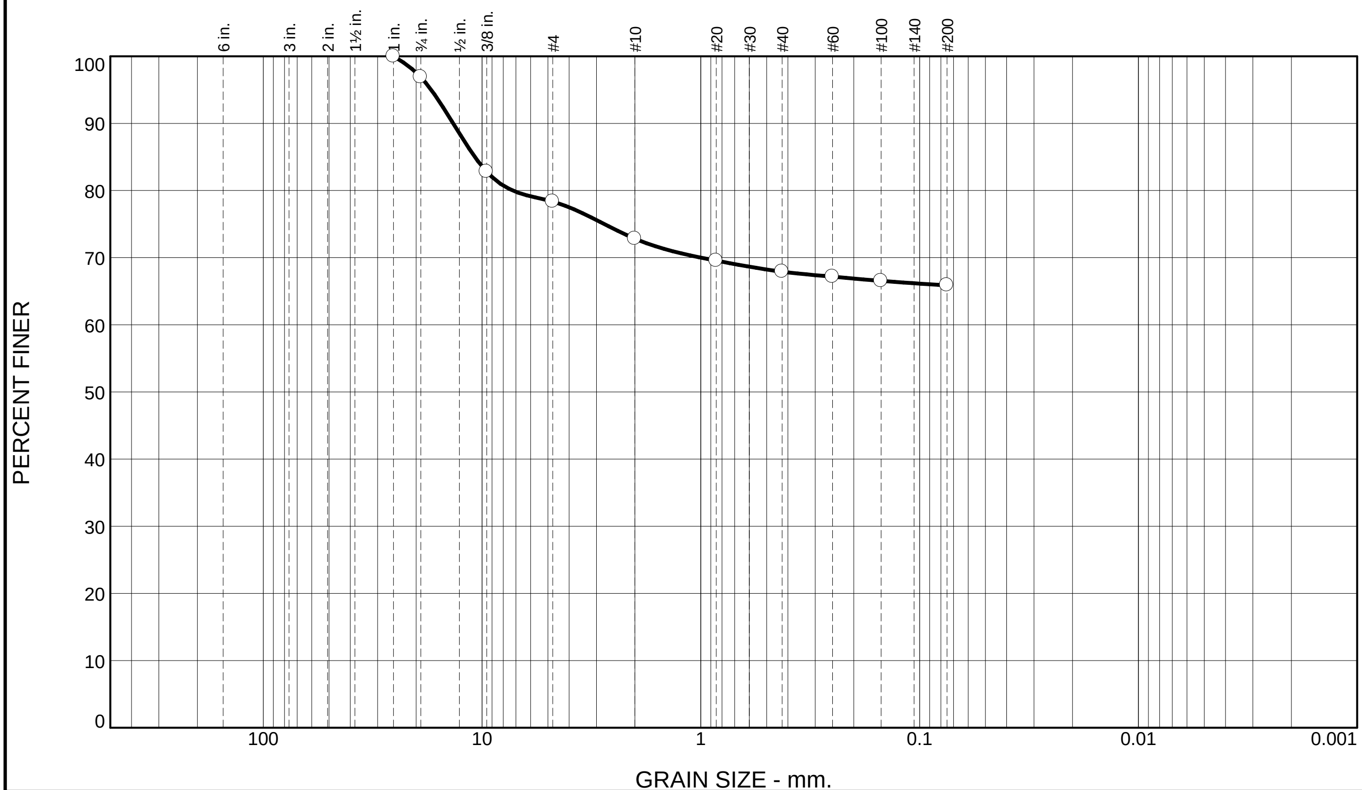
Phone: 859-252-7558

Client: CODY DUCKWORTH
Project: FLEMING COUNTY INCIDENT

Project No: 17052 **Figure**

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	3.1	18.5	5.6	4.9	2.0	65.9	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1"	100.0		
3/4"	96.9		
3/8"	82.8		
#4	78.4		
#10	72.8		
#20	69.6		
#40	67.9		
#60	67.2		
#100	66.5		
#200	65.9		

* (no specification provided)

Material Description

Gravelley Lean Clay (CL)

Atterberg Limits

PL= 24 LL= 40 PI= 16

Classification

USCS= CL AASHTO= A-6(9)

Remarks

Location: TP09 - 01
Sample Number: 21793

Date: 5/12/20

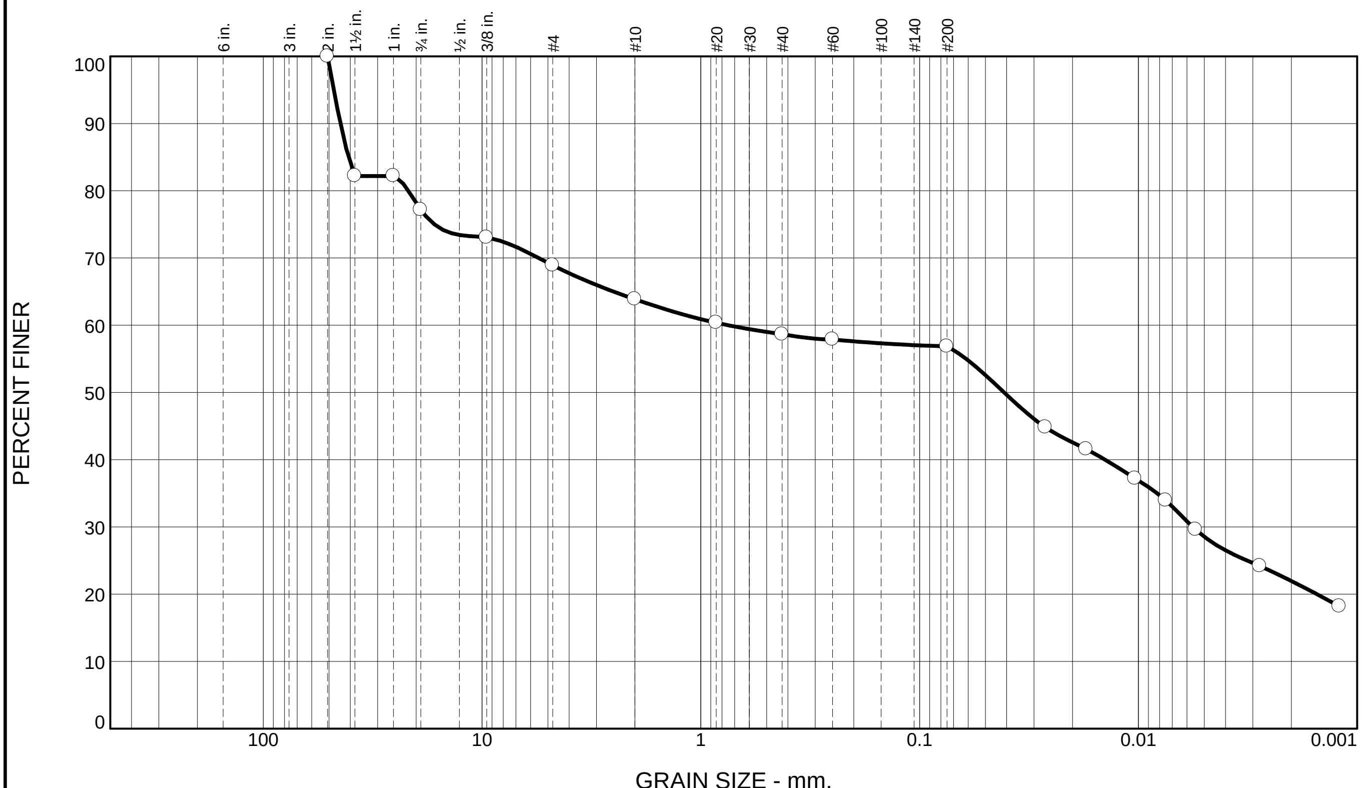
L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

Client: CODY DUCKWORTH
Project: FLEMING COUNTY INCIDENT

Project No: 17052 **Figure**

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	22.8	8.3	5.0	5.3	1.7	28.4	28.5

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
2"	100.0		
1.5"	82.2		
1"	82.2		
3/4"	77.2		
3/8"	73.0		
#4	68.9		
#10	63.9		
#20	60.4		
#40	58.6		
#60	57.9		
#200	56.9		

* (no specification provided)

Material Description

Gravelly Lean Clay (CL)

Atterberg Limits

PL= 26 LL= 45 PI= 19

Classification

USCS= CL AASHTO= A-7-6(9)

Remarks

Location: BGC - 25 - 01
Sample Number: 21794

Date: 5/12/20

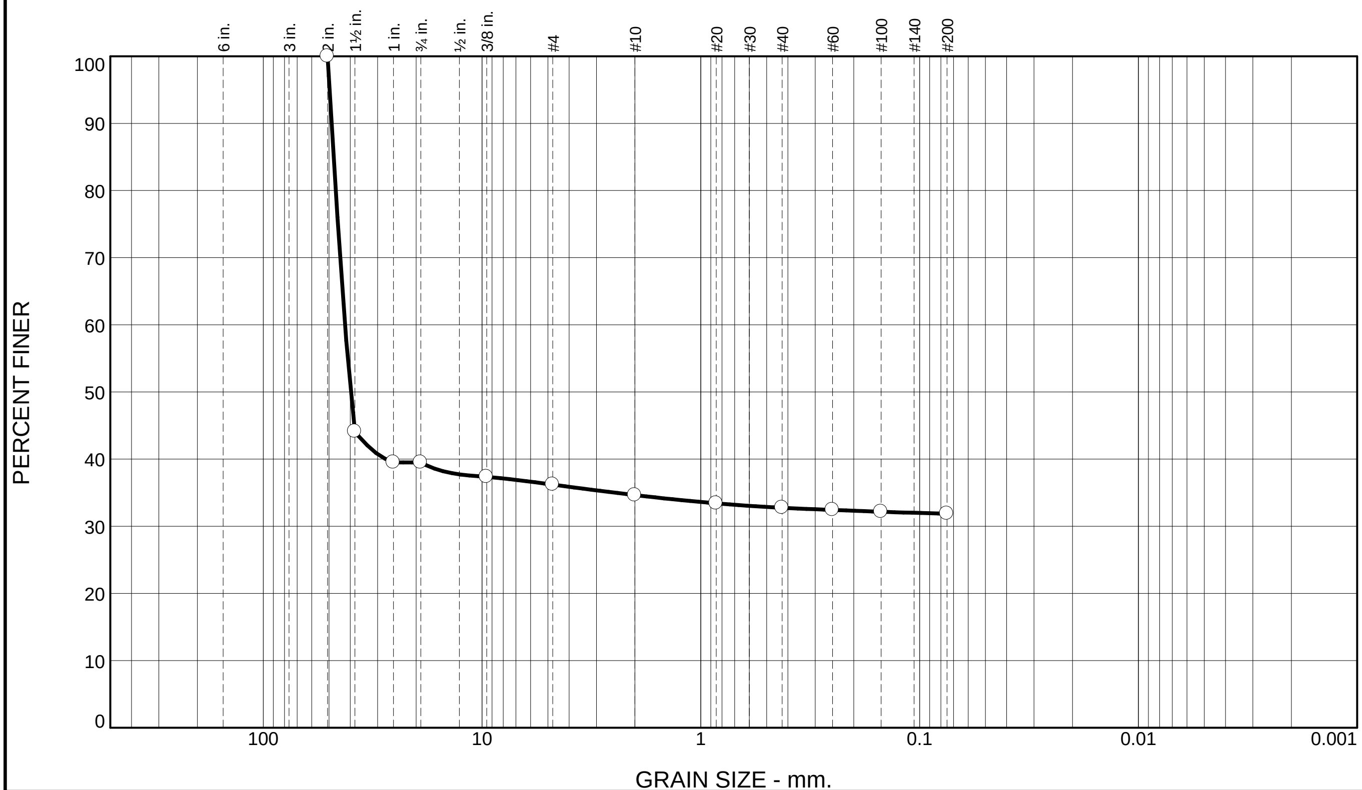
L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

Client: CODY DUCKWORTH
Project: FLEMING COUNTY INCIDENT

Project No: 17052 **Figure**

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	60.5	3.3	1.6	1.9	0.8	31.9	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
2"	100.0		
1.5"	44.1		
1"	39.5		
3/4"	39.5		
3/8"	37.4		
#4	36.2		
#10	34.6		
#20	33.4		
#40	32.7		
#60	32.4		
#100	32.2		
#200	31.9		

* (no specification provided)

Material Description

Clayey Gravel (GC)

Atterberg Limits

PL= 27 LL= 52 PI= 25

Classification

USCS= GC AASHTO= A-2-7(3)

Remarks

Location: BGC - 25 - 02
Sample Number: 21795

Date: 5/12/20

L.E. Gregg Associates, Inc.
2456 Fortune Dr, Ste 155, Lexington, KY 40509
Phone: 859-252-7558

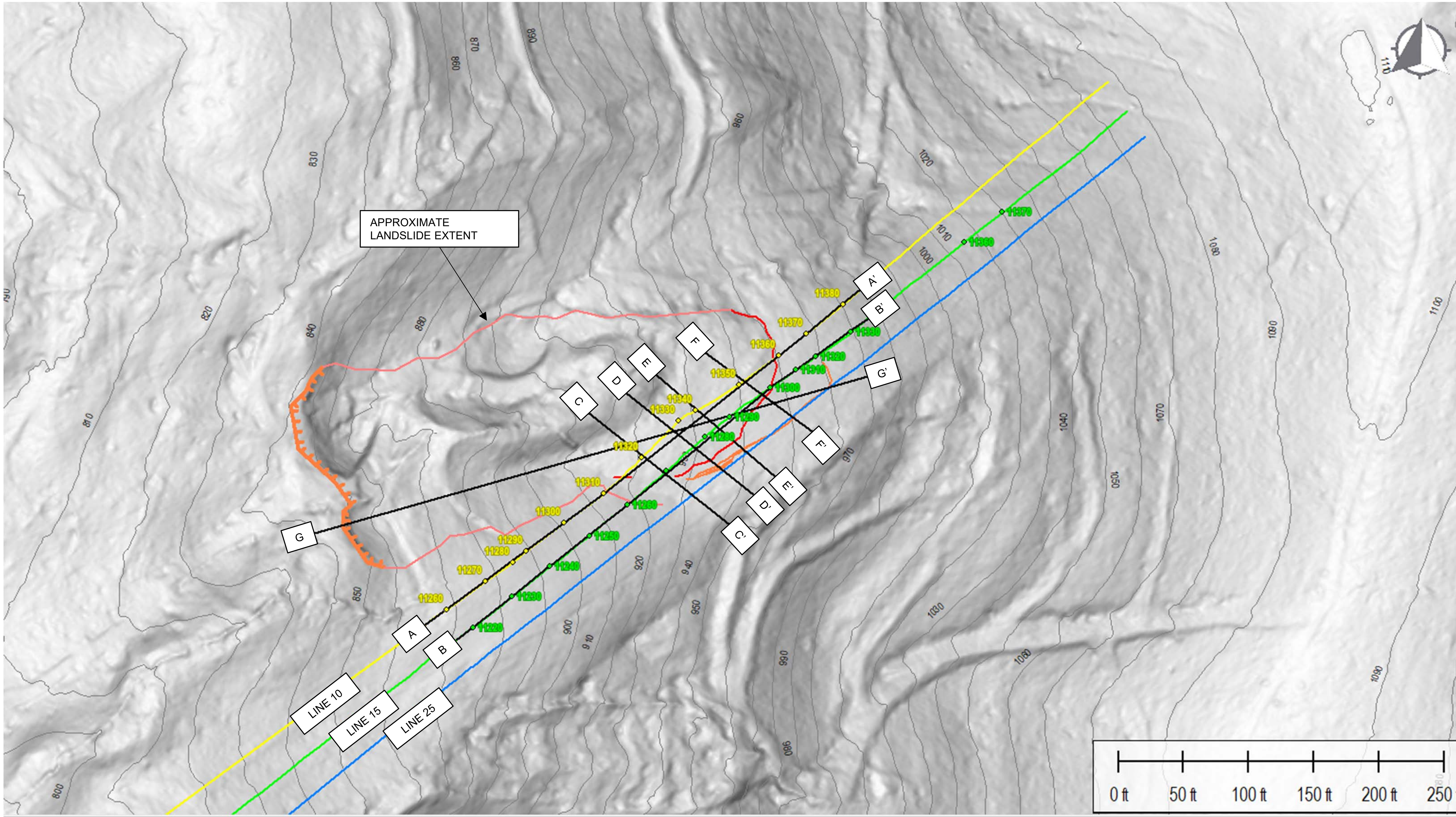
Client: CODY DUCKWORTH
Project: FLEMING COUNTY INCIDENT

Project No: 17052 **Figure**

Tested By: B. DAVENPORT **Checked By:** S. MORTIMER

APPENDIX H
BEDROCK PROFILES

04-2021



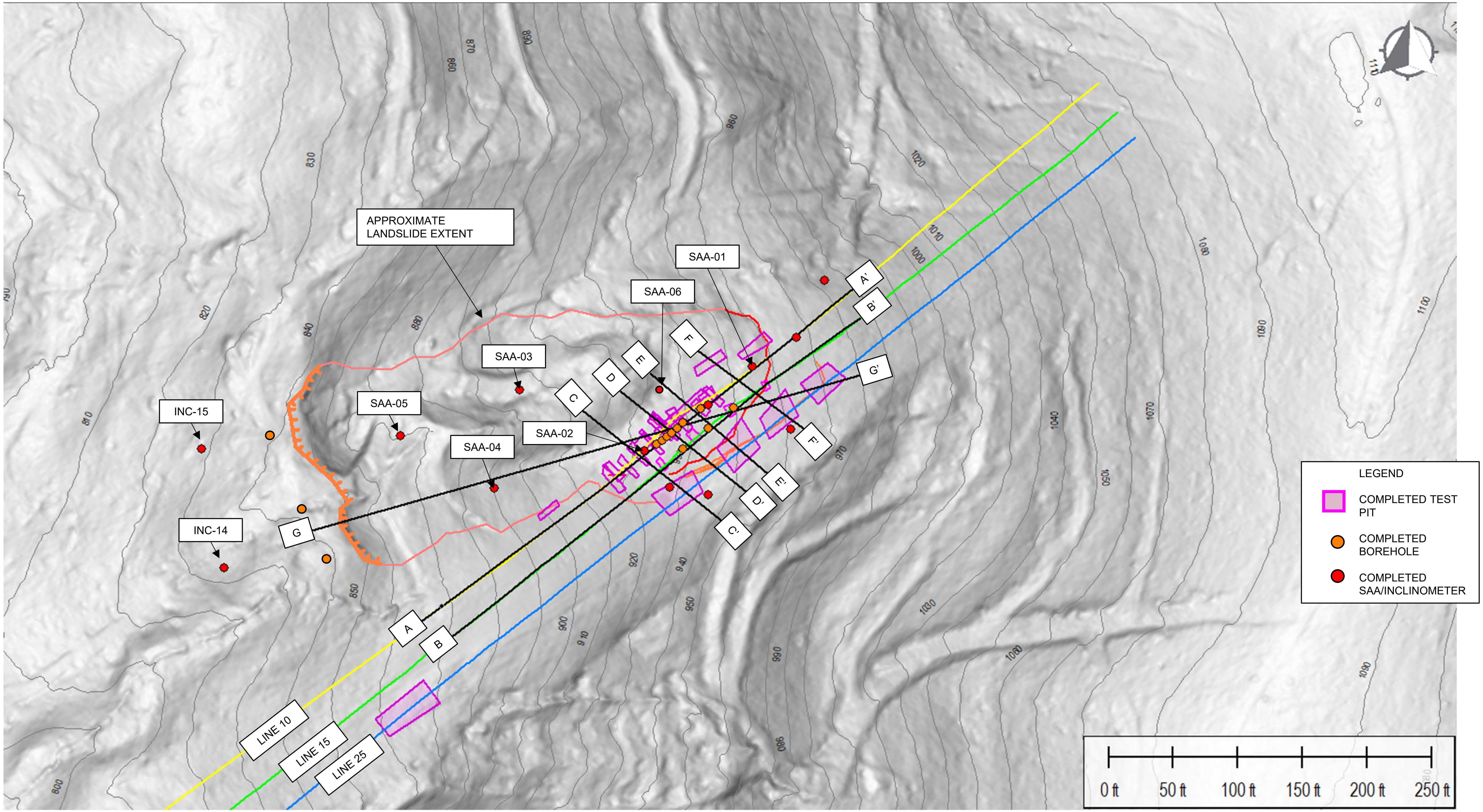
NOTES:

1. This figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. All dimensions are in feet and are approximate.
3. Line 10 and Line 15 girth weld coordinates are based on survey data collected during excavation, provided by SGC Engineering. Surveyed pipeline centerline data collected by SGC (May 6, 2020).
4. Base image based on digital elevation model from November 2019 lidar data provided by TETLP.
5. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: WCD	FIGURE TITLE: PLAN VIEW – CROSS SECTIONS			
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: H-1	

0 5 10 mm in ANSI B sized paper

BGC ENGINEERING INC.

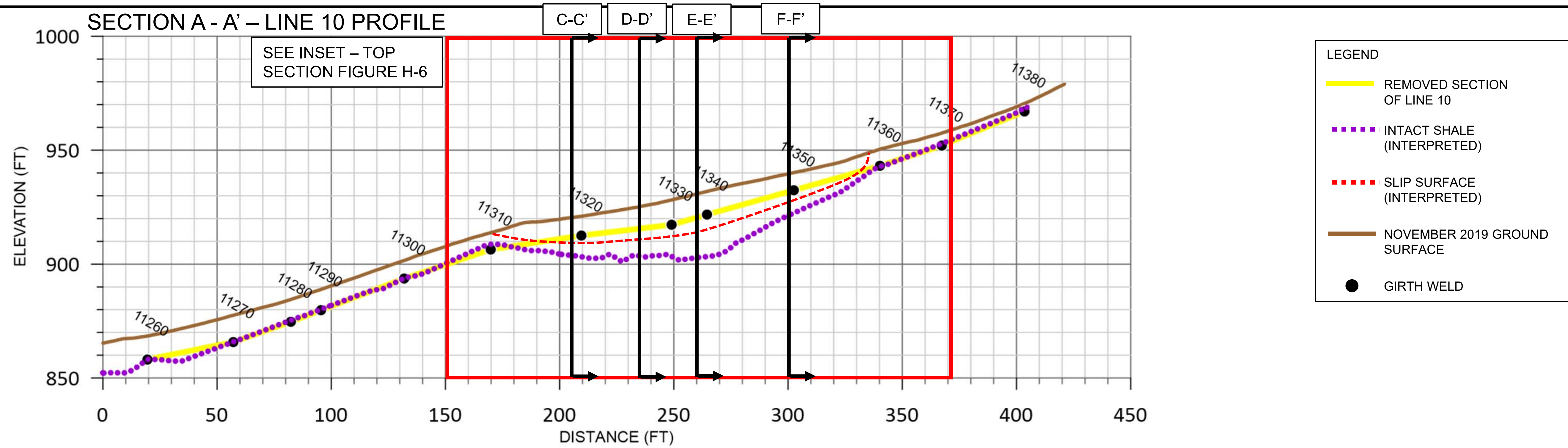


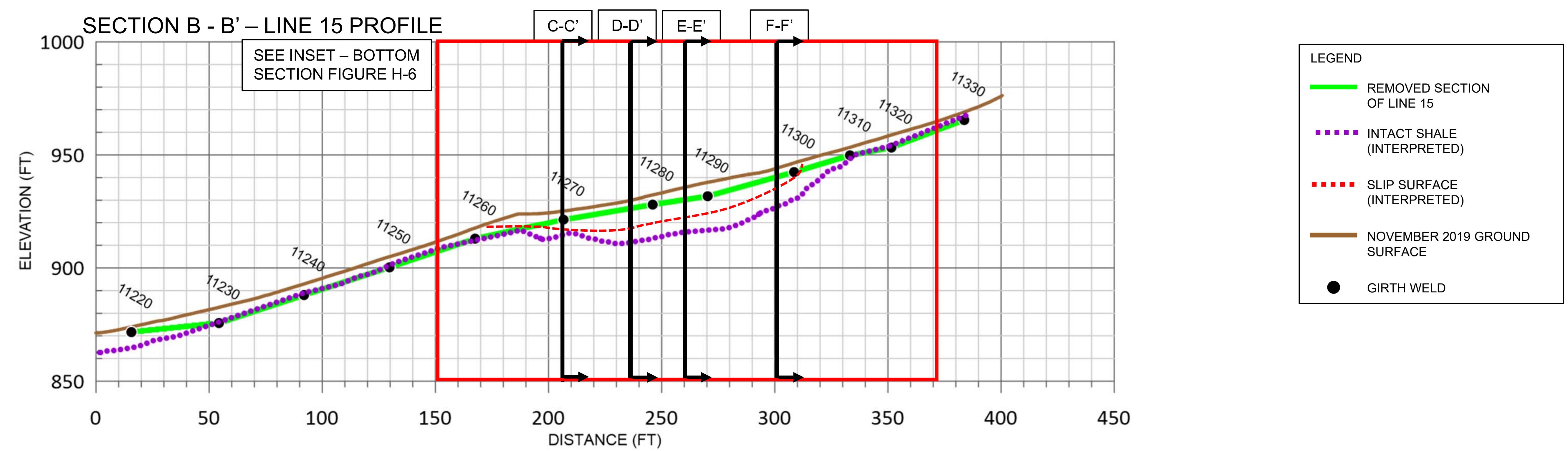
NOTES:

1. This figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. All dimensions are in feet and are approximate.
3. Line 10 and Line 15 girth weld coordinates are based on survey data collected during excavation, provided by SGC Engineering. Surveyed pipeline centerline data collected by SGC (May 6, 2020).
4. Base image based on digital elevation model from November 2019 lidar data provided by TETLP.
5. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: WCD	FIGURE TITLE: PLAN VIEW - TEST PITS AND BOREHOLES
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP
APPROVED BY: CAD	SCALE: AS SHOWN; PROJECT NO: 1607024; FIGURE NO: H-2

0 5 10 mm in ANSI B sized paper





NOTES:
1. This figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. All dimensions are in feet and are approximate.
3. Line 10 and Line 15 girth weld coordinates are based on survey data collected during excavation, provided by SGC Engineering. Surveyed pipeline centerline data collected by SGC (May 6, 2020).
4. Ground profile based on digital elevation model from November 2019 lidar data provided by TETLP.
5. Bedrock elevations based on excavation observations, test pitting and drilling completed May through October 2020.
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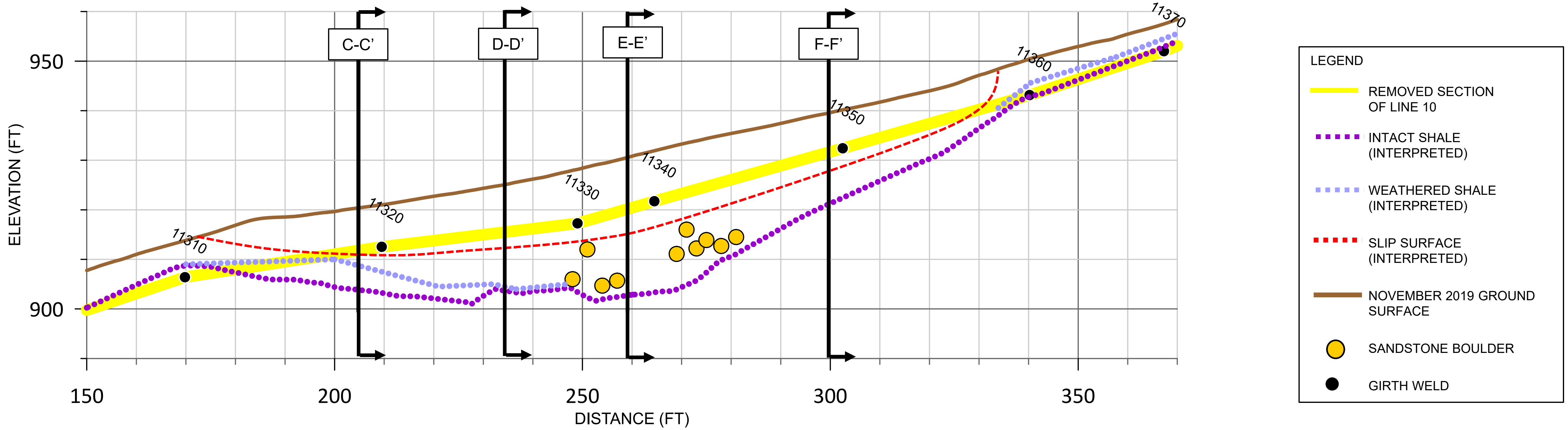
PREPARED BY: WCD	FIGURE TITLE: LINES 10 AND 15 CROSS SECTIONS – CUTOUT SCALE		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: H-3

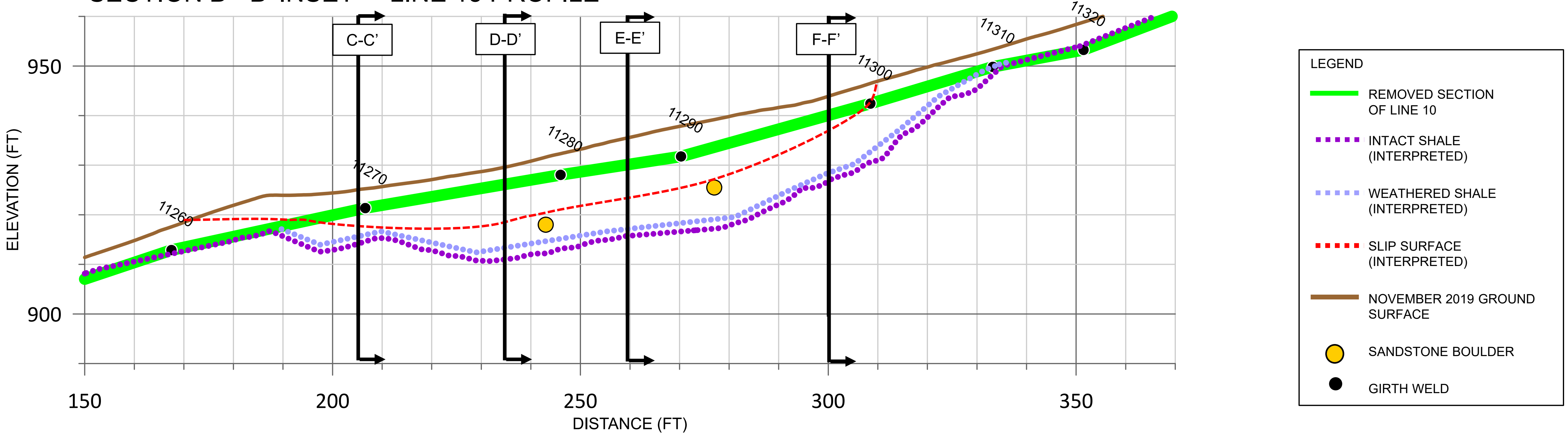
0 5 10 mm in ANSI B sized paper

04-2021

SECTION A - A' INSET – LINE 10 PROFILE



SECTION B - B' INSET – LINE 15 PROFILE



NOTES:

1. This figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. All dimensions are in feet and are approximate.
3. Line 10 and Line 15 girth weld coordinates are based on survey data collected during excavation, provided by SGC Engineering. Surveyed pipeline centerline data collected by SGC (May 6, 2020).
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PREPARED BY: WCD	FIGURE TITLE: LINES 10 AND 15 CROSS SECTIONS – BEDROCK DEPTHS		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: H-4

0 5 10 mm in ANSI B sized paper

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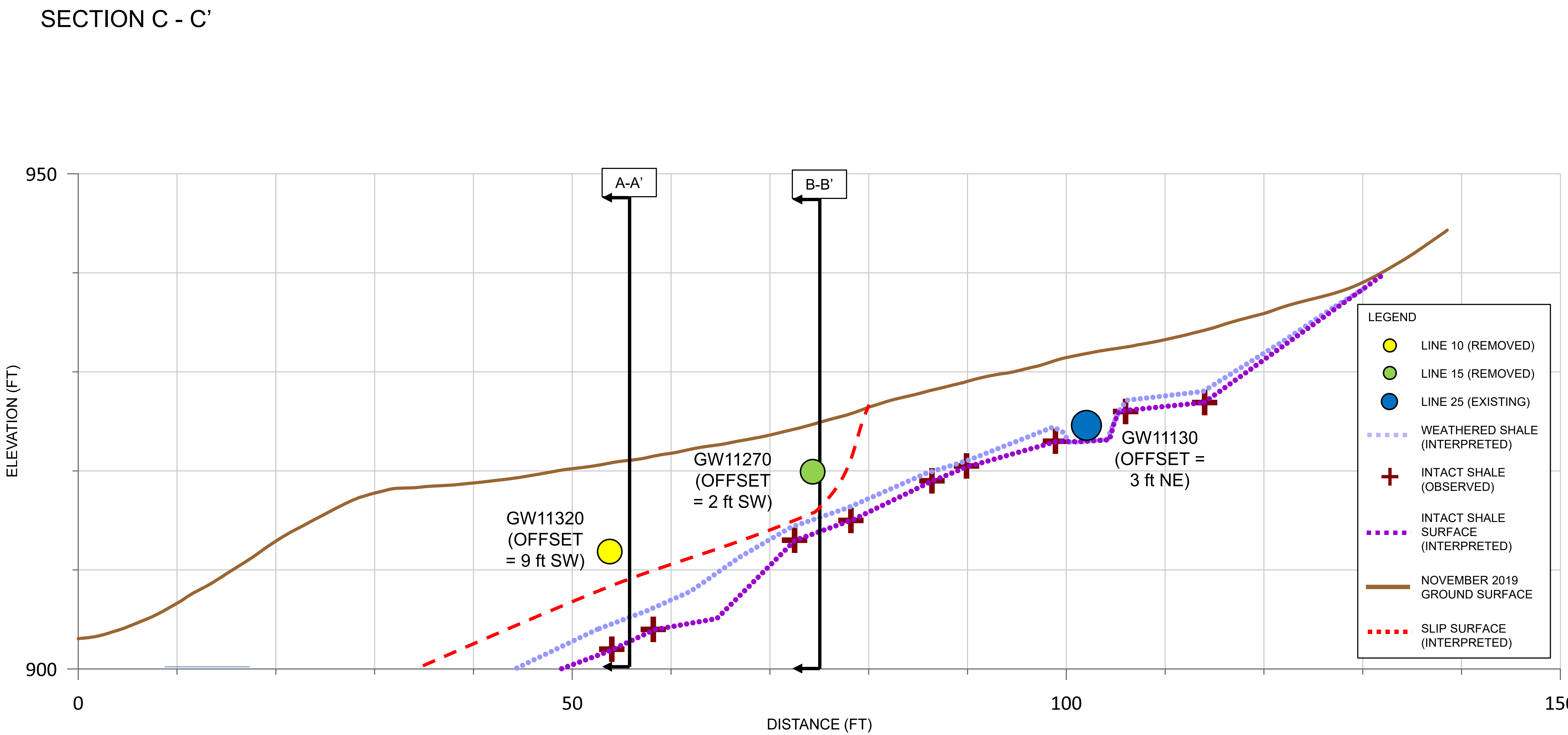

NOTES:
1. This figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. All dimensions are in feet and are approximate.
3. Line 10 and Line 15 girth weld coordinates are based on survey data collected during excavation, provided by SGC Engineering. Surveyed pipeline centerline data collected by SGC (May 6, 2020).
4. Ground profile based on digital elevation model from November 2019 lidar data provided by TETLP.
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PREPARED BY:	FIGURE TITLE		
WCD	CROSS SECTION C-C'		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: H-5

0 5 10 mm in ANSI B sized paper

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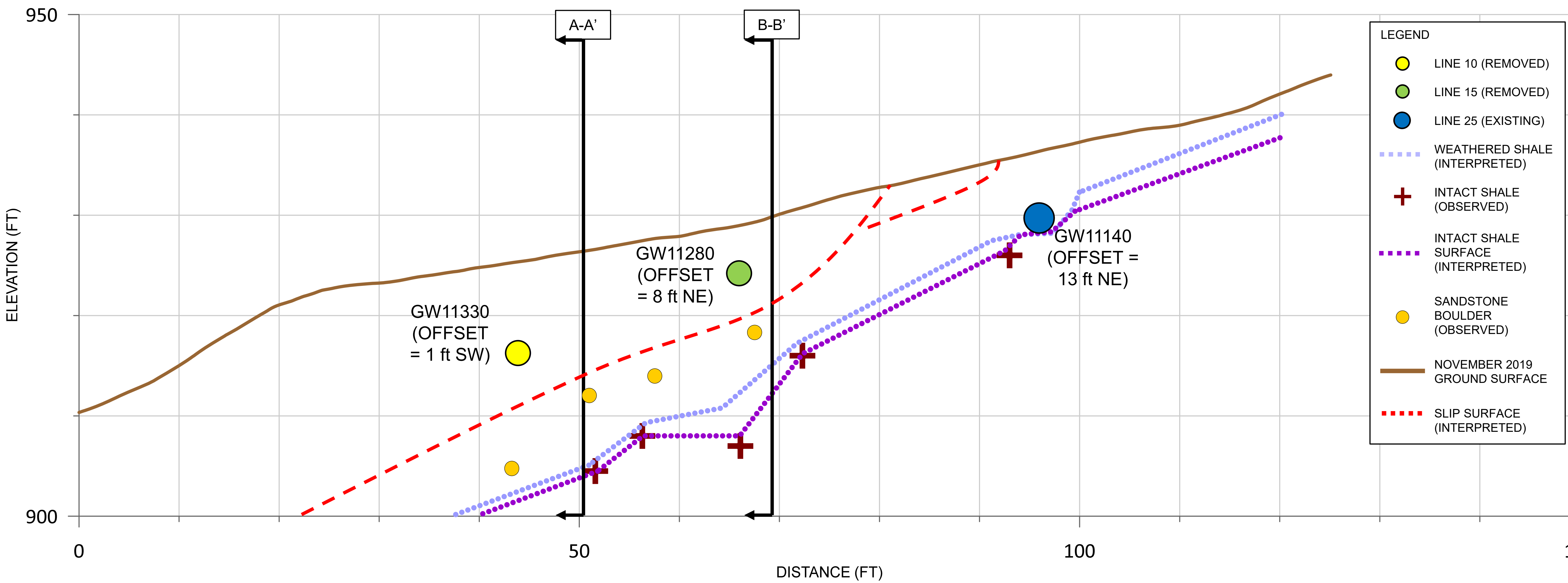
SECTION D - D'



NOTES:

1. This figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. All dimensions are in feet and are approximate.
3. Line 10 and Line 15 girth weld coordinates are based on survey data collected during excavation, provided by SGC Engineering. Surveyed pipeline centerline data collected by SGC (May 6, 2020).
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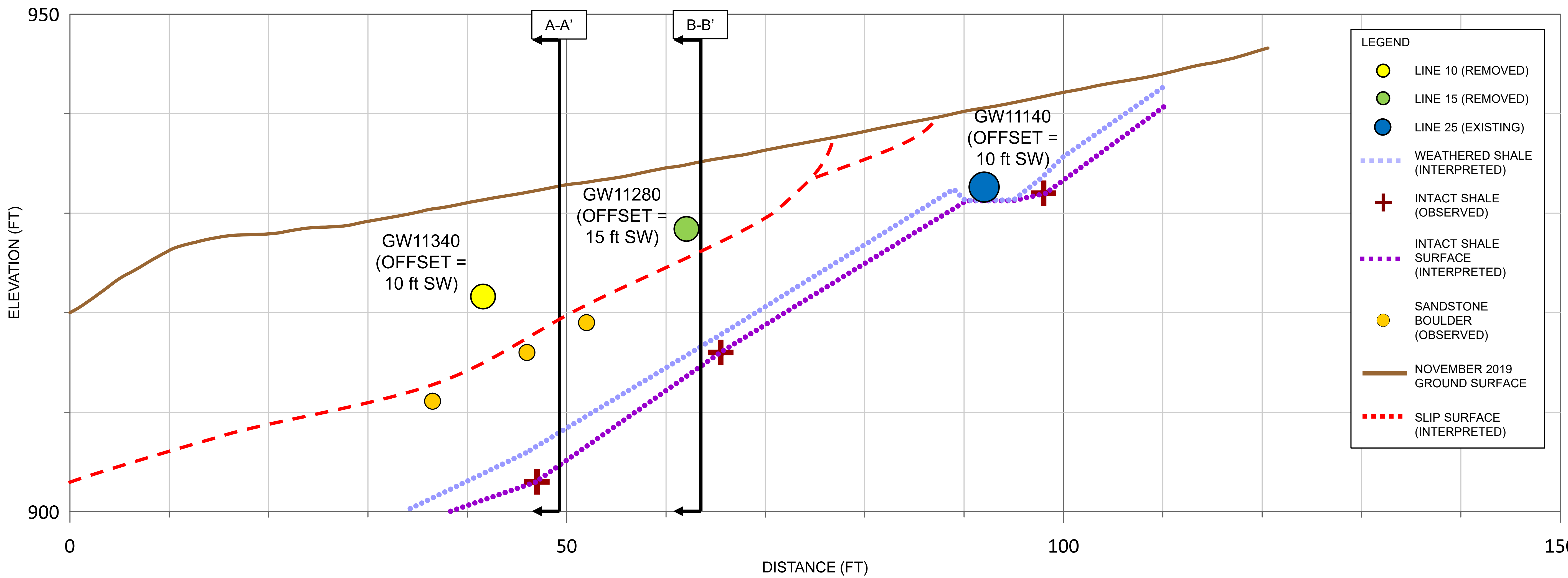
PREPARED BY:	FIGURE TITLE		
WCD	CROSS SECTION D-D'		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: H-6

0 5 10 mm in ANSI B sized paper

SECTION E - E'



NOTES:
1. This figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. All dimensions are in feet and are approximate.
3. Line 10 and Line 15 girth weld coordinates are based on survey data collected during excavation, provided by SGC Engineering. Surveyed pipeline centerline data collected by SGC (May 6, 2020).
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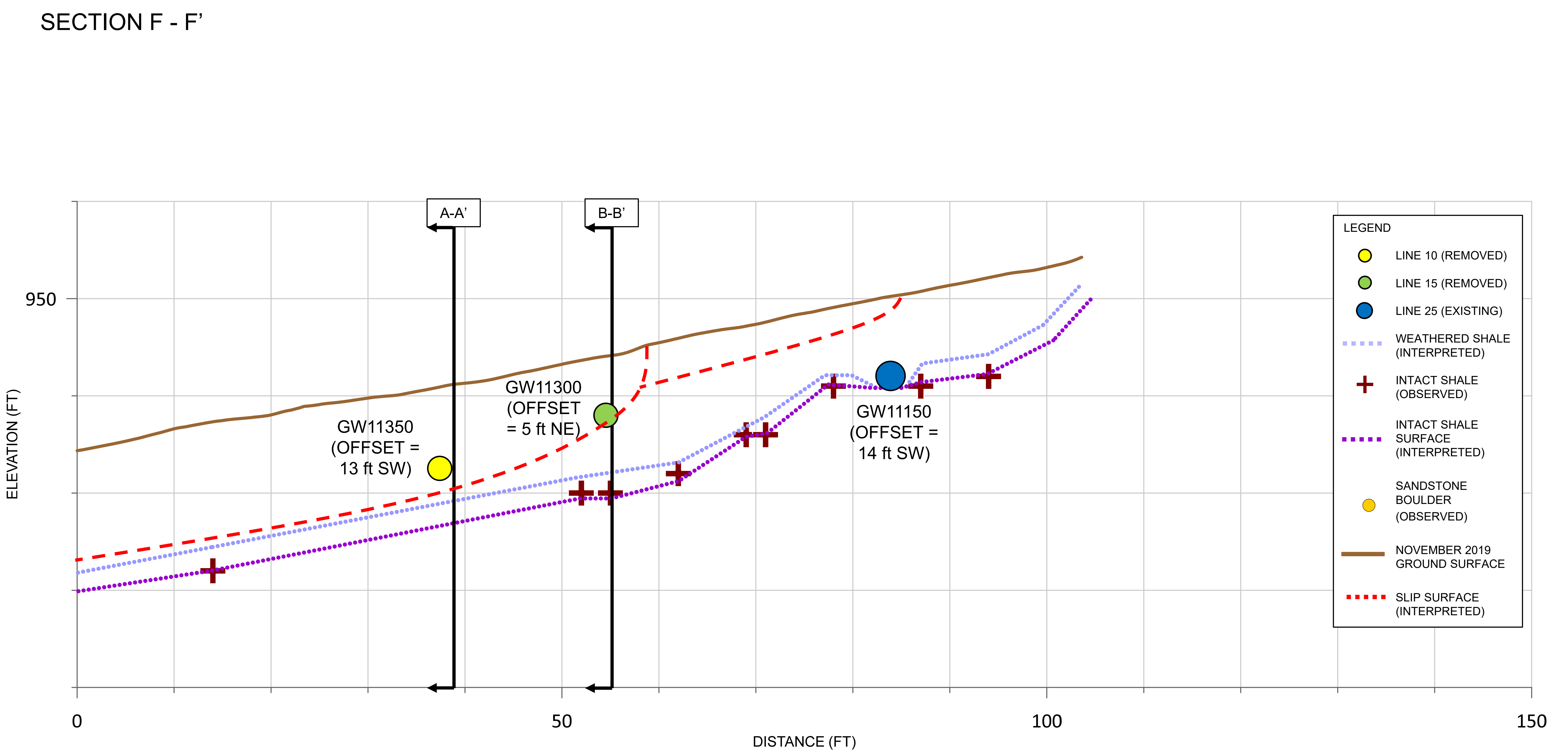
PREPARED BY:	FIGURE TITLE		
WCD	CROSS SECTION E-E'		
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: H-7

0 5 10 mm in ANSI B sized paper

04-2021



NOTES:

1. This figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. All dimensions are in feet and are approximate.
3. Line 10 and Line 15 girth weld coordinates are based on survey data collected during excavation, provided by SGC Engineering. Surveyed pipeline centerline data collected by SGC (May 6, 2020).
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PREPARED BY: WCD	FIGURE TITLE: CROSS SECTION F-F'
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP
APPROVED BY: CAD	SCALE: AS SHOWN; PROJECT NO: 1607024; FIGURE NO: H-8

0 5 10 mm in ANSI B sized paper

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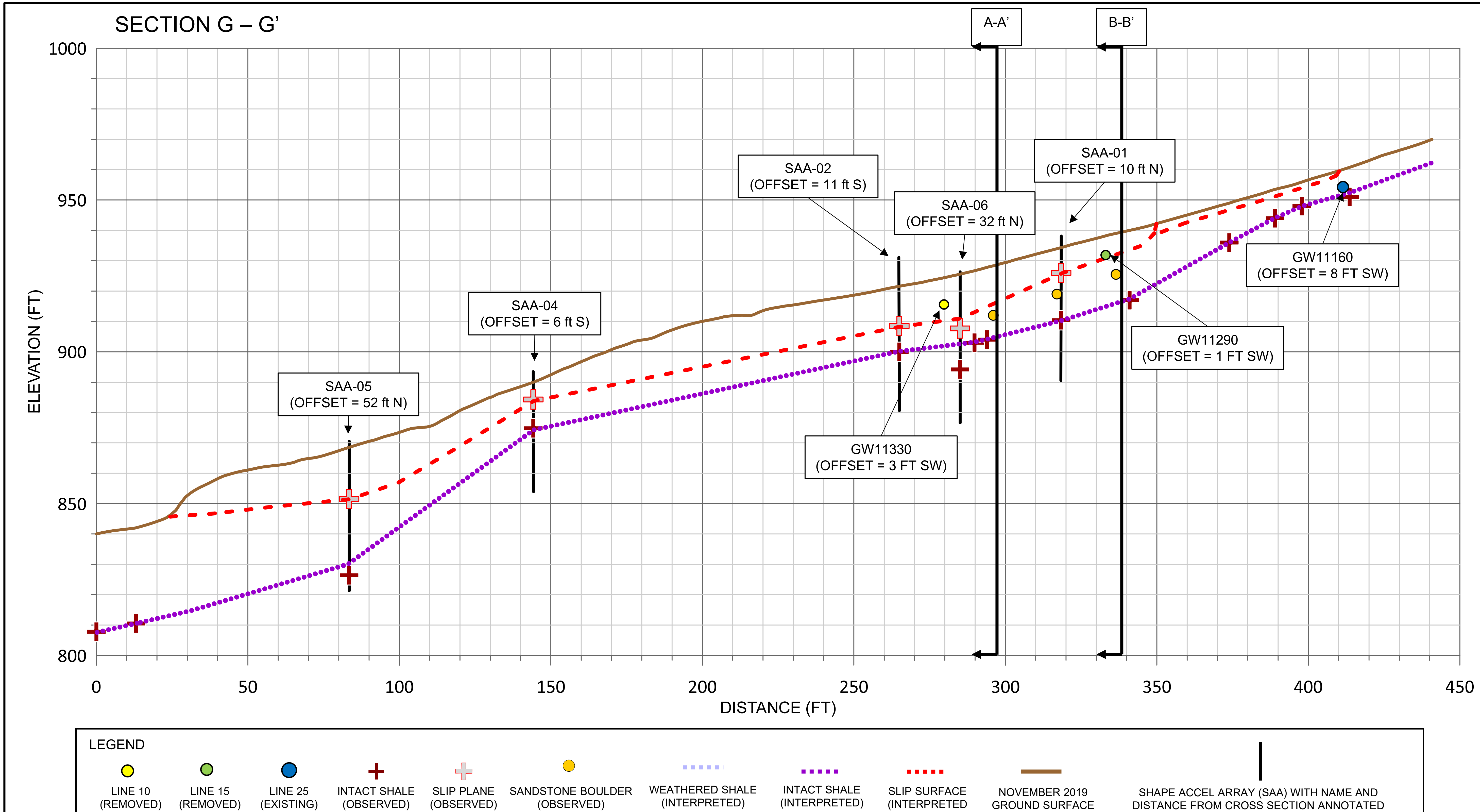

NOTES:

1. This figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. All dimensions are in feet and are approximate.
3. Line 10 and Line 15 girth weld coordinates are based on survey data collected during excavation, provided by SGC Engineering. Surveyed pipeline centerline data collected by SGC (May 6, 2020).
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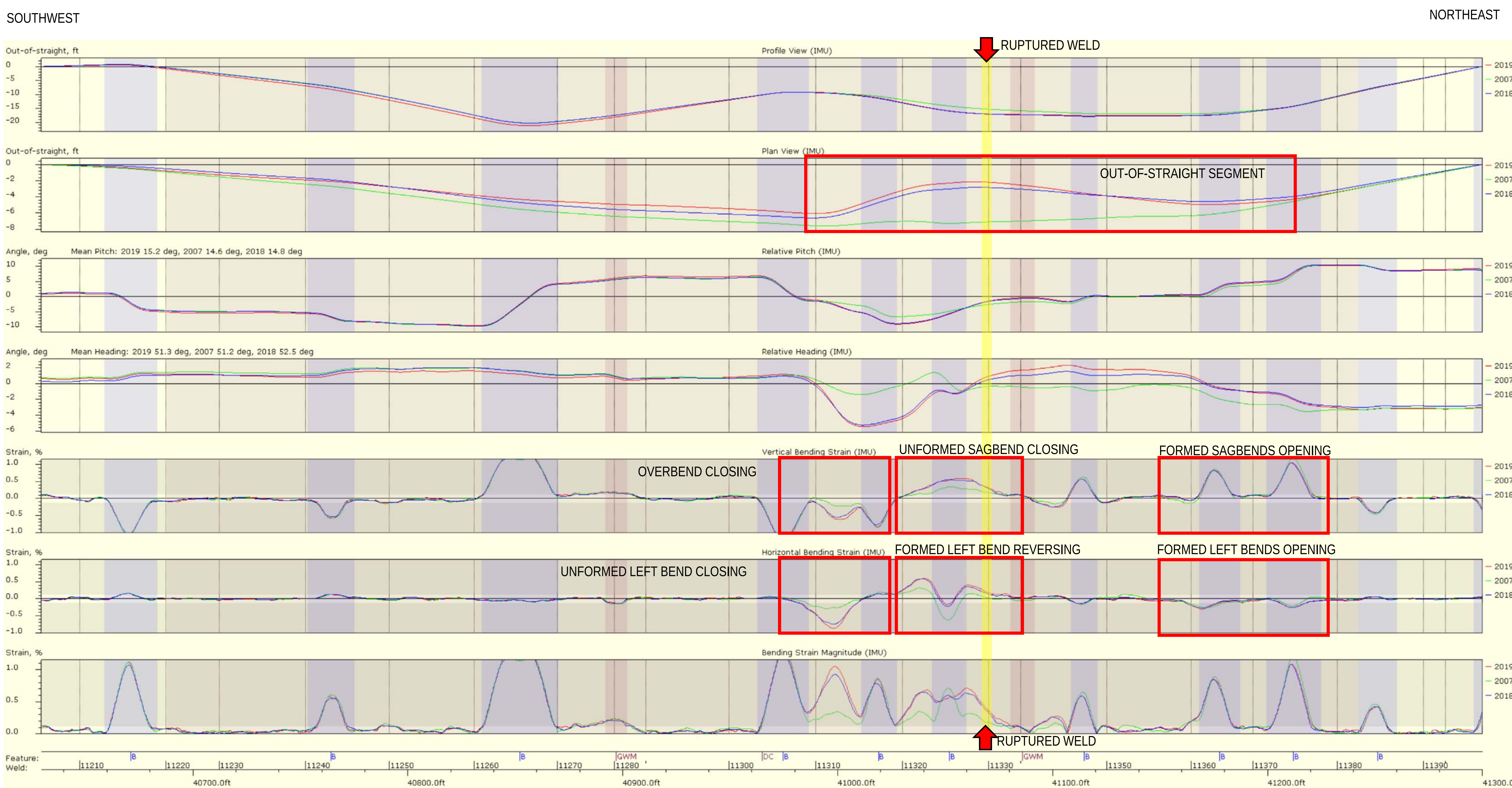
PREPARED BY: WCD	FIGURE TITLE: CROSS SECTION E-E'
CHECKED BY: TM	CLIENT: TEXAS EASTERN TRANSMISSION, LP
APPROVED BY: CAD	SCALE: AS SHOWN; PROJECT NO: 1607024; FIGURE NO: H-9

0 5 10 mm in ANSI B sized paper

APPENDIX I
LINE 10 IMU ASSESSMENT



NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Plots prepared by Baker Hughes using a 3 m gage length. Plots correspond to OWSV_10 2019 Strain Feature 17.
3. Blue zones are vendor-delineated formed bends.
4. GWM indicates vendor-delineated girth weld misalignment.
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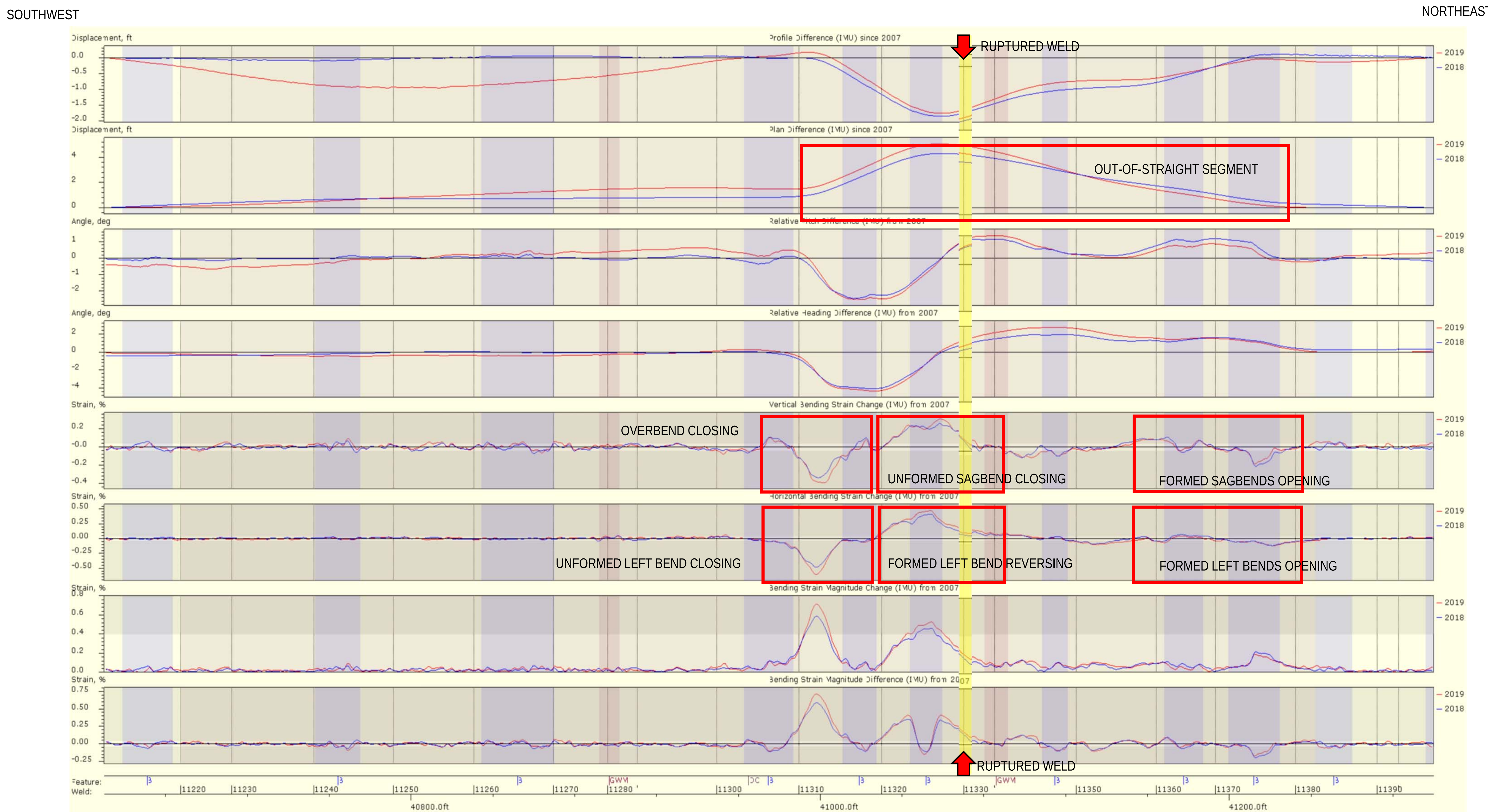
PREPARED BY: CRS	FIGURE TITLE: LINE 10 BENDING STRAIN FEATURE-SCALE PLOT		
CHECKED BY: WCD	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: I-1

0 5 10 mm in ANSI B sized paper

BGC ENGINEERING INC.



NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Plots prepared by Baker Hughes using a 3 m gage length. Plots correspond to OWSV_10 2019 Strain Feature 17.
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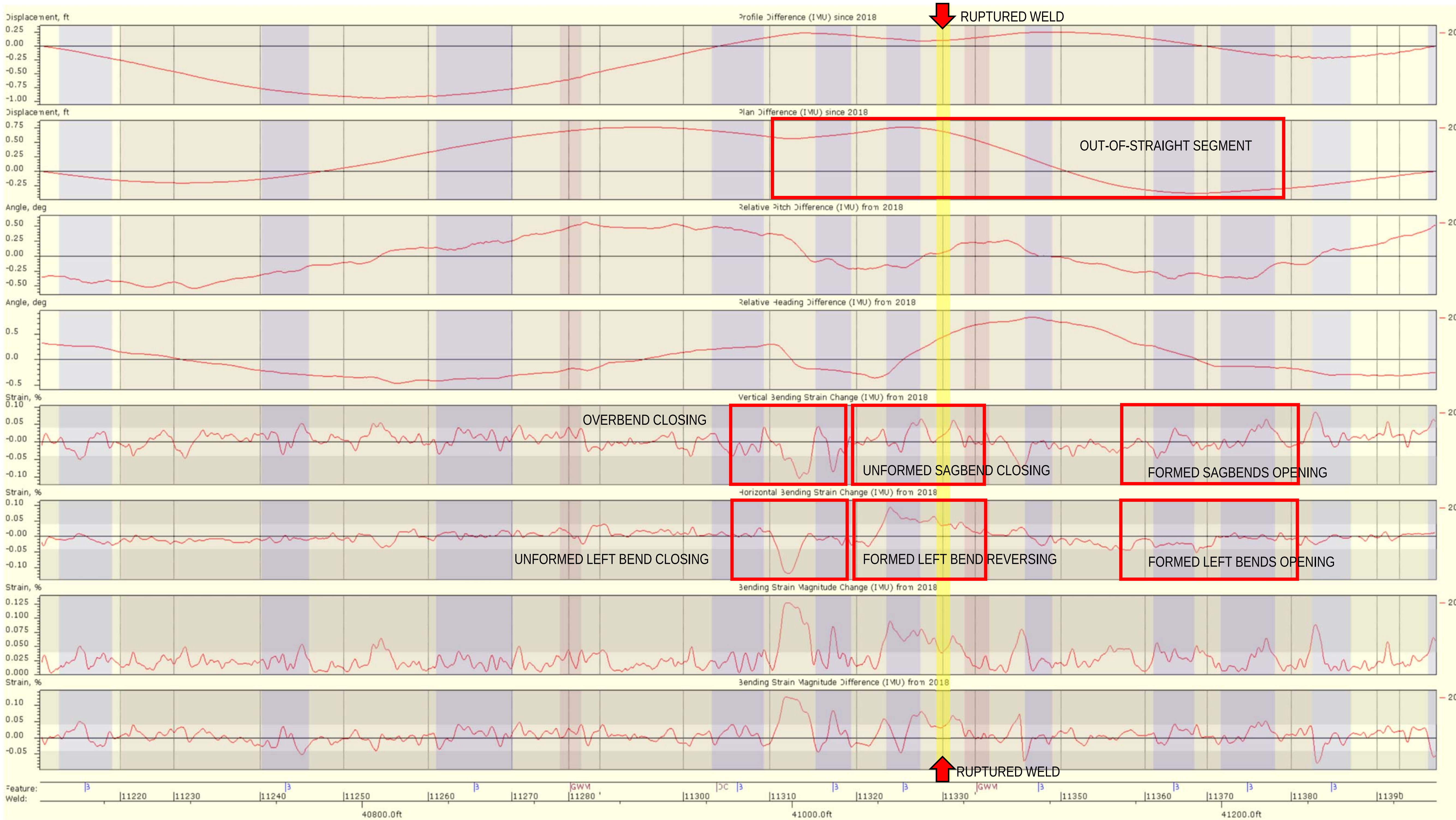
PREPARED BY: CRS	FIGURE TITLE: LINE 10 BENDING STRAIN DIFFERENCES (2007 BASE)			
CHECKED BY: WCD	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: I-2	

0 5 10 mm in ANSI B sized paper

04-2021

SOUTHWEST NORTHEAST



NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Plots prepared by Baker Hughes using a 3 m gage length. Plots correspond to OWSV_10 2019 Strain Feature 17.
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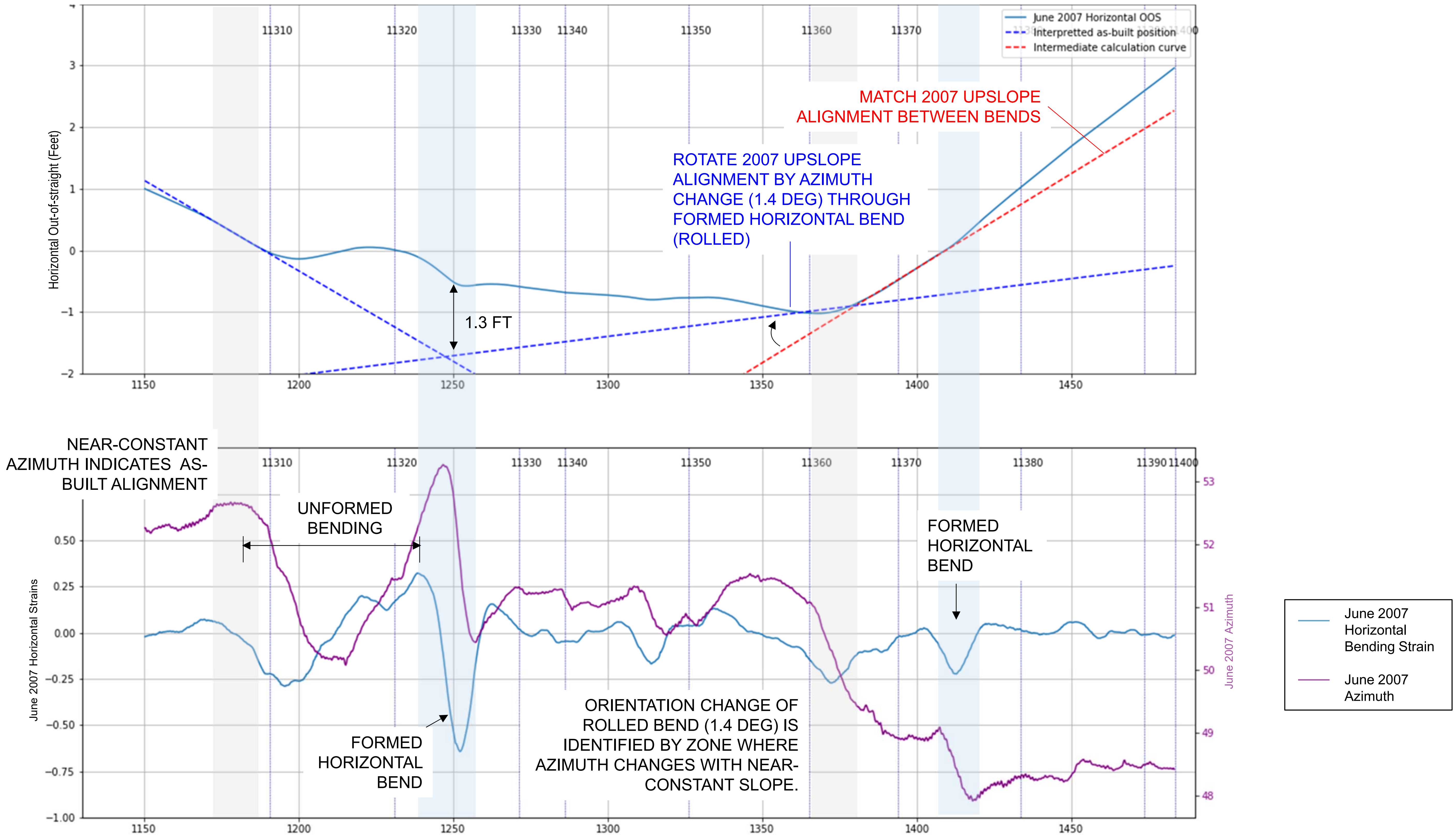
PREPARED BY: CRS	FIGURE TITLE: LINE 10 BENDING STRAIN DIFFERENCES (2018 BASE)		
CHECKED BY: WCD	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: I-3

0 5 10 mm in ANSI B sized paper

BGC ENGINEERING INC.



NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Plots prepared using raw data provided by Baker Hughes.
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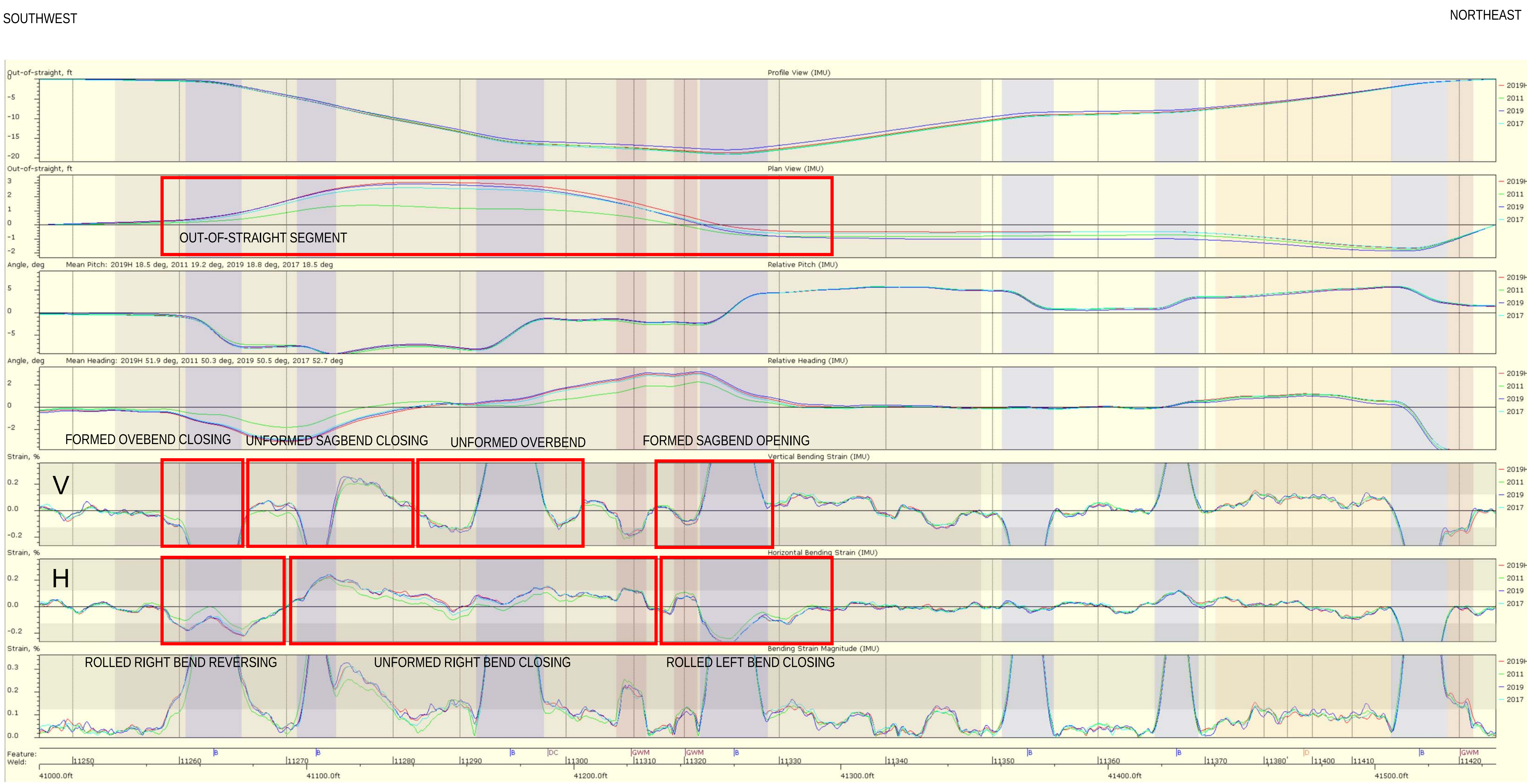
PREPARED BY: CRS	FIGURE TITLE: LINE 10 INFERRED AS-BUILT POSITION
CHECKED BY: WCD	CLIENT: TEXAS EASTERN TRANSMISSION, LP
APPROVED BY: CAD	SCALE: AS SHOWN; PROJECT NO: 1607024; FIGURE NO: I-4

0 5 10 mm in ANSI B sized paper

APPENDIX J
LINE 15 IMU ASSESSMENT



NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Plots prepared by Baker Hughes using a 3 m gage length. Plots correspond to OWSV_15 2019 Strain Feature 29.
3. 2019H corresponds to the October 2019 IMU run. 2019 corresponds to the May 2019 IMU run.
4. Blue zones are vendor-delineated formed bends.
5. GWM indicates vendor-delineated girth weld misalignment.
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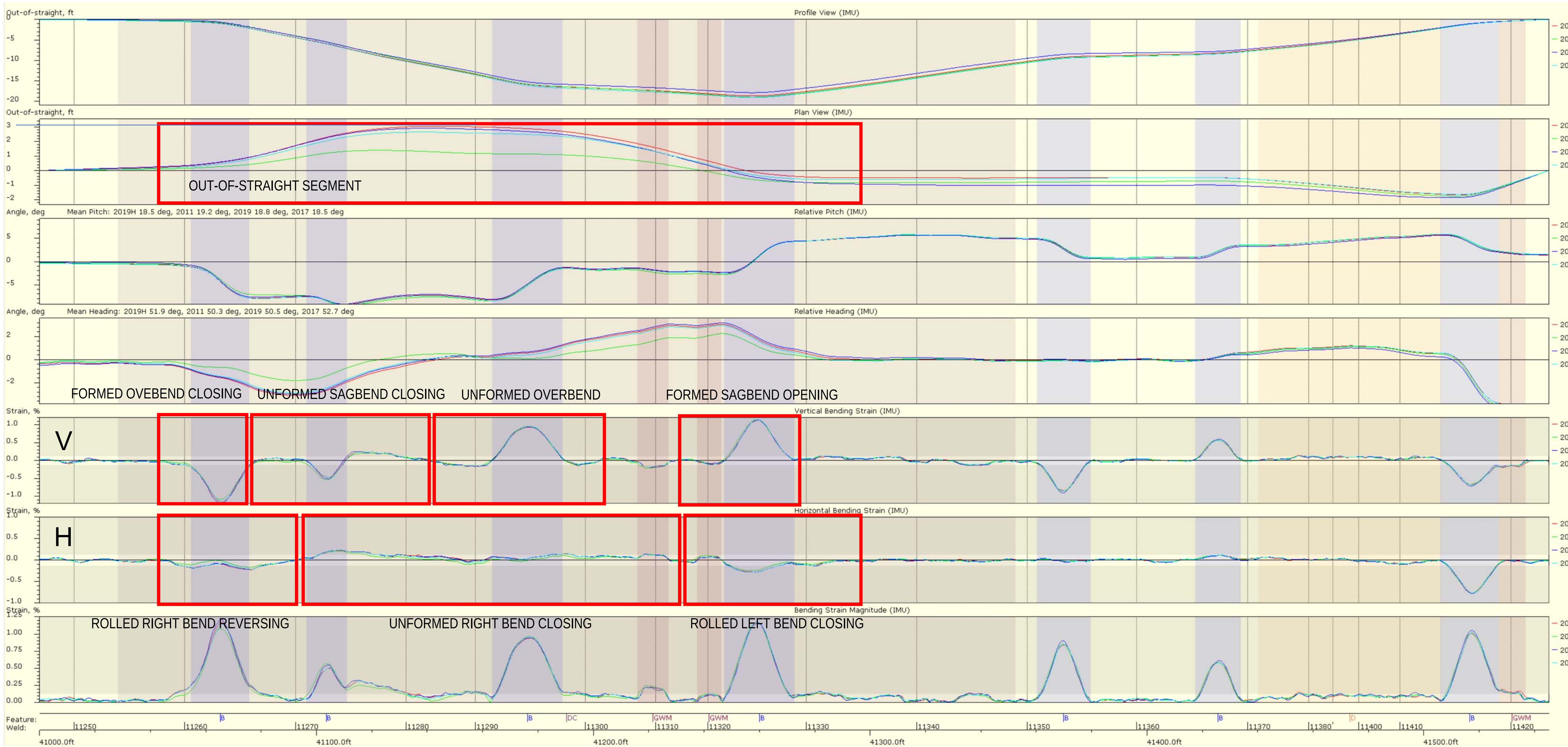
PREPARED BY: CRS	FIGURE TITLE: LINE 15 BENDING STRAIN FEATURE-SCALE PLOT
CHECKED BY: WCD	CLIENT: TEXAS EASTERN TRANSMISSION, LP
APPROVED BY: CAD	SCALE: AS SHOWN; PROJECT NO: 1607024; FIGURE NO: J-1

0 5 10 mm in ANSI B sized paper

SOUTHWEST NORTHEAST



NOTES:

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PREPARED BY: CRS	FIGURE TITLE: LINE 15 BENDING STRAIN BEND-SCALE PLOT		
CHECKED BY: WCD	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: J-2

0 5 10 mm in ANSI B sized paper

NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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PREPARED BY: CRS	FIGURE TITLE: LINE 15 BENDING STRAIN DIFFERENCES (2011 BASE)		
CHECKED BY: WCD	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: J-3

0 5 10 mm in ANSI B sized paper

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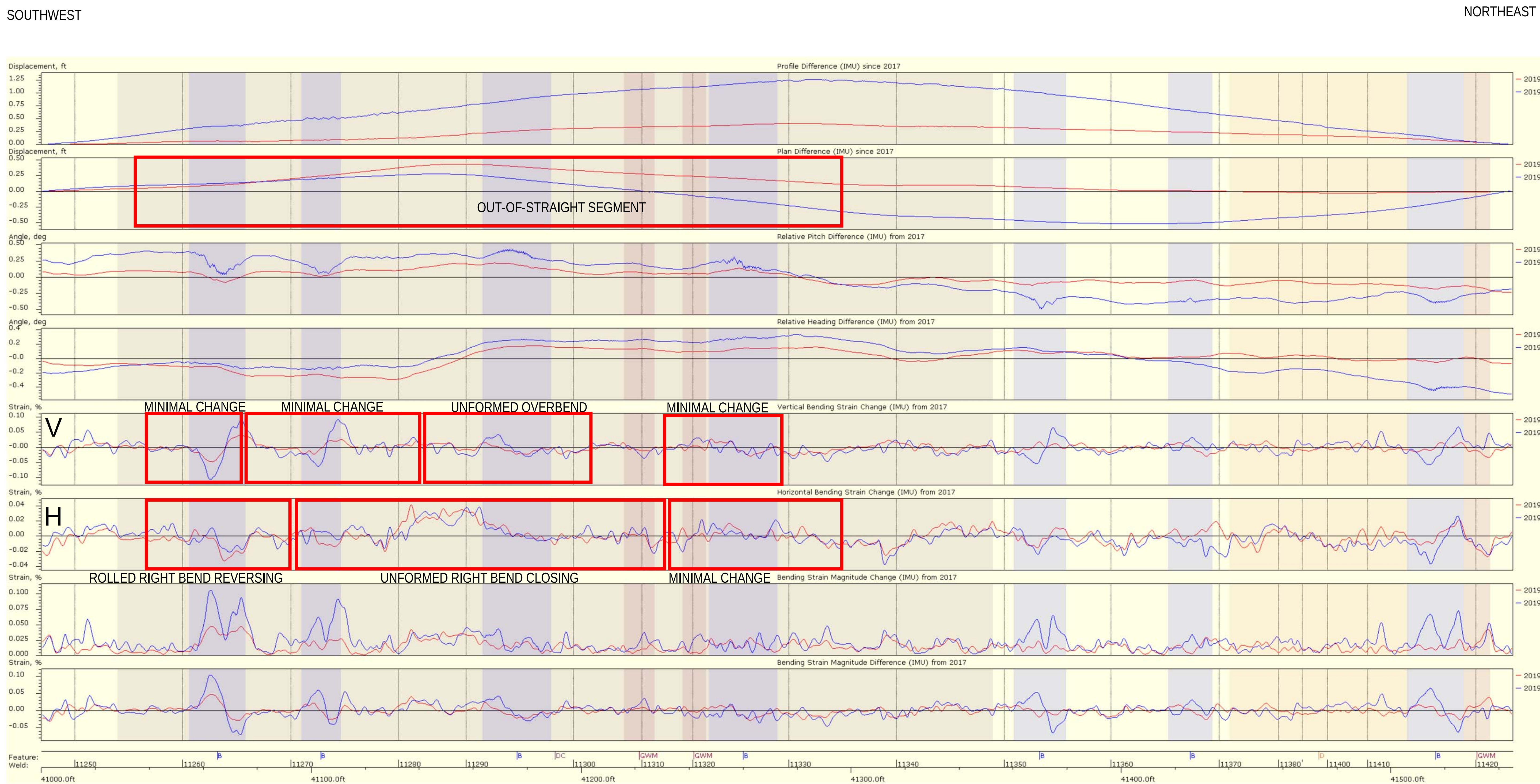

NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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4. Blue zones are vendor-delineated formed bends.
5. GWM indicates vendor-delineated girth weld misalignment.
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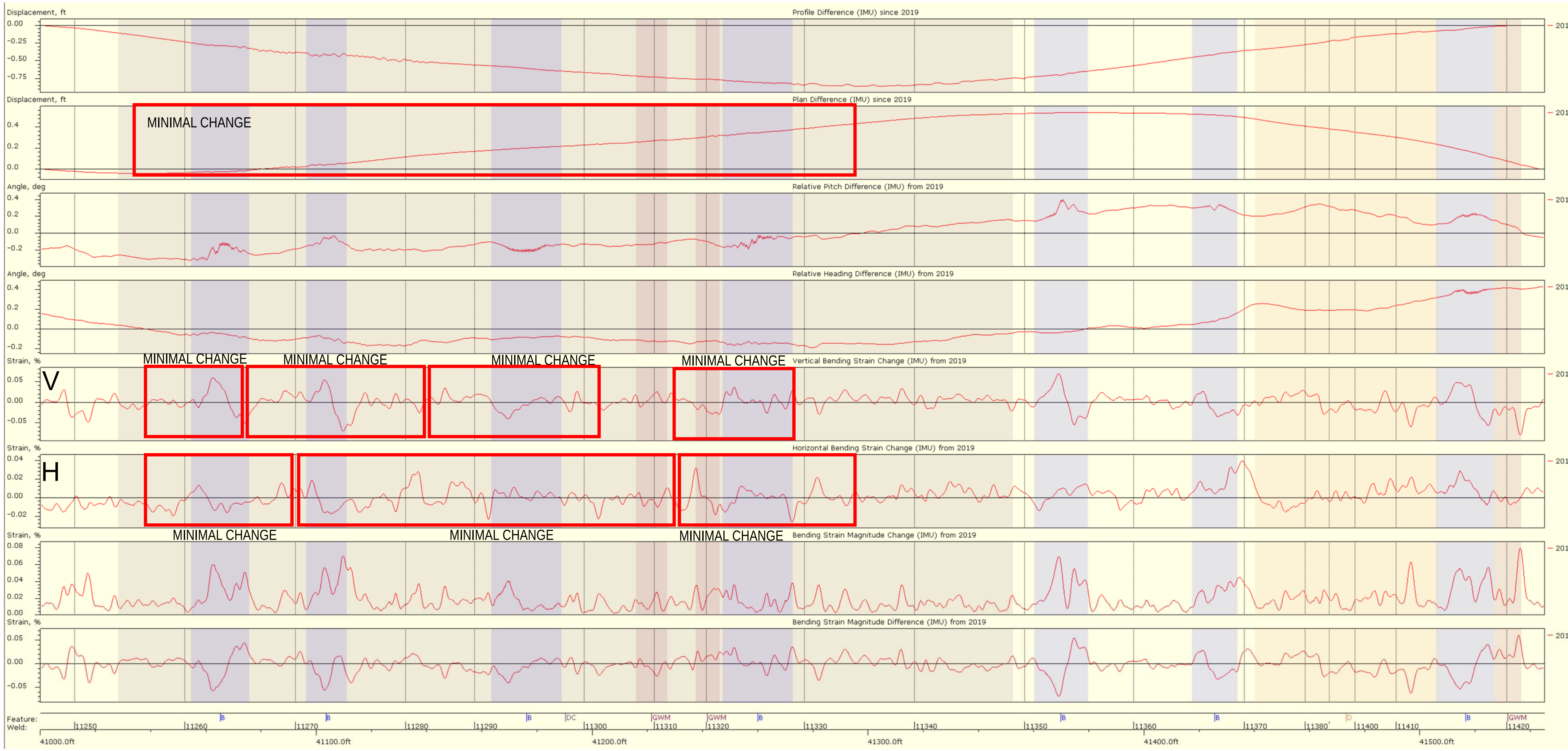
PREPARED BY: CRS	FIGURE TITLE: LINE 15 BENDING STRAIN DIFFERENCES (2017 BASE)		
CHECKED BY: WCD	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: J-4

0 5 10 mm in ANSI B sized paper

BGC ENGINEERING INC.

SOUTHWEST

NORTHEAST



NOTES:
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2. Plots prepared by Baker Hughes using a 3 m gage length. Plots correspond to OWSV_15 2019 Strain Feature 29.
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PREPARED BY:	FIGURE TITLE		
CRS	LINE 15 BENDING STRAIN DIFFERENCES (MAY 2019 BASE)		
CHECKED BY: WCD	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: J-5

0 5 10 mm in ANSI B sized paper

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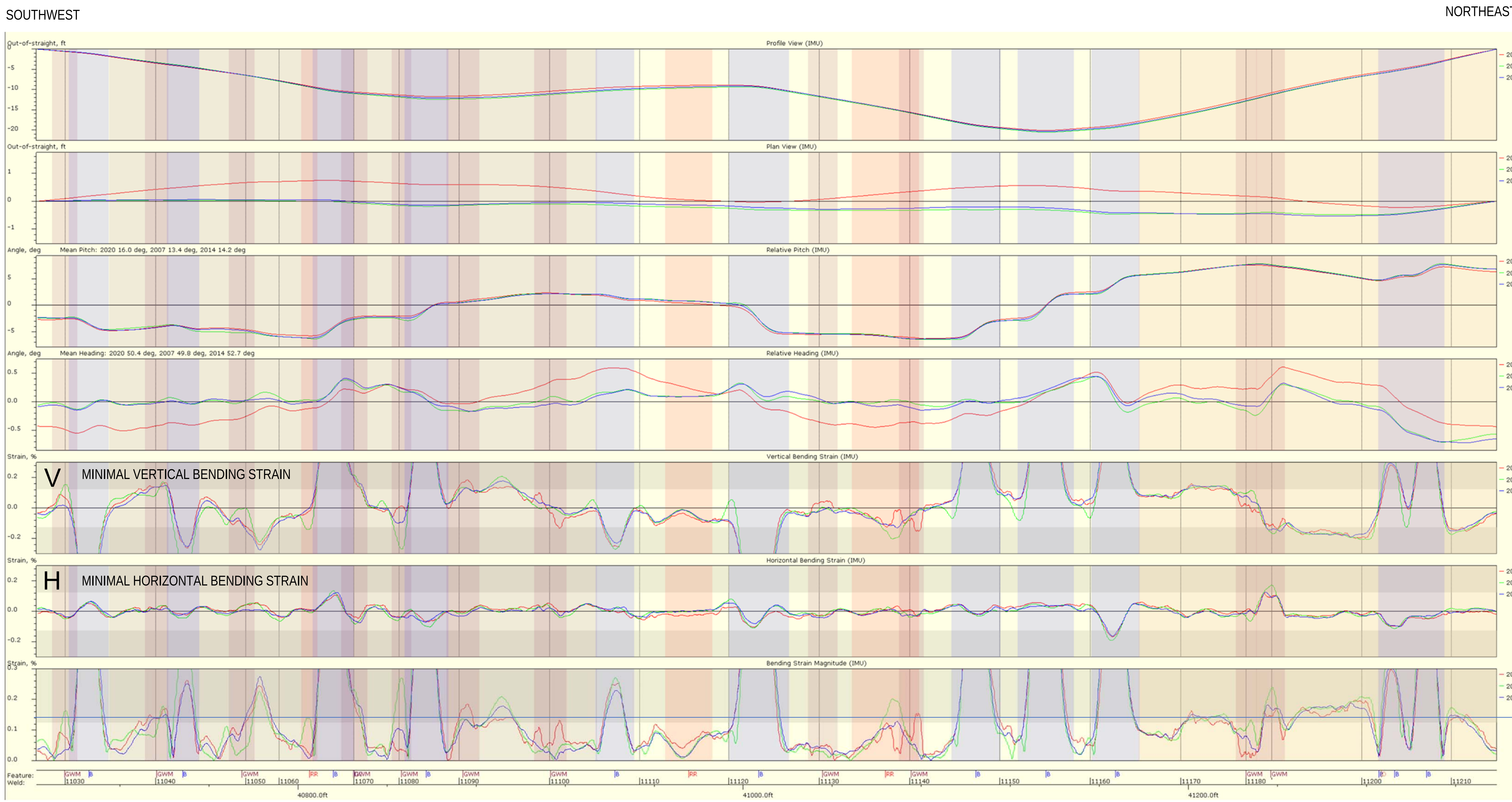
APPENDIX K
LINE 25 IMU ASSESSMENT

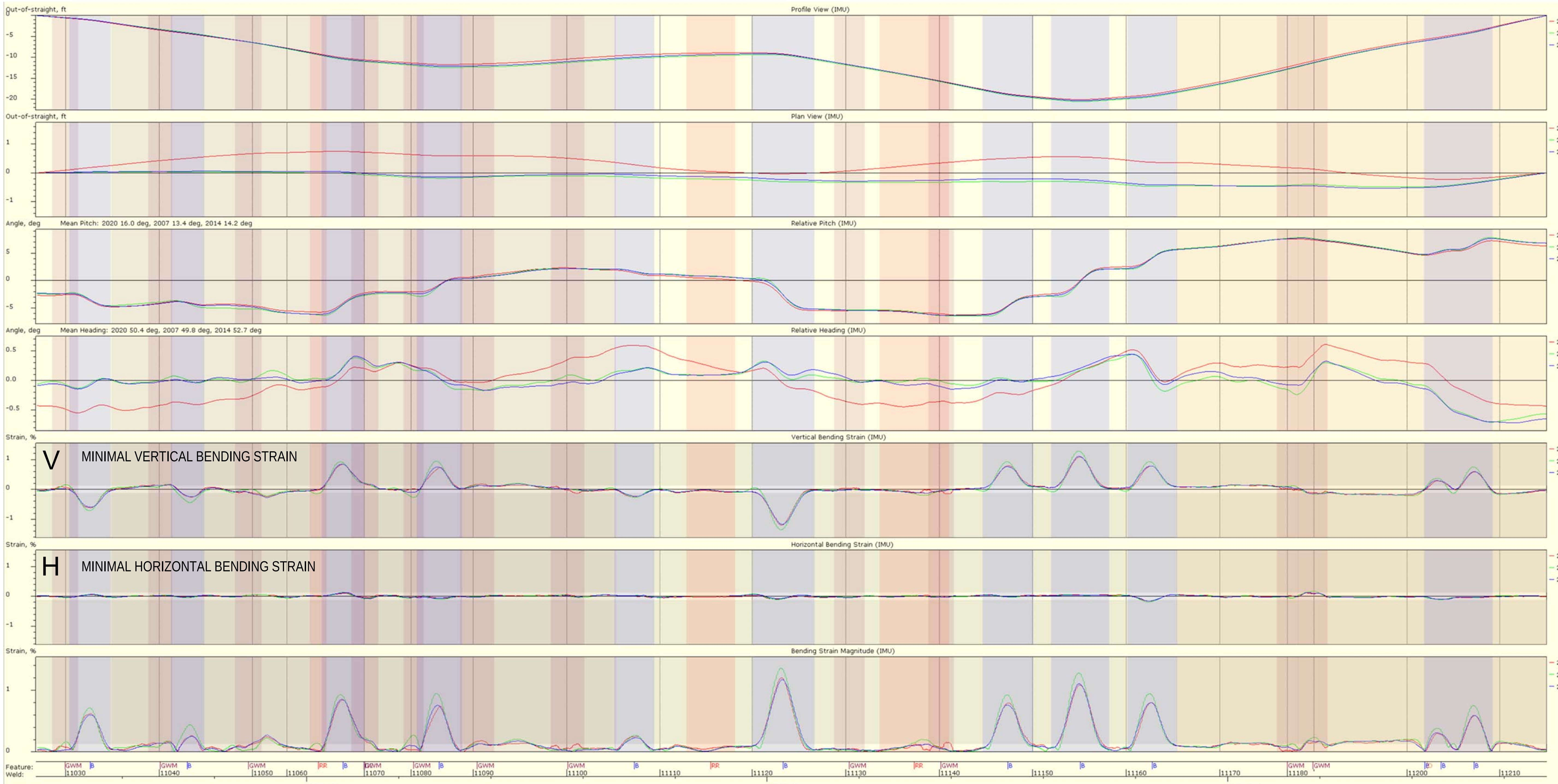


NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Plots prepared by Baker Hughes at special request using a 3 m gage length. No vendor-identified strain feature was reported.
3. Blue zones are vendor-delineated formed bends.
4. GWM indicates vendor-delineated girth weld misalignment.
5. RR indicates vendor-delineated Red Rings (spurious data).
6. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: WCD	FIGURE TITLE: LINE 25 BENDING STRAIN FEATURE-SCALE PLOT		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: K-1

0 5 10 mm in ANSI B sized paper



NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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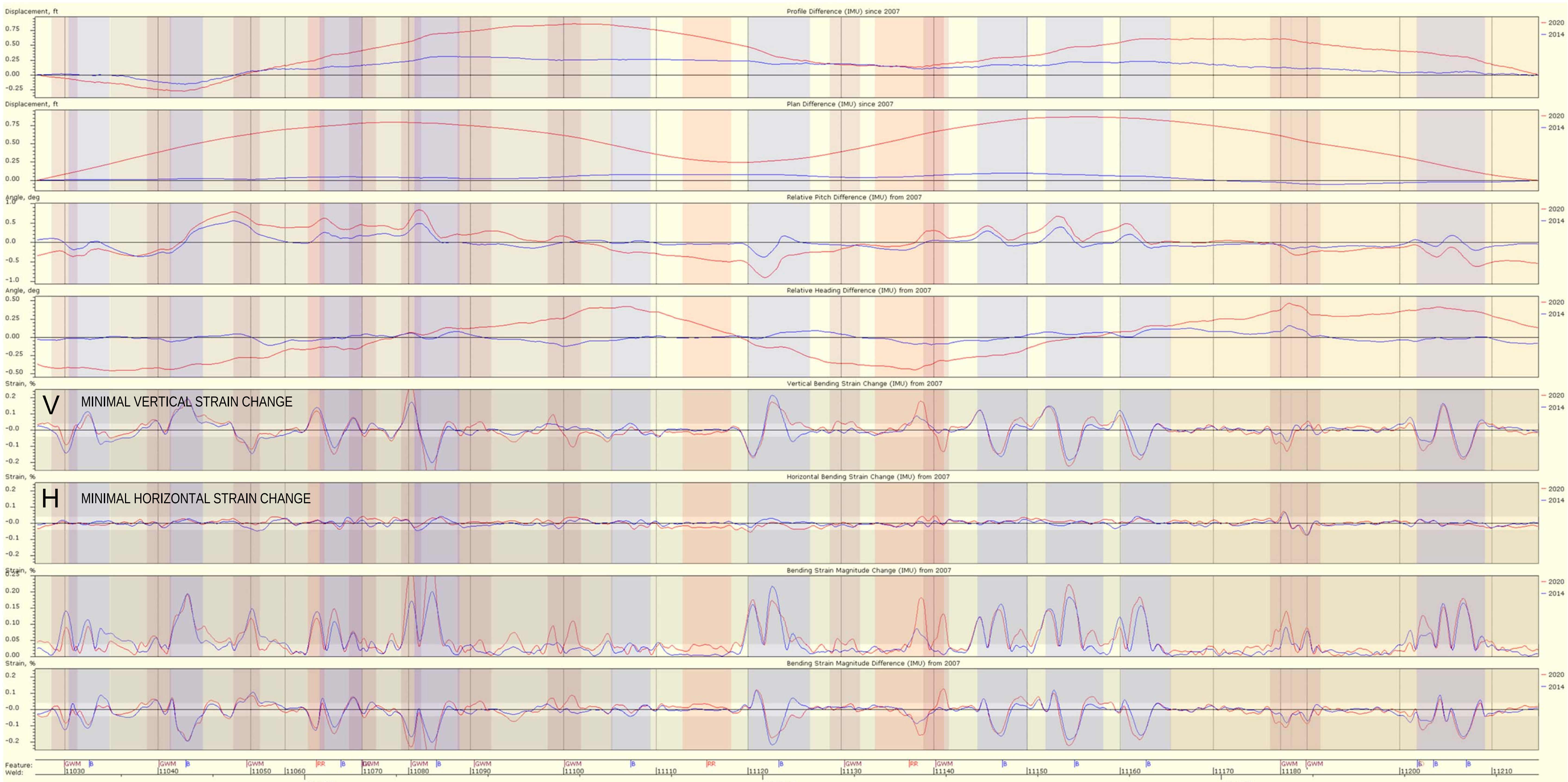
PREPARED BY: WCD	FIGURE TITLE: LINE 25 BENDING STRAIN BEND-SCALE PLOT			
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: K-2	

0 5 10 mm in ANSI B sized paper

04-2021

SOUTHWEST NORTHEAST



NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Plots prepared by Baker Hughes at special request using a 3 m gage length. No vendor-identified strain feature was reported.
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5. RR indicates vendor-delineated Red Rings (spurious data).
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PREPARED BY: WCD	FIGURE TITLE: LINE 25 BENDING STRAIN DIFFERENCES (2007 BASE)		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: K-3

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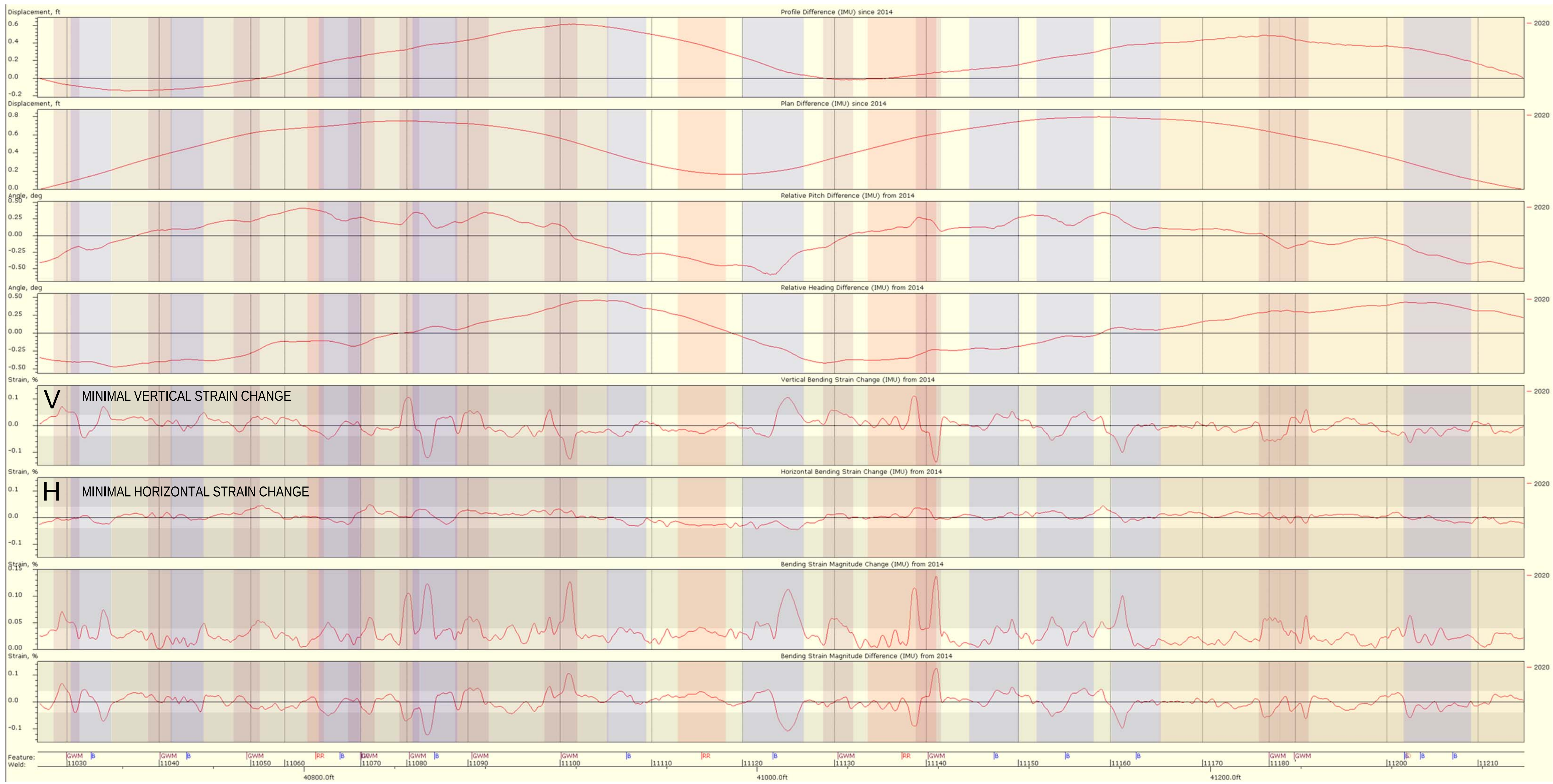
SOUTHWEST NORTHEAST



NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Plots prepared by Baker Hughes at special request using a 3 m gage length. No vendor-identified strain feature was reported.
3. Blue zones are vendor-delineated formed bends.
4. GWM indicates vendor-delineated girth weld misalignment.
5. RR indicates vendor-delineated Red Rings (spurious data).
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PREPARED BY: WCD	FIGURE TITLE: LINE 25 BENDING STRAIN DIFFERENCES (2014 BASE)		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: K-4

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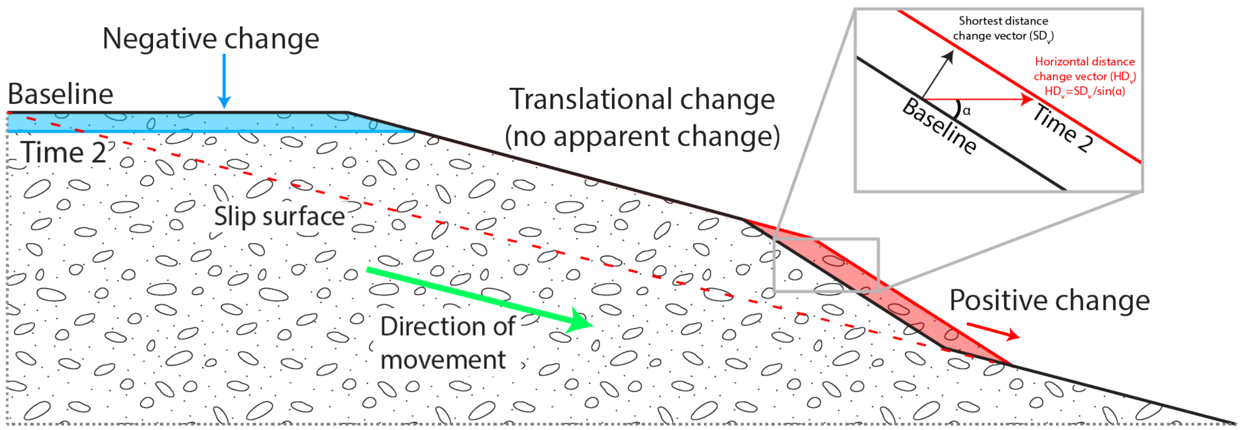
APPENDIX L
LIDAR CHANGE DETECTION RESULTS

L.1. METHODOLOGY

LCD is performed by computing the topographical difference between two 3D models of a given site collected at different points in time. Analysis of topographical change between ALS datasets involves spatially aligning datasets and determining the limit of detectable change ($LoD_{95\%}$) where 95% of the cumulative alignment error distribution is considered noise or instrument error.

The change detection results are presented as colour-contoured images illustrating the 3D shortest distance measurements of differences greater than the $LoD_{95\%}$ between the two datasets. Noise and/or errors may be present in the results where there are significant gaps or differences in point resolution between the two ALS datasets.

A limitation of ALS change detection analysis is the inability to detect translational movement where the ground and slip surfaces are parallel; in this instance, the ground surface appears unchanged between the two datasets (Schematic L-1). Because the ALS data represent the surface topography at each date, the analysis reflects surface changes only and cannot necessarily be extrapolated to interpret slide movements at depth.



Schematic L-1: Simplified schematic diagram of a landslide showing positive change in the direction of movement. The amount of change along the shortest distance vector can be used to calculate the true horizontal change.

L.2. RESULTS

Using the available ALS datasets, six LCD analyses were conducted (Table L-1), three at the regional scale and three at the scale of the Site. The results of the LCD analyses and various profiles are reported in a series of figures as outlined in Table L-2 and in Figures L-1 through L-22.

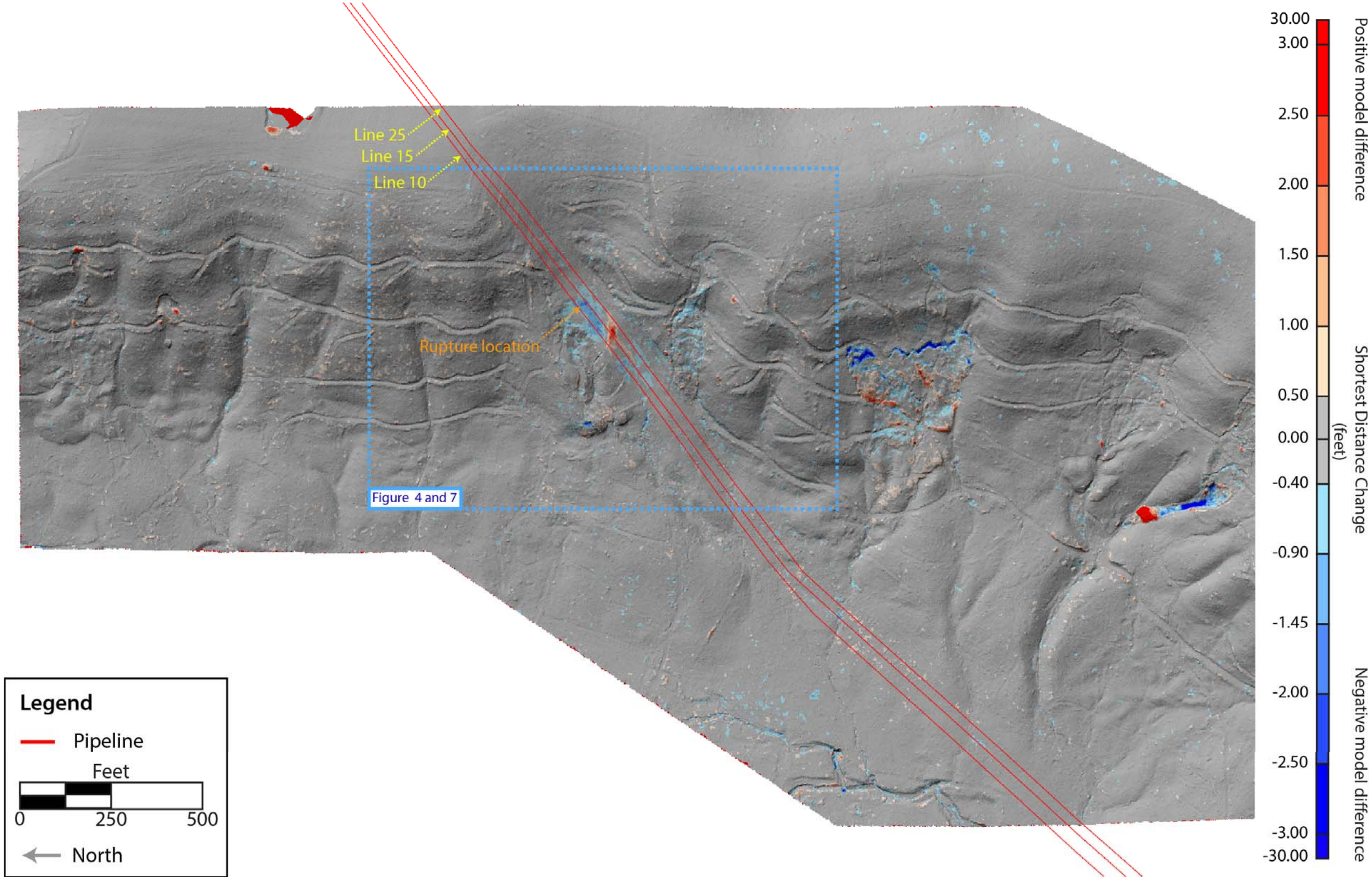
Table L-1. Lidar change detection analyses and observations.

Baseline dataset	Comparison dataset	Extent	Mean alignment error (ft)	Standard deviation (ft)	Limit of Detectable Change (LoD95%) (ft)
2017	November 2019	Regional	0.02	0.22	-0.40 to +0.50
2017	November 2019	FCI site	0.02	0.19	-0.35 to +0.40
2017	May 06, 2020	Regional	0.02	0.22	-0.40 to +0.50
2017	May 06, 2020	FCI site	-0.01	0.20	-0.40 to +0.40
November 2019	May 06, 2020	Regional	0.00	0.12	-0.25 to +0.25
November 2019	May 06, 2020	FCI site	0.00	0.12	-0.20 to +0.20

Table L-2. Summary of lidar change detection results.

Figure	Date range	Limit of Detectable Change (LoD95%) (ft)	View	Extent	Notes
Figure L-1	2017 vs November 2019	-0.40 to +0.50	Plan view	Regional extent	Pipelines overlain
Figure L-2	2017 vs May 06, 2020	-0.40 to +0.50	Plan view	Regional extent	Pipelines overlain
Figure L-3	2019 vs May 06, 2020	-0.25 to +0.25	Plan view	Regional extent	Pipelines overlain
Figure L-4	2017 vs November 2019	-0.35 to +0.40	Plan view	FCI site	Pipeline and IMU strains overlain
Figure L-5	2017 vs May 06, 2020	-0.40 to +0.40	Plan view	FCI site	Pipeline and IMU strains overlain
Figure L-6	2019 vs May 06, 2020	-0.20 to +0.20	Plan view	FCI site	Pipeline and IMU strains overlain
Figure L-7	2017 vs November 2019	-0.35 to +0.40	Oblique view	FCI site	Pipeline and IMU strains overlain
Figure L-8	2017 vs May 06, 2020	-0.40 to +0.40	Oblique view	FCI site	Pipeline and IMU strains overlain
Figure L-9	2019 vs May 06, 2020	-0.20 to +0.20	Oblique view	FCI site	Pipeline and IMU strains overlain
Figure L-10	2017 vs. May 06, 2020	-0.40 to +0.50	Plan view	Regional extent	Profiles A through H identified
Figure L-11	2017, 2019 and 2020	n/a	Profile	A1-A1’	Profile through FCI site (zoom in of road at mid-slope)
Figure L-12	2017, 2019 and 2020	n/a	Profile	A2-A2’	Profile through FCI site (zoom in of toe)
Figure L-13	2017, 2019 and 2020	n/a	Profile	A2-A2’	Profile through FCI site (zoom in of headscarp)
Figure L-14	2017, 2019 and 2020	n/a	Profile	A3-A3’	Profile through FCI site (zoom in of toe)

Figure	Date range	Limit of Detectable Change (LoD95%) (ft)	View	Extent	Notes
Figure L-15	2017, 2019 and 2020	n/a	Profile	A3-A3’	Profile through FCI site (zoom in of gully)
Figure L-16	2017, 2019 and 2020	n/a	Profile	B-B’	Profile through landslide adjacent to ROW
Figure L-17	2017, 2019 and 2020	n/a	Profile	C-C’	Profile through inactive landslide feature near the Site
Figure L-18	2017, 2019 and 2020	n/a	Profile	D-D’	Profile through inactive landslide feature near the Site
Figure L-19	2017, 2019 and 2020	n/a	Profile	E-E’	Profile through active landslide feature near the Site
Figure L-20	2017, 2019 and 2020	n/a	Profile	F-F’	Profile through active landslide feature near the Site
Figure L-21	2017, 2019 and 2020	n/a	Profile	G-G’	Profile through inactive landslide feature near the Site
Figure L-22	2017, 2019 and 2020	n/a	Profile	H-H’	Profile through active landslide feature near the Site



NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. 2017 ALS bare earth point data downloaded from Kentucky government portal (https://kygeonet.ky.gov/govmaps/).
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4. Shortest distance change detection analysis results presented on November 2019 ALS hillshade.
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PREPARED BY: MJL	FIGURE TITLE: REGIONAL LCD 2017 VS NOVEMBER 2019			
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-1	

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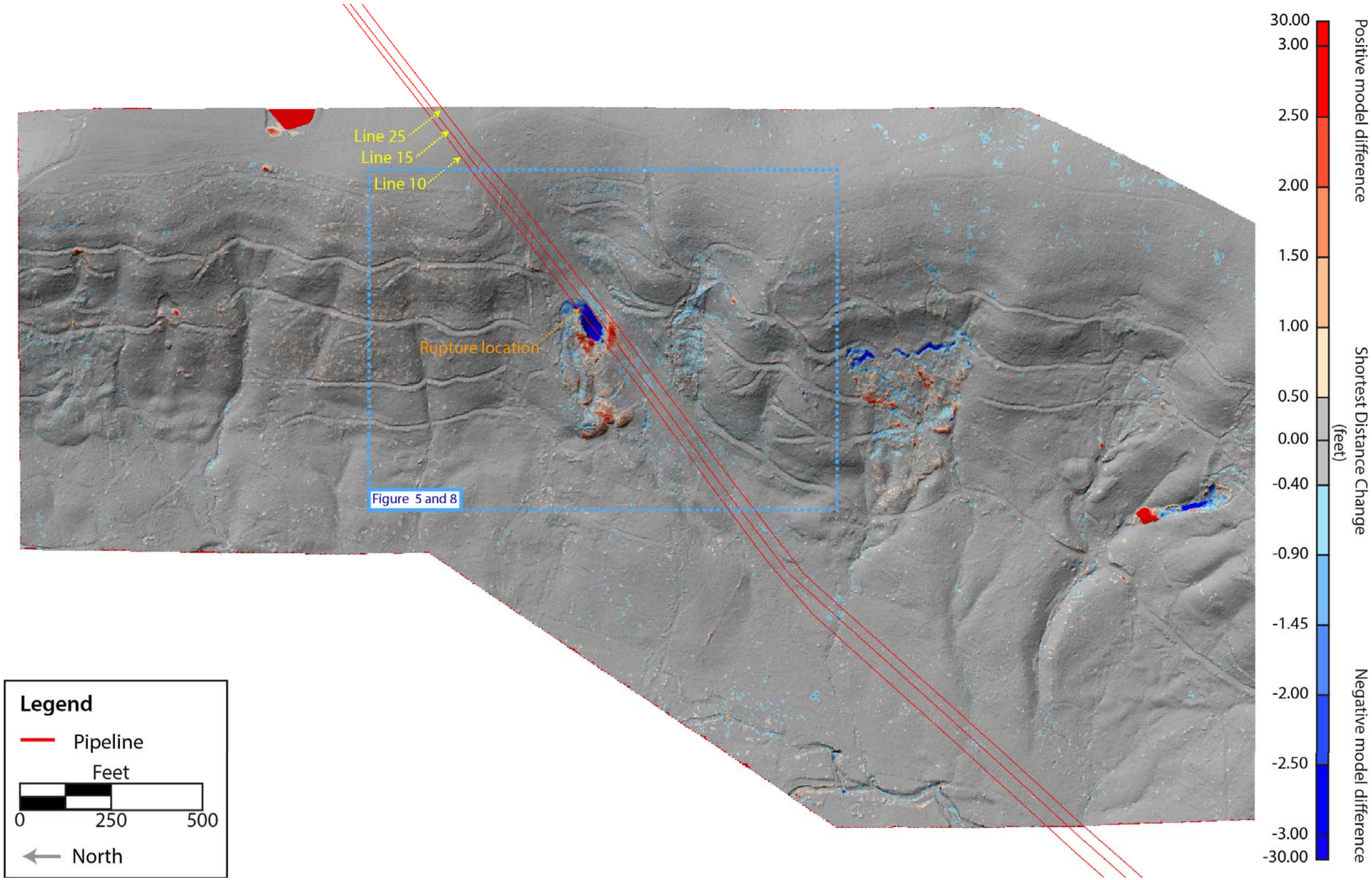

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
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PREPARED BY: MJL	FIGURE TITLE: REGIONAL LCD 2017 VS MAY 6, 2020		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-2

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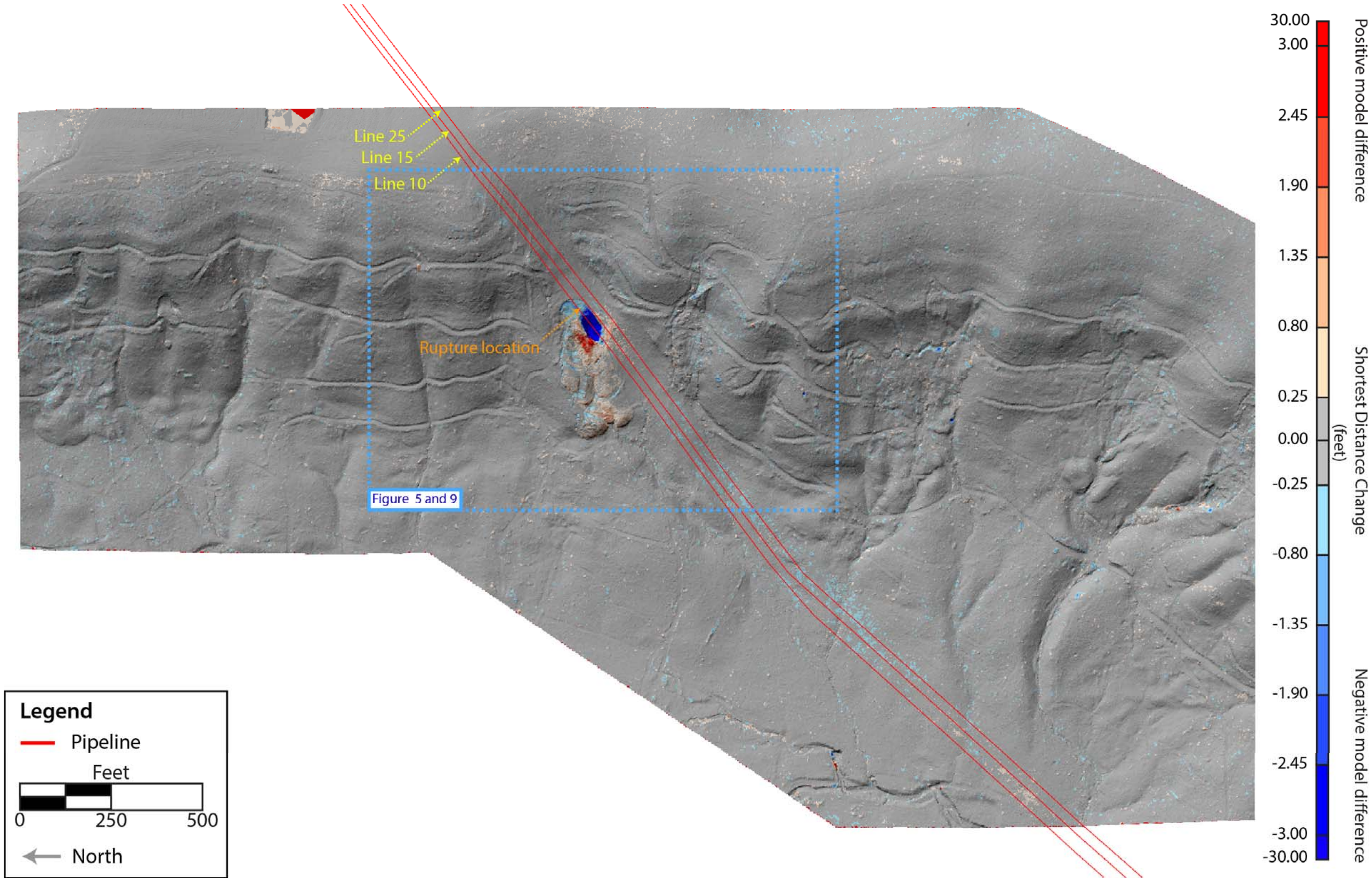

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. November 2019 and May 2020 ALS point cloud data acquired by Quantum Spatial and provided to BGC by TETLP.
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PREPARED BY: MJL	FIGURE TITLE: REGIONAL LCD NOVEMBER 2019 VS MAY 6, 2020			
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-3	

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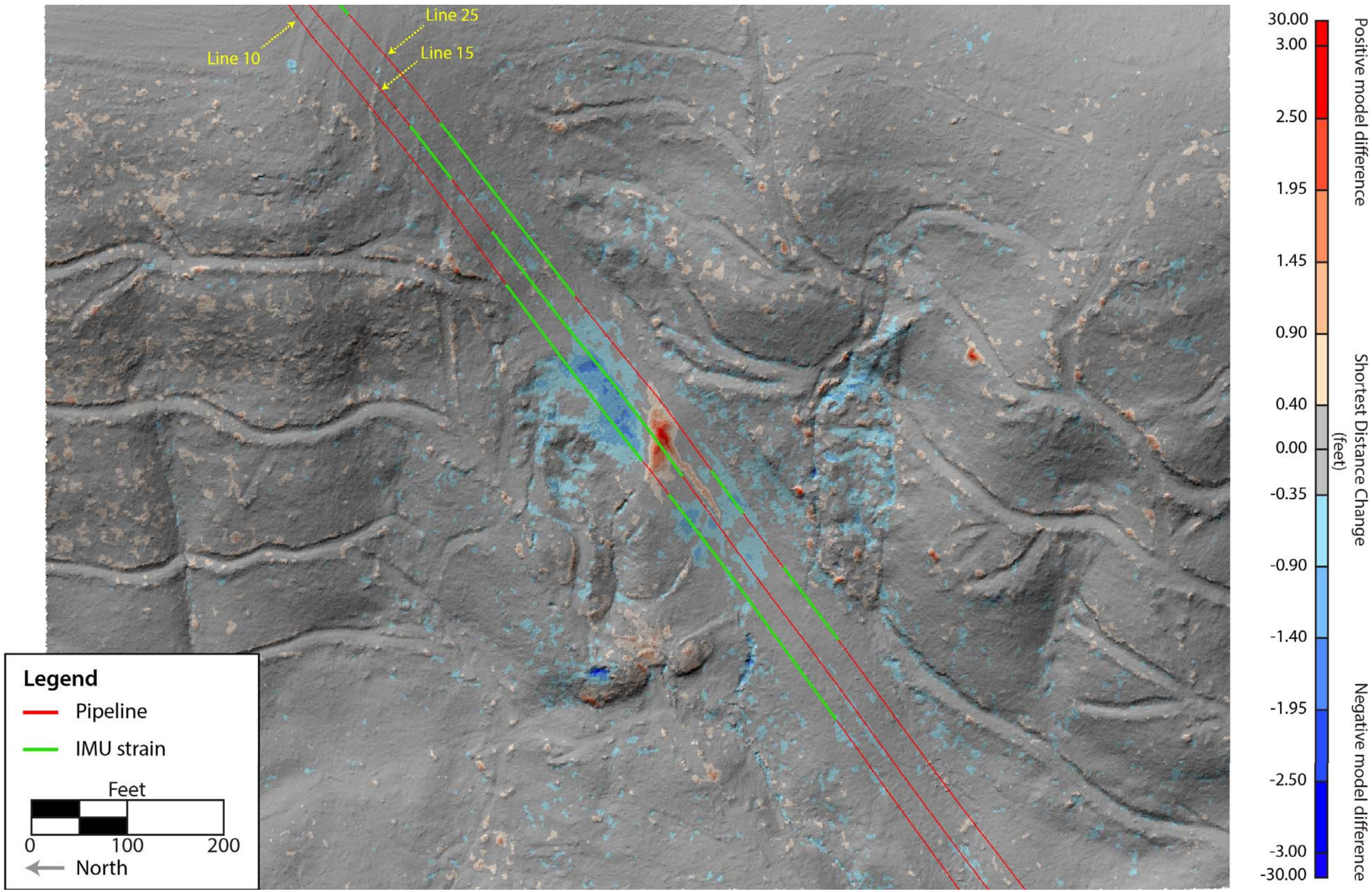

NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. 2017 ALS bare earth point data downloaded from Kentucky government portal (https://kygeonet.ky.gov/govmaps/).
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PREPARED BY: MJL	FIGURE TITLE: FCI SITE LCD 2017 VS NOVEMBER 2019			
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APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-4	

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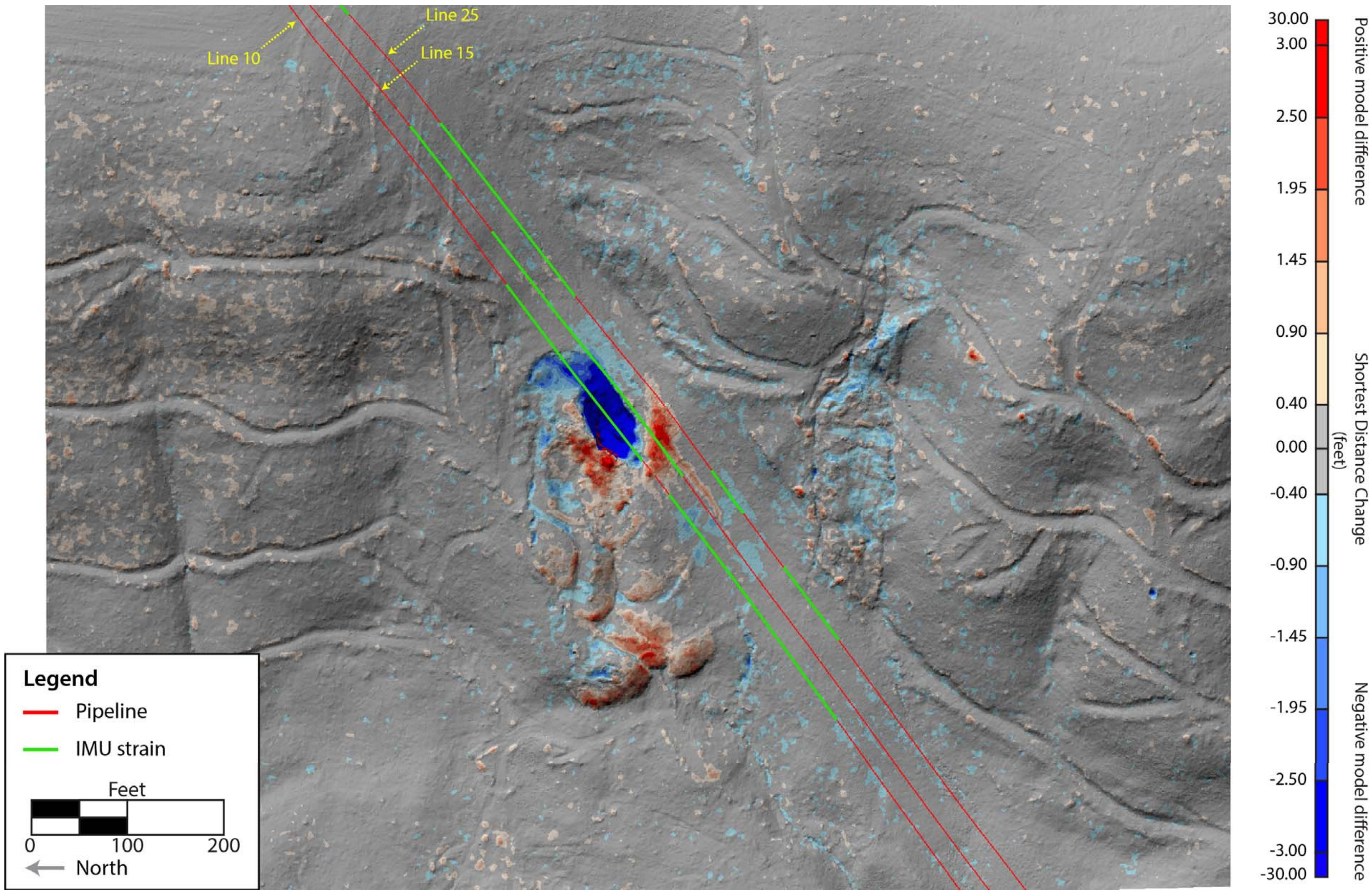

NOTES:

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MJL	FCI SITE LCD 2017 VS MAY 6, 2020		
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APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-5

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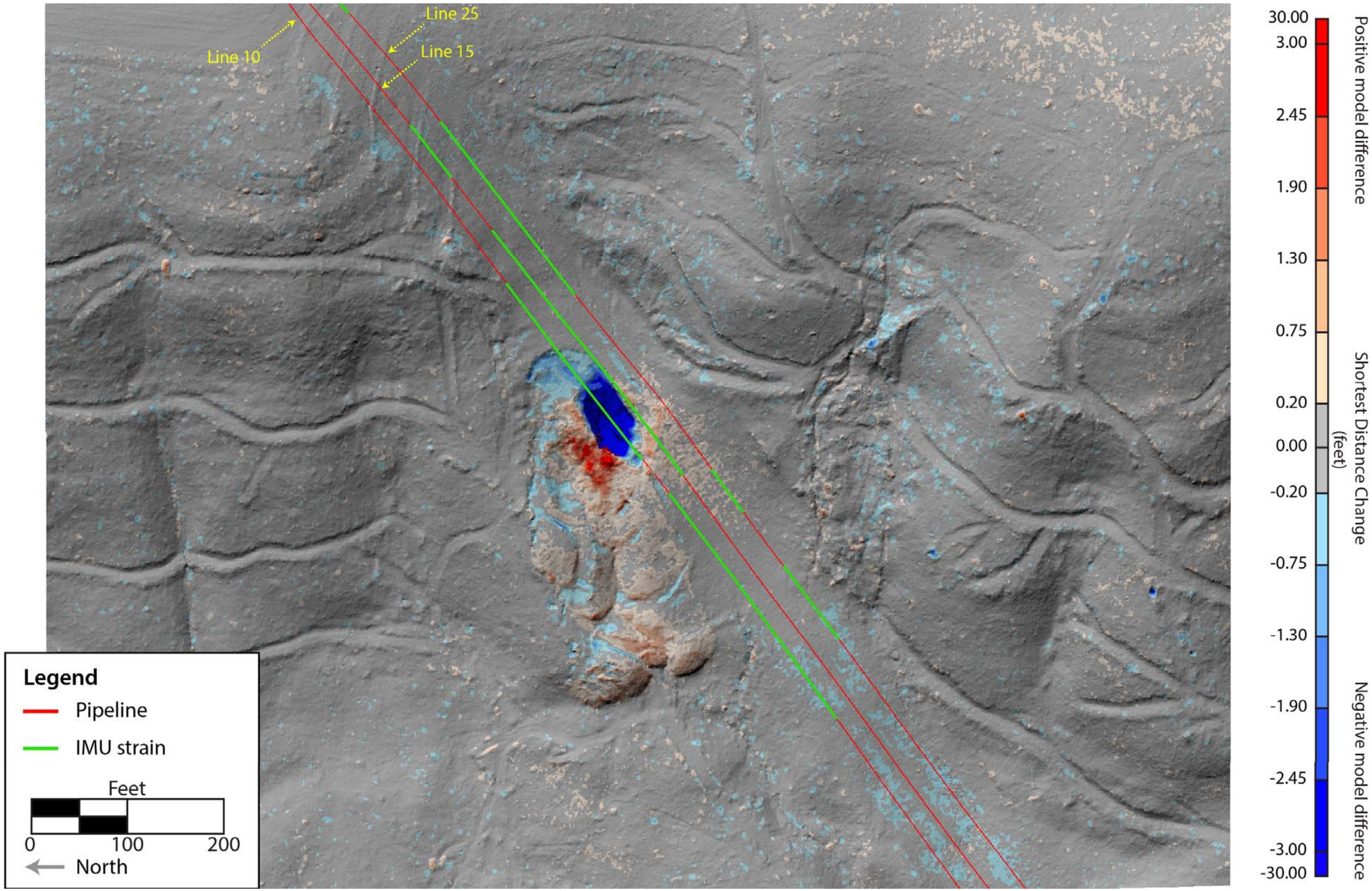

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. November 2019 and May 2020 ALS point cloud data acquired by Quantum Spatial and provided to BGC by TETLP.
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PREPARED BY: MJL	FIGURE TITLE: FCI SITE LCD NOVEMBER 2019 VS MAY 6, 2020			
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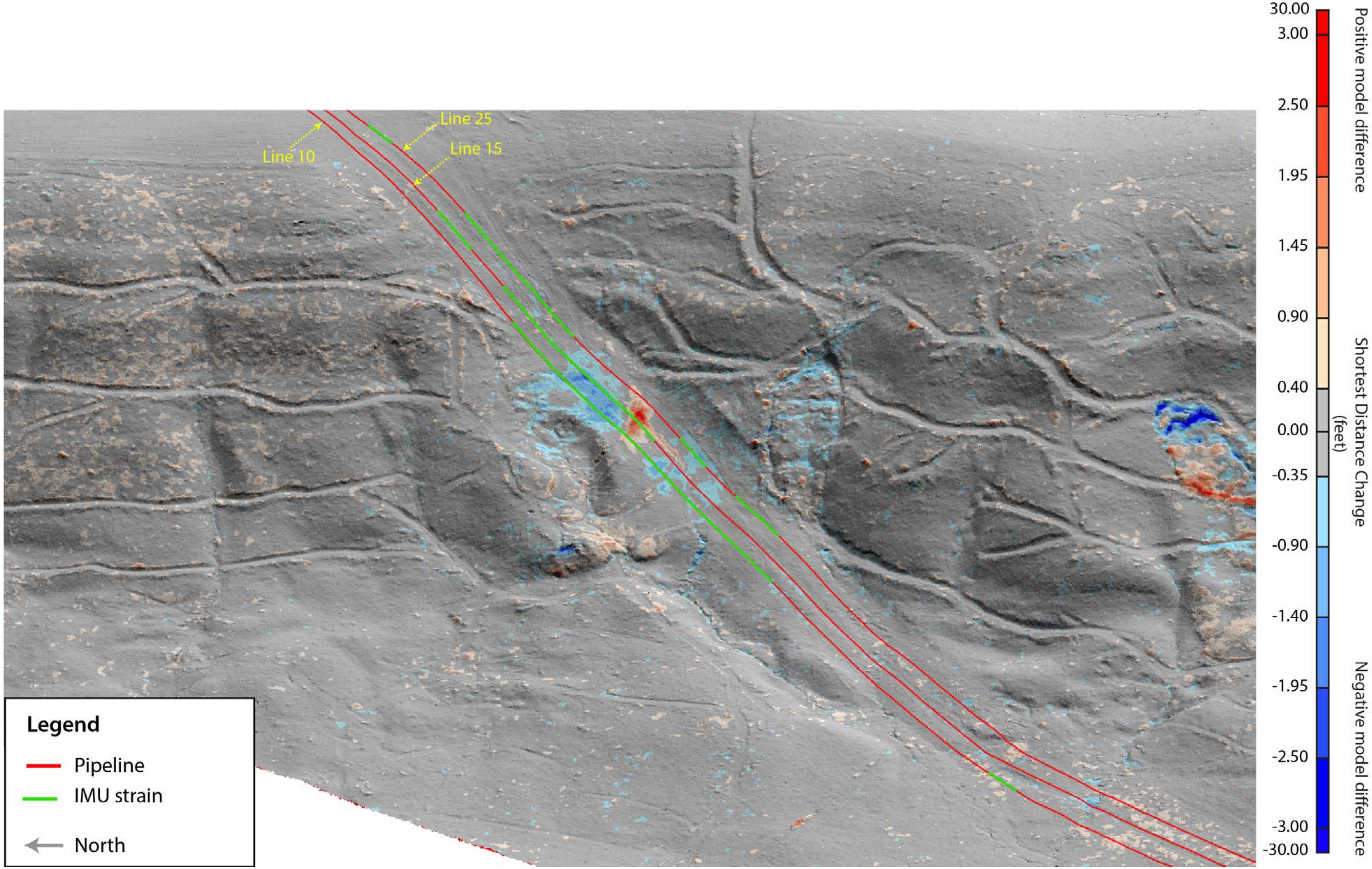
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-6	



NOTES:
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PREPARED BY: MJL	FIGURE TITLE: FCI SITE LCD 2017 VS NOVEMBER 2019 (OBLIQUE)			
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-7	

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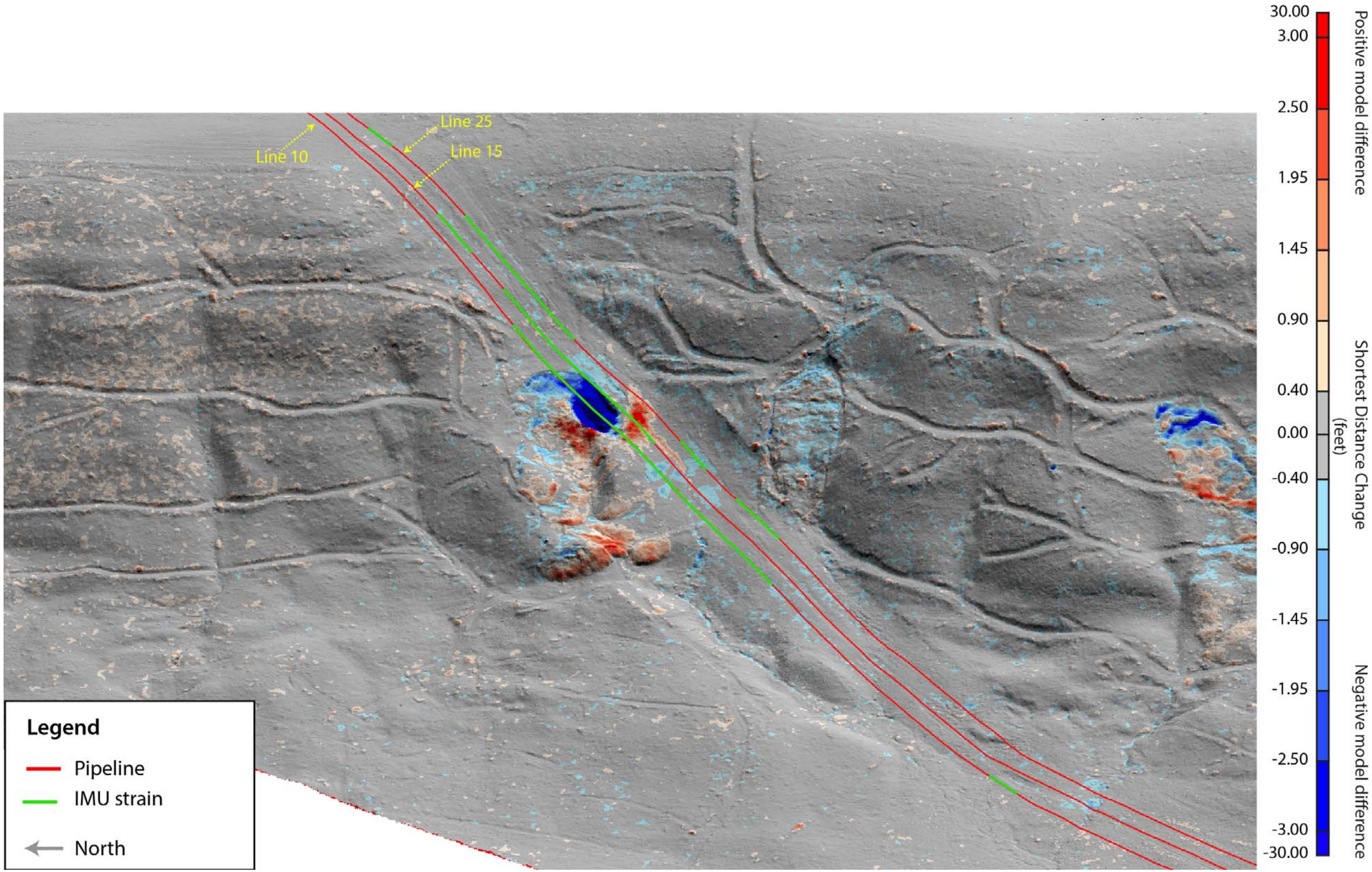

NOTES:

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PREPARED BY: MJL	FIGURE TITLE: FCI SITE LCD 2017 VS MAY 6, 2020 (OBLIQUE)			
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APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-8	

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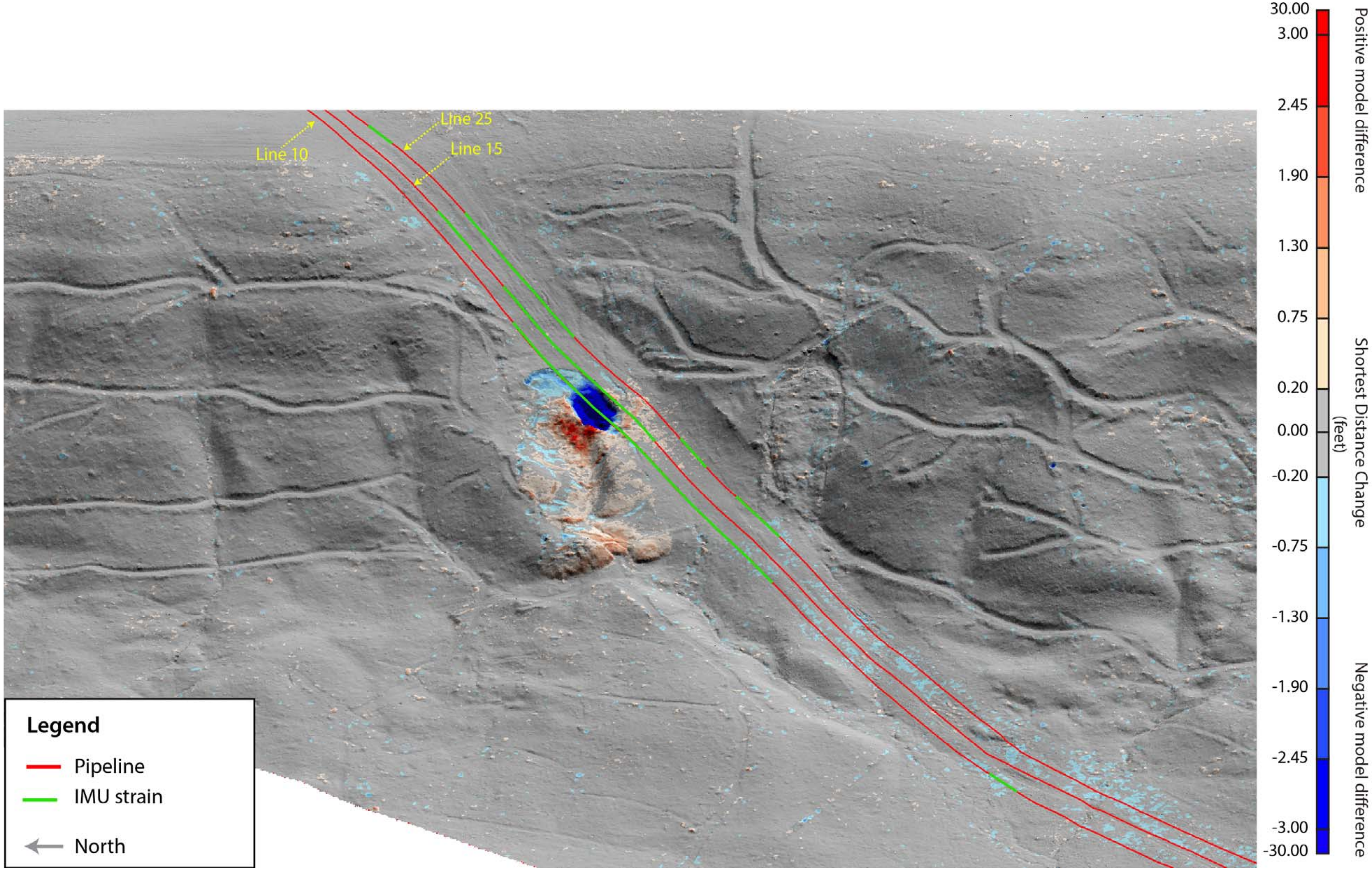

NOTES:

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PREPARED BY: MJL	FIGURE TITLE: FCI SITE LCD NOVEMBER 2019 VS MAY 6, 2020 (OBLIQUE)			
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-9	

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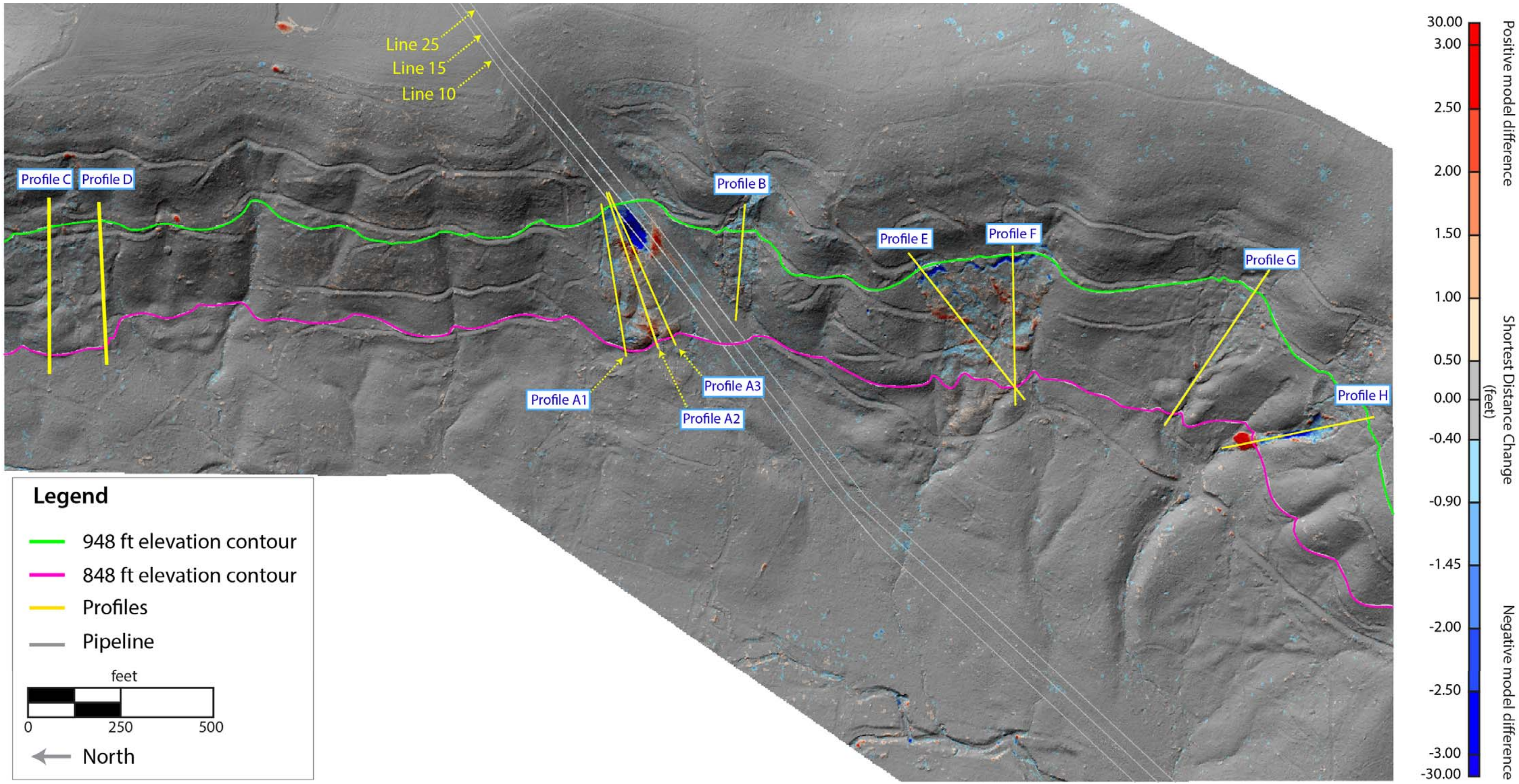

NOTES:
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PREPARED BY:	FIGURE TITLE		
MJL	PROFILE LOCATIONS		
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APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-10

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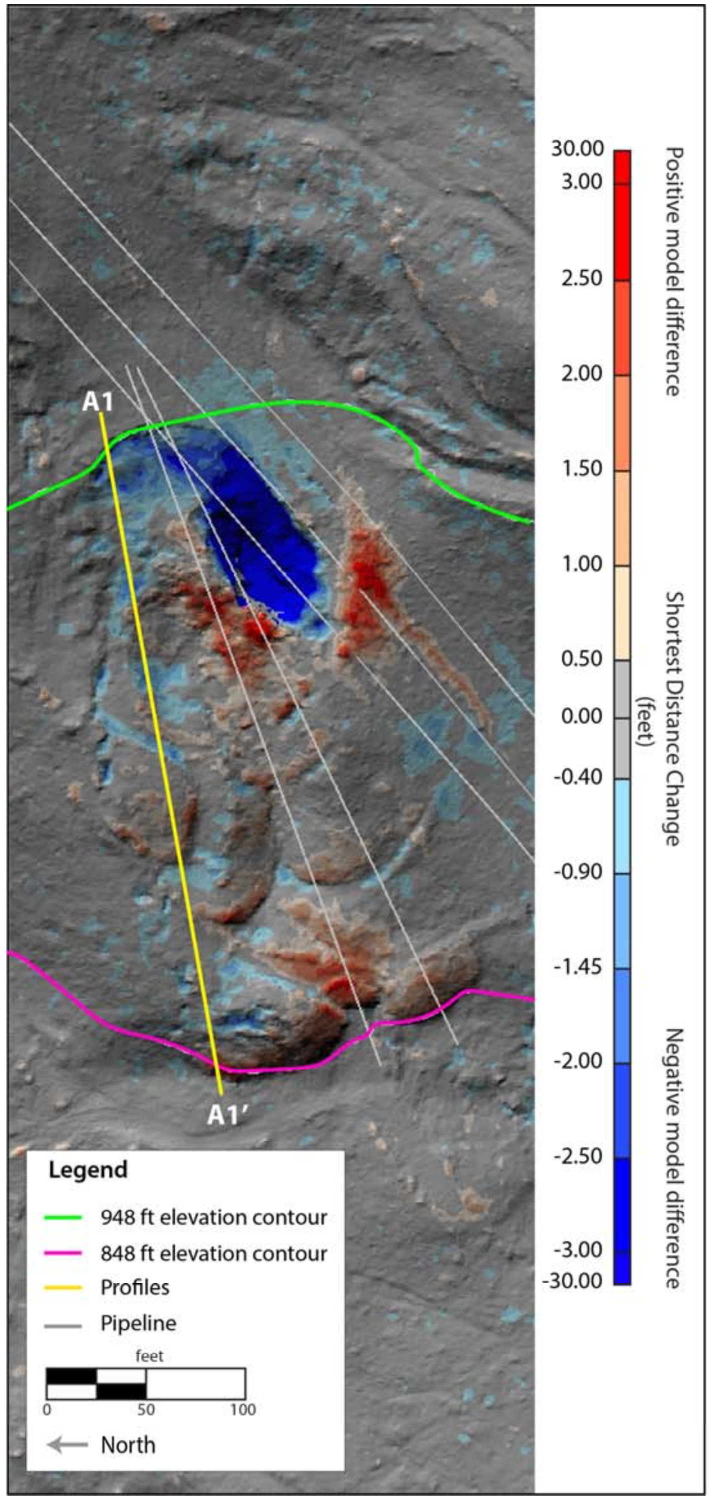

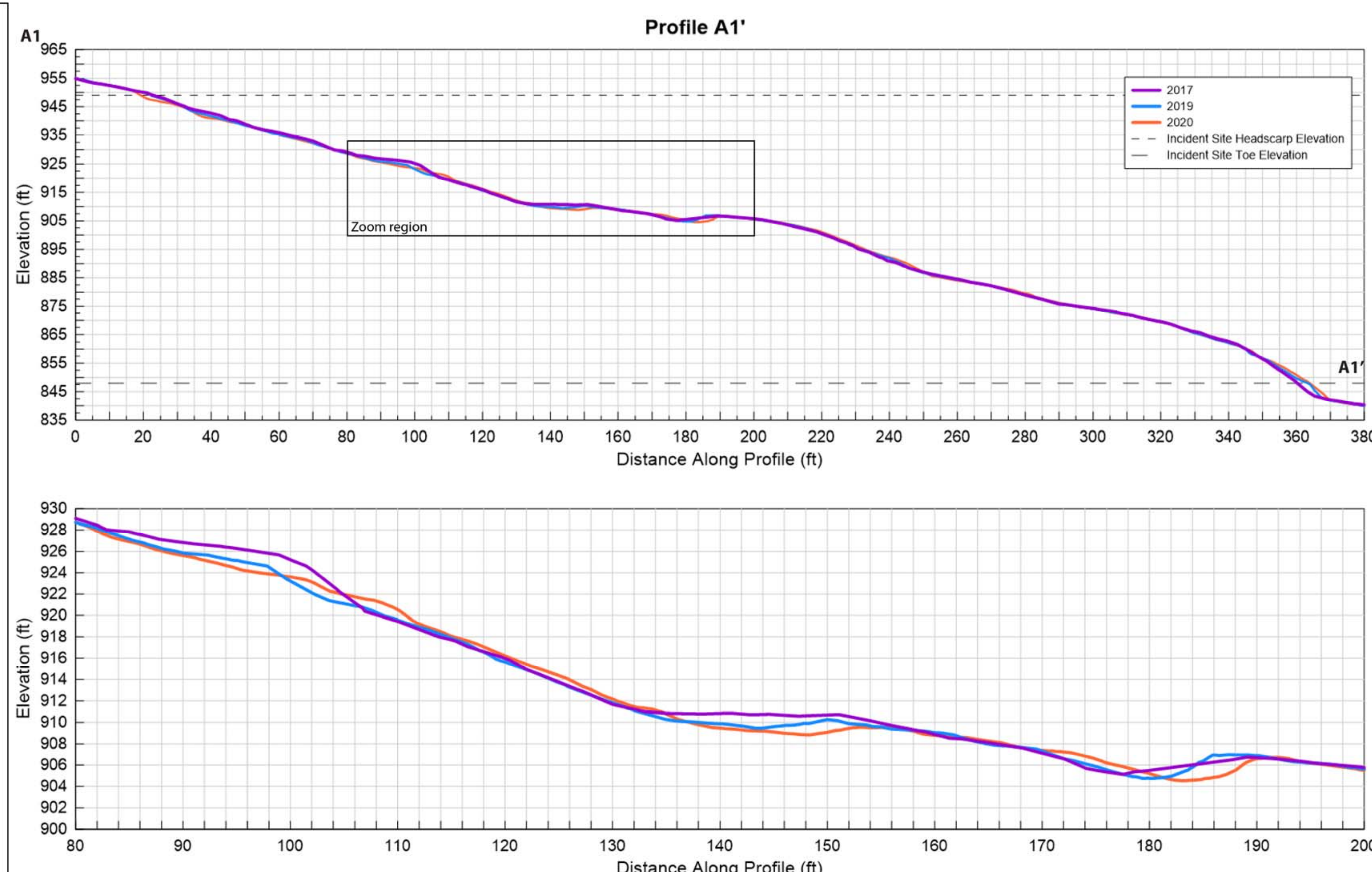

NOTES:

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2. 2017 ALS bare earth point data downloaded from Kentucky government portal (https://kygeonet.ky.gov/govmaps/).
3. November 2019 and May 2020 ALS point cloud data acquired by Quantum Spatial and provided to BGC by TETLP.
4. 2017 vs May 2020 shortest distance change detection analysis results represented on May 2020 ALS hillshade.
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PREPARED BY: MJL	FIGURE TITLE: PROFILE A1			
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APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-11	

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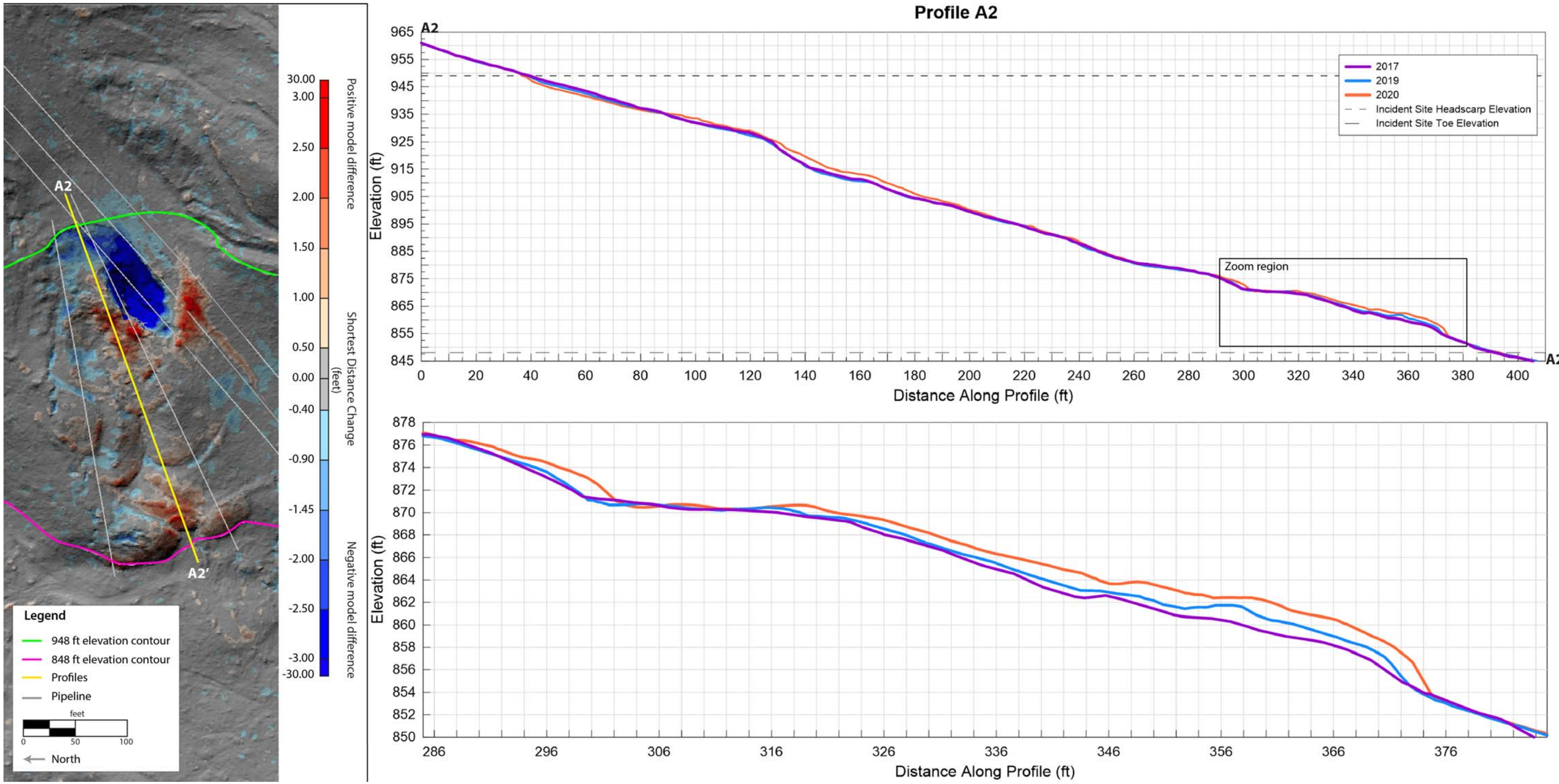

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. 2017 ALS bare earth point data downloaded from Kentucky government portal (https://kygeonet.ky.gov/govmaps/).
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PREPARED BY: MJL	FIGURE TITLE: PROFILE A2 (TOE ZOOM IN)			
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APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-12	

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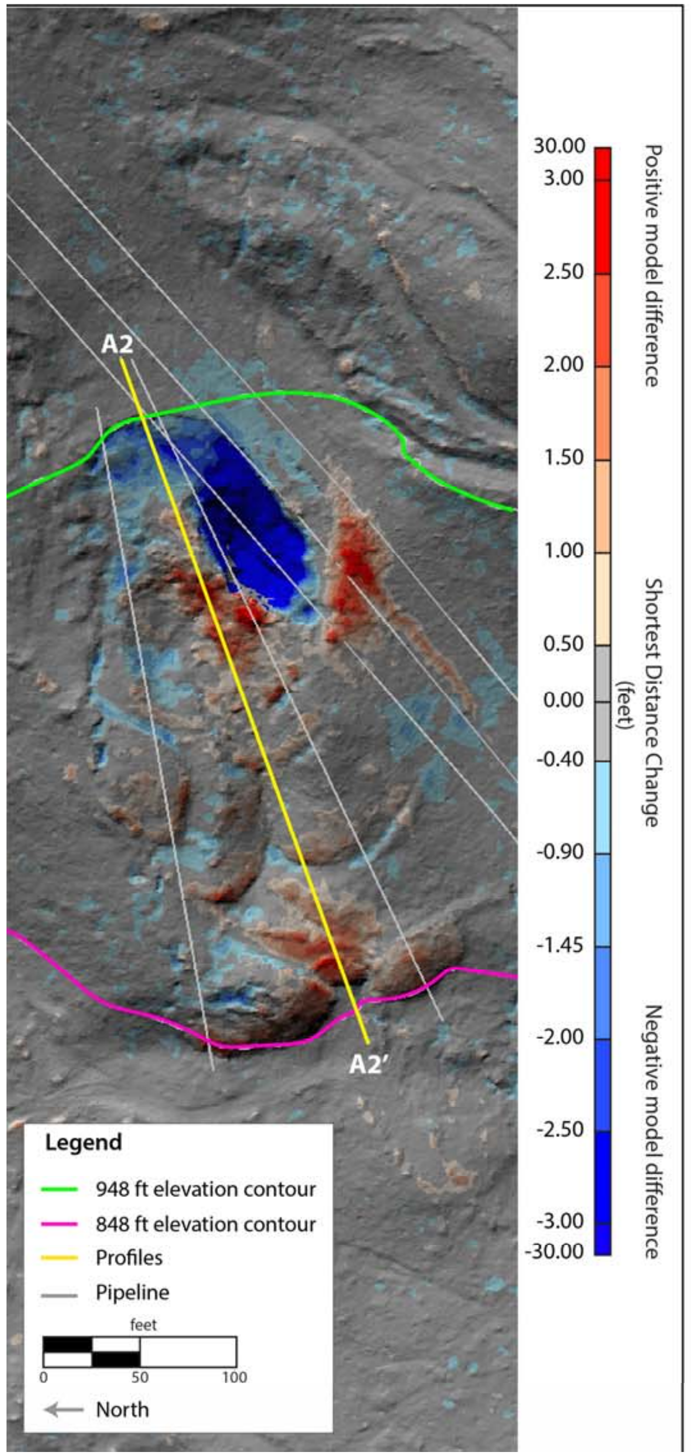

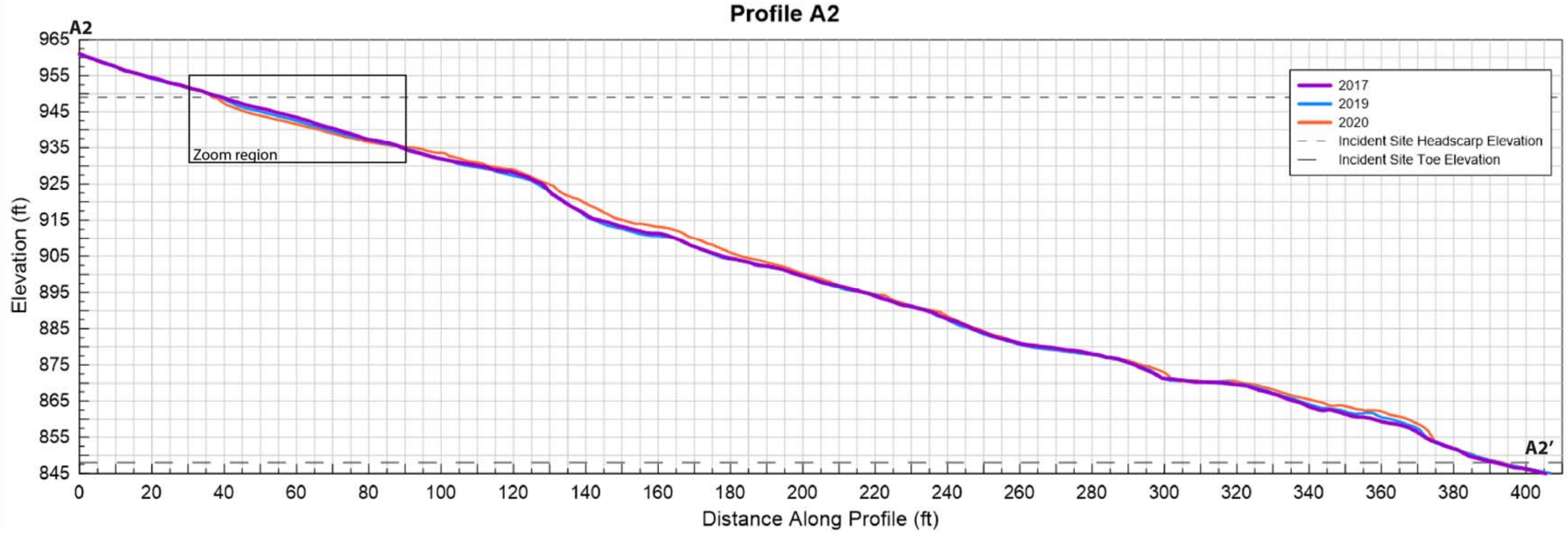

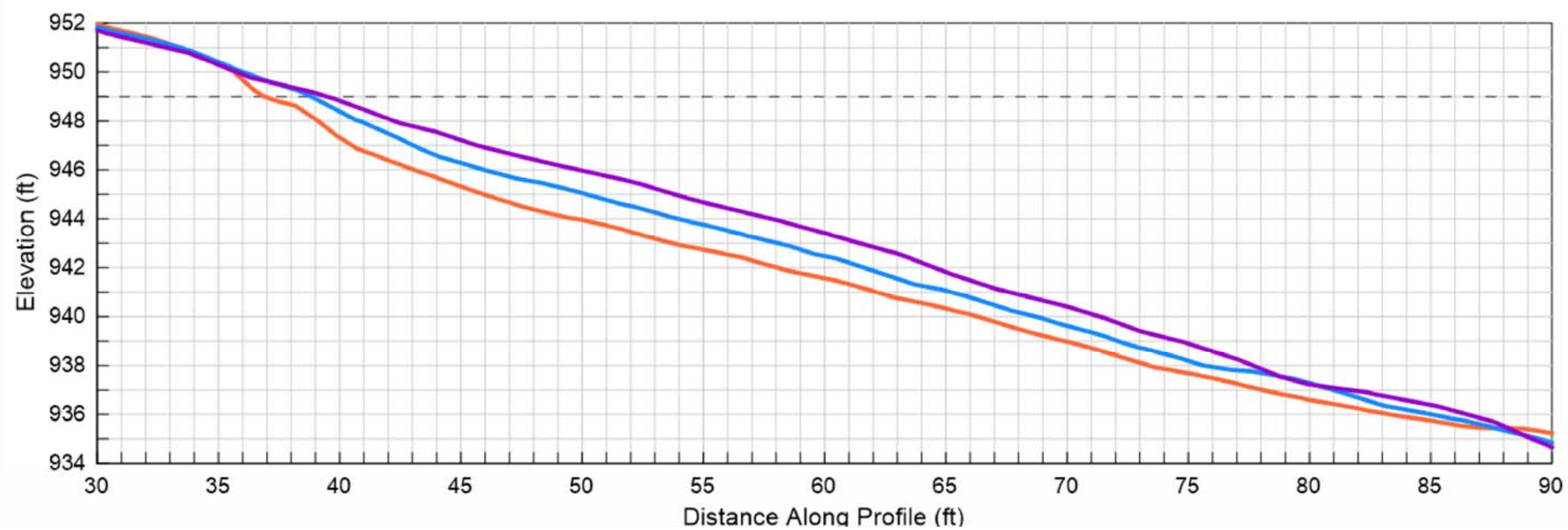

NOTES:
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CRS	TEXAS EASTERN TRANSMISSION LP		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
CAD	AS SHOWN	1607024	L-13

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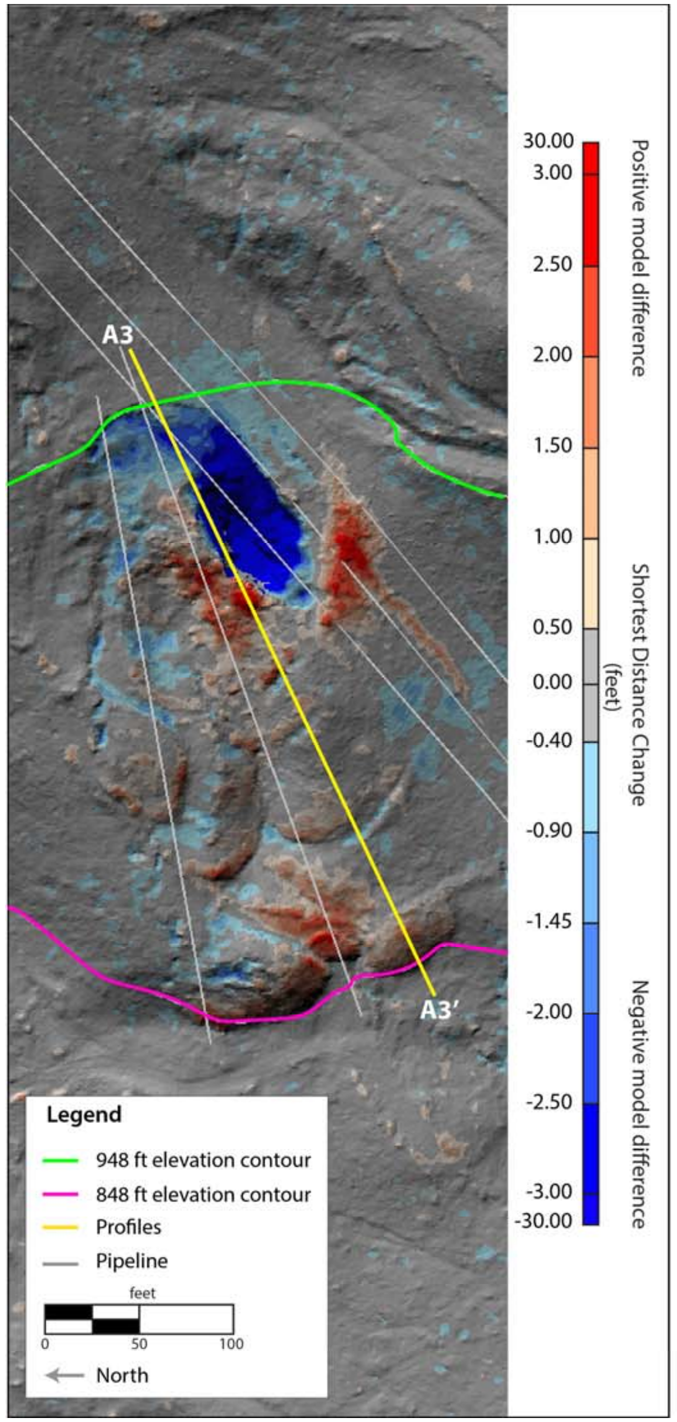
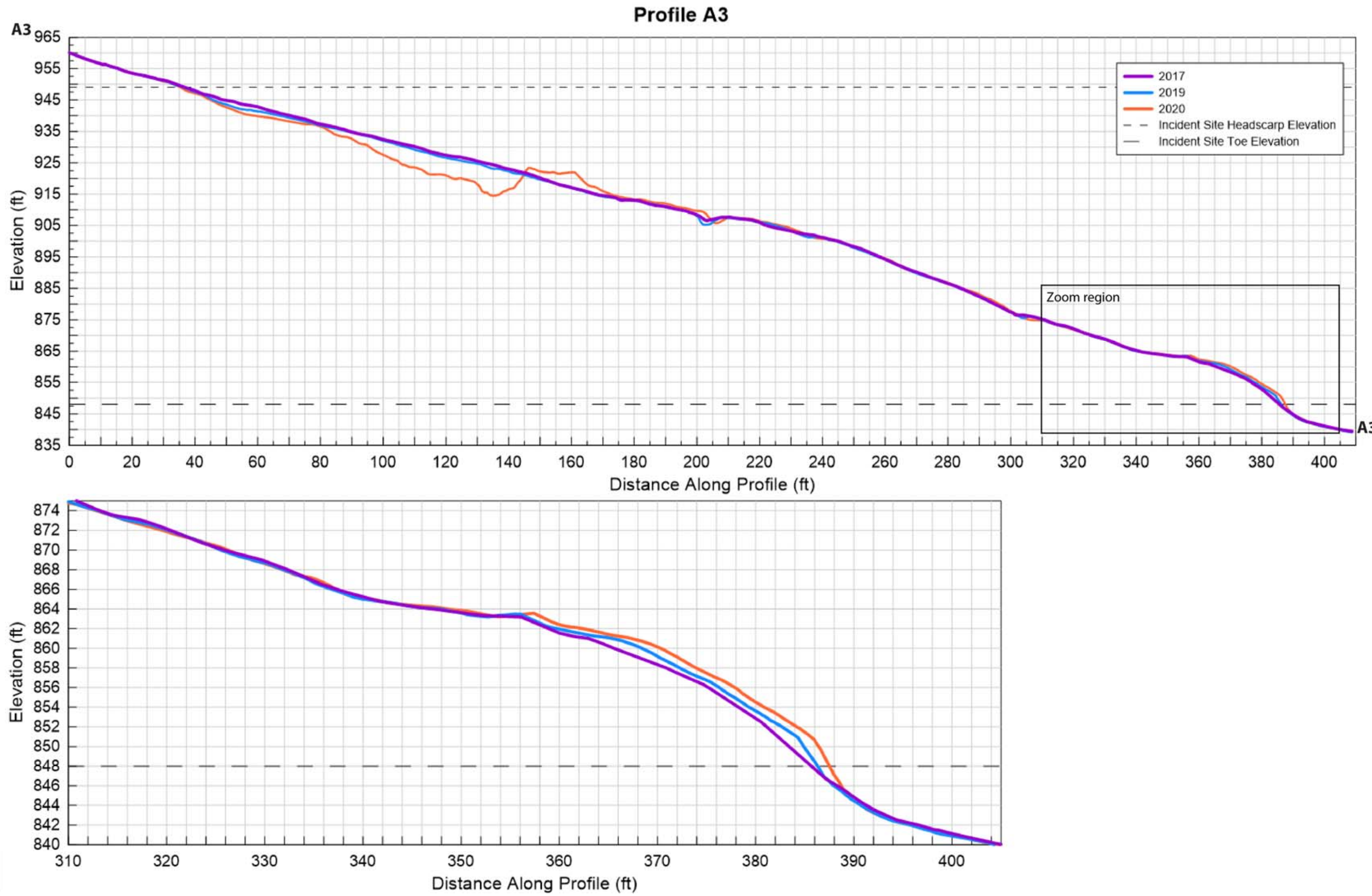


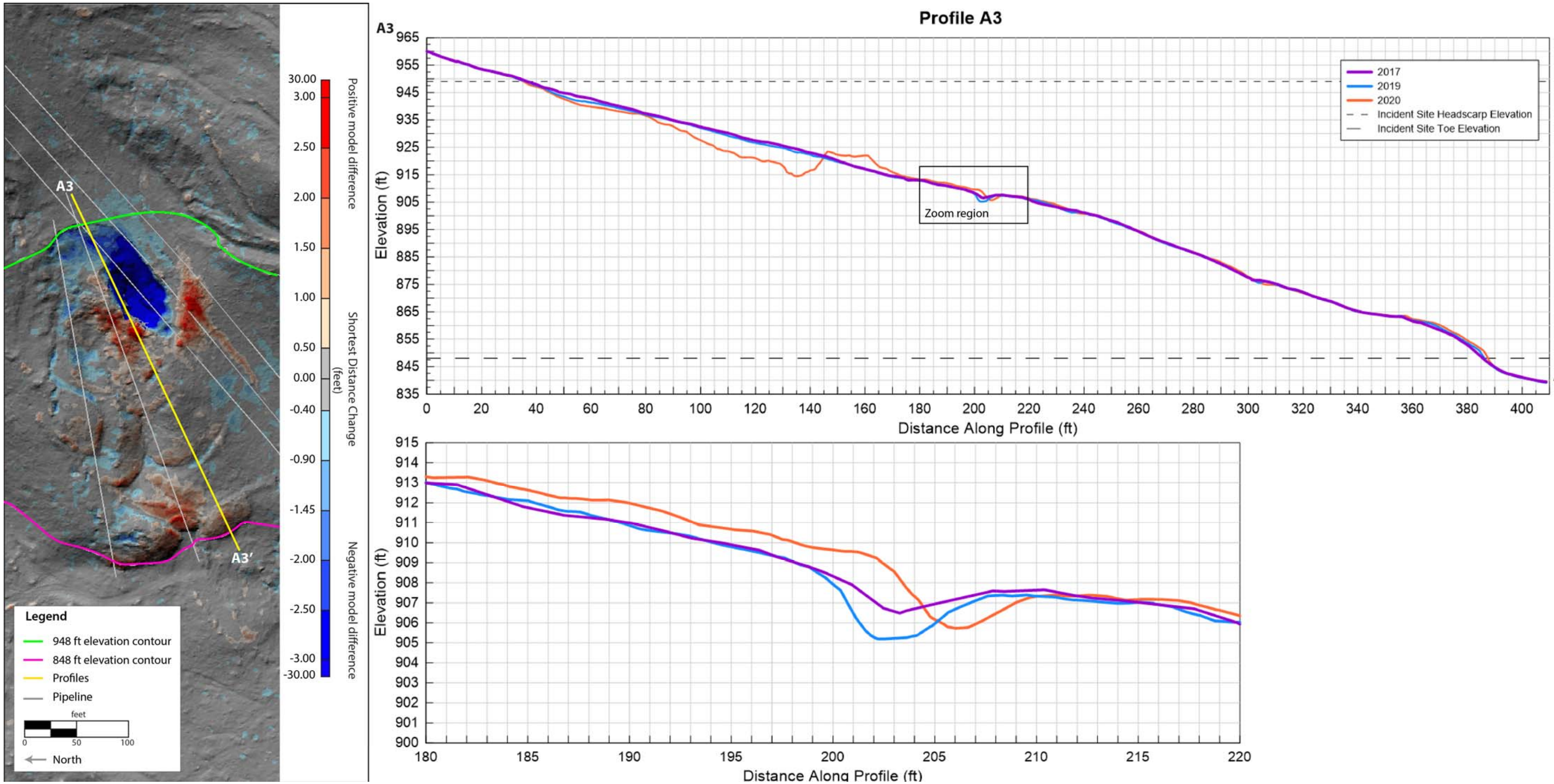


NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. 2017 ALS bare earth point data downloaded from Kentucky government portal (https://kygeonet.ky.gov/govmaps/).
3. November 2019 and May 2020 ALS point cloud data acquired by Quantum Spatial and provided to BGC by TETLP.
4. 2017 vs May 2020 shortest distance change detection analysis results represented on May 2020 ALS hillshade.
5. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY:	FIGURE TITLE		
MJL	PROFILE A3 (TOE ZOOM IN)		
CHECKED BY:	CLIENT:		
CRS	TEXAS EASTERN TRANSMISSION LP		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
CAD	AS SHOWN	1607024	L-14

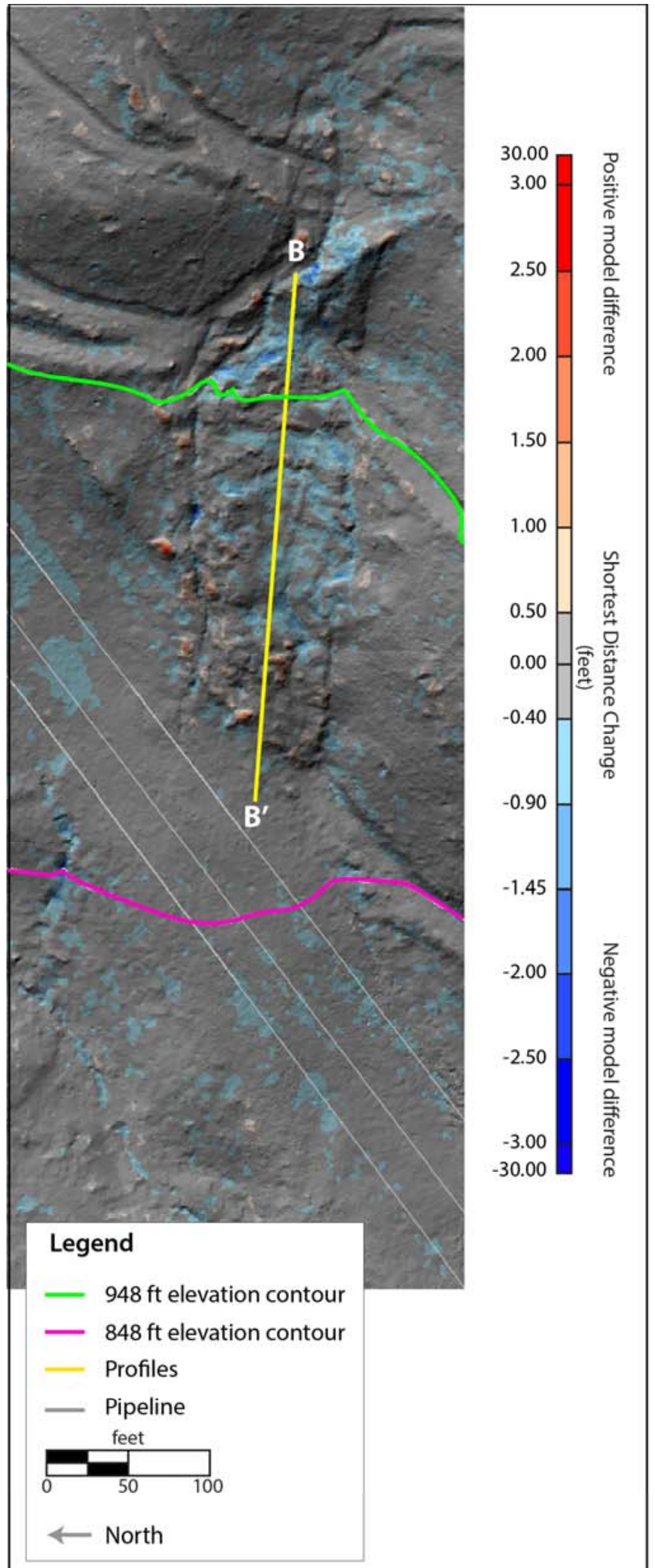
0 5 10 mm in ANSI B sized paper

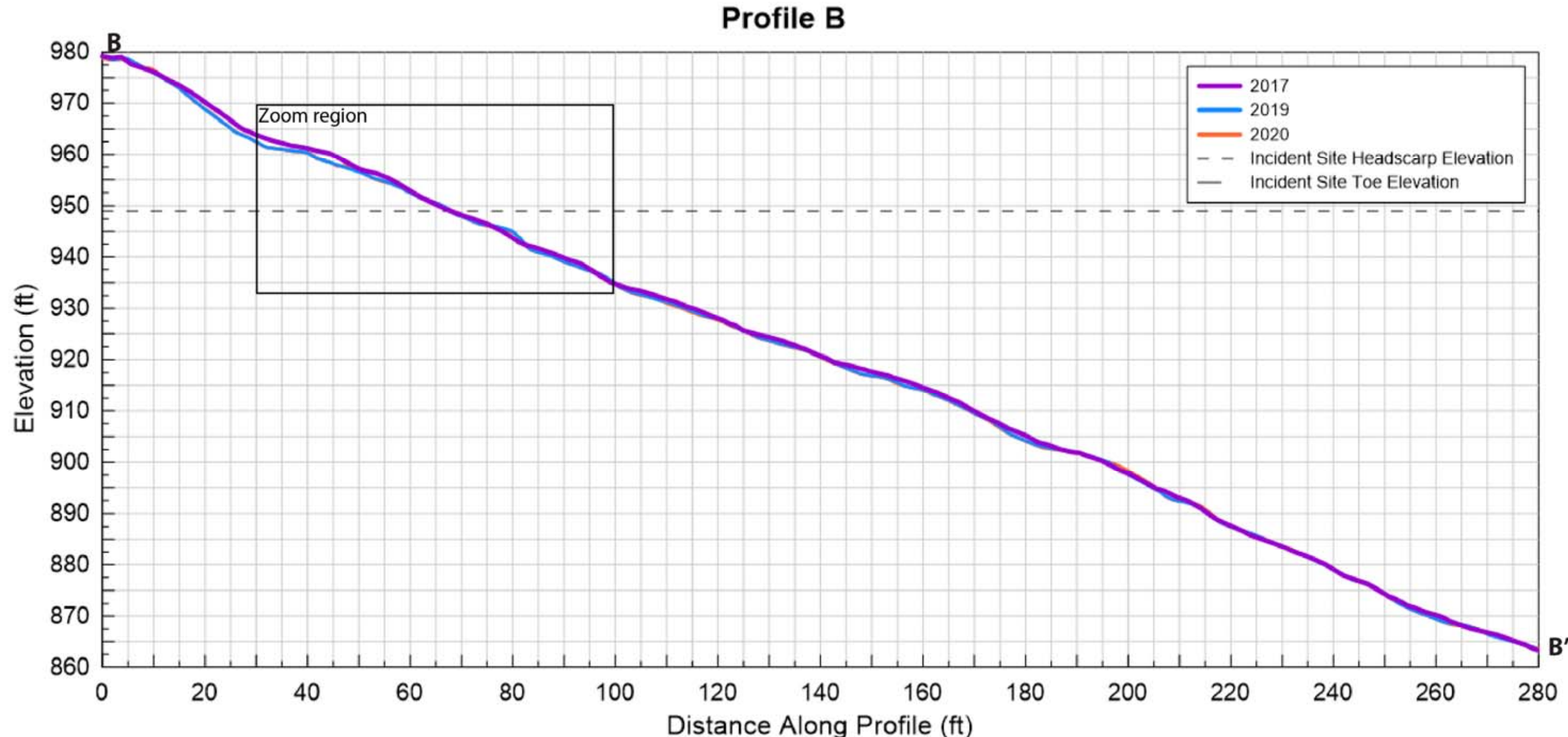


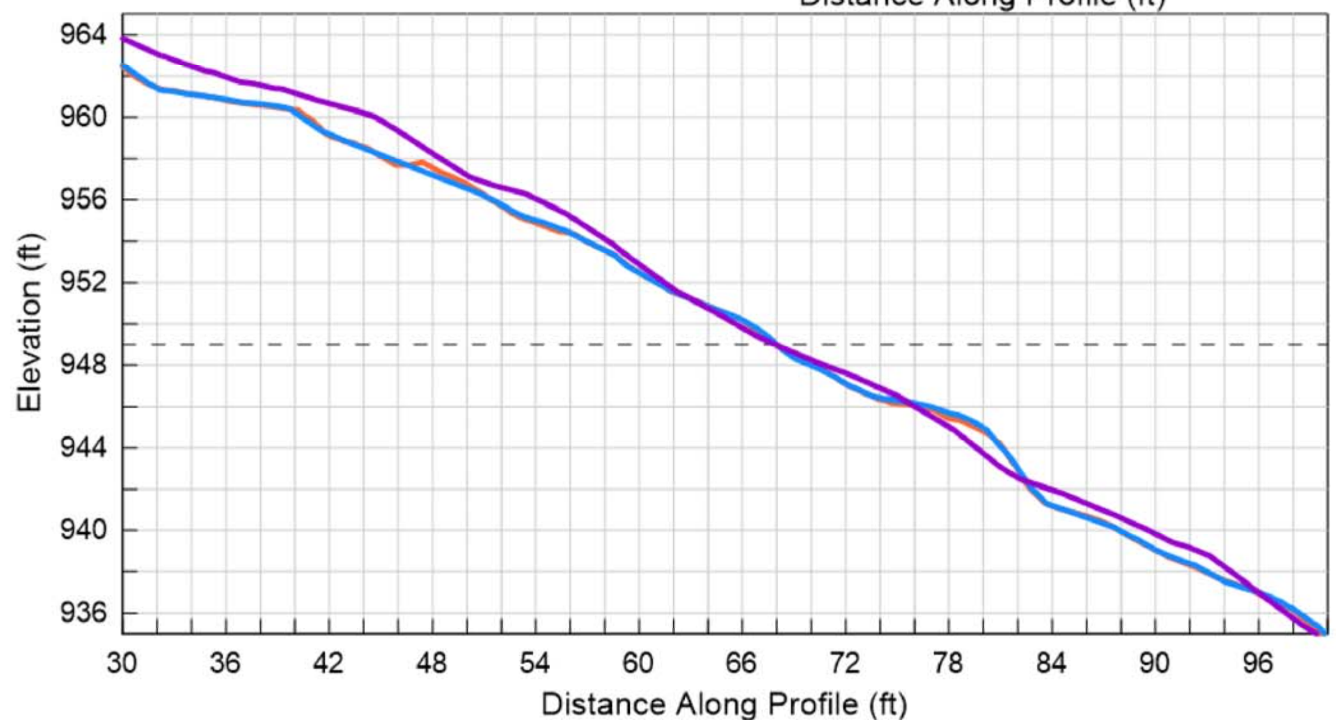
NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. 2017 ALS bare earth point data downloaded from Kentucky government portal (https://kygeonet.ky.gov/govmaps/).
3. November 2019 and May 2020 ALS point cloud data acquired by Quantum Spatial and provided to BGC by TETLP.
4. 2017 vs May 2020 shortest distance change detection analysis results represented on May 2020 ALS hillshade.
5. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: MJL	FIGURE TITLE: Profile A3 (gully zoom in)			
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-15	

0 5 10 mm in ANSI B sized paper







NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. 2017 ALS bare earth point data downloaded from Kentucky government portal (https://kygeonet.ky.gov/govmaps/).
3. November 2019 and May 2020 ALS point cloud data acquired by Quantum Spatial and provided to BGC by TETLP.
4. 2017 vs May 2020 shortest distance change detection analysis results represented on May 2020 ALS hillshade.
5. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: MJL	FIGURE TITLE: PROFILE B		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-16

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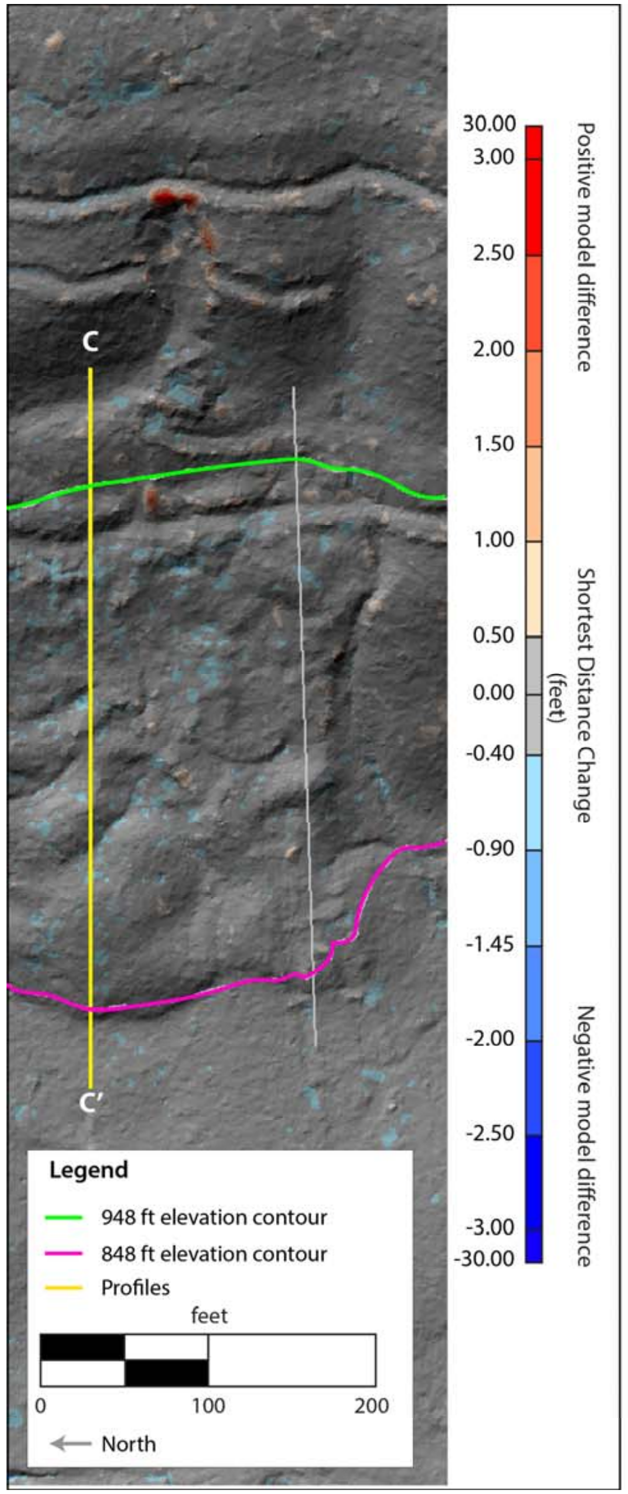
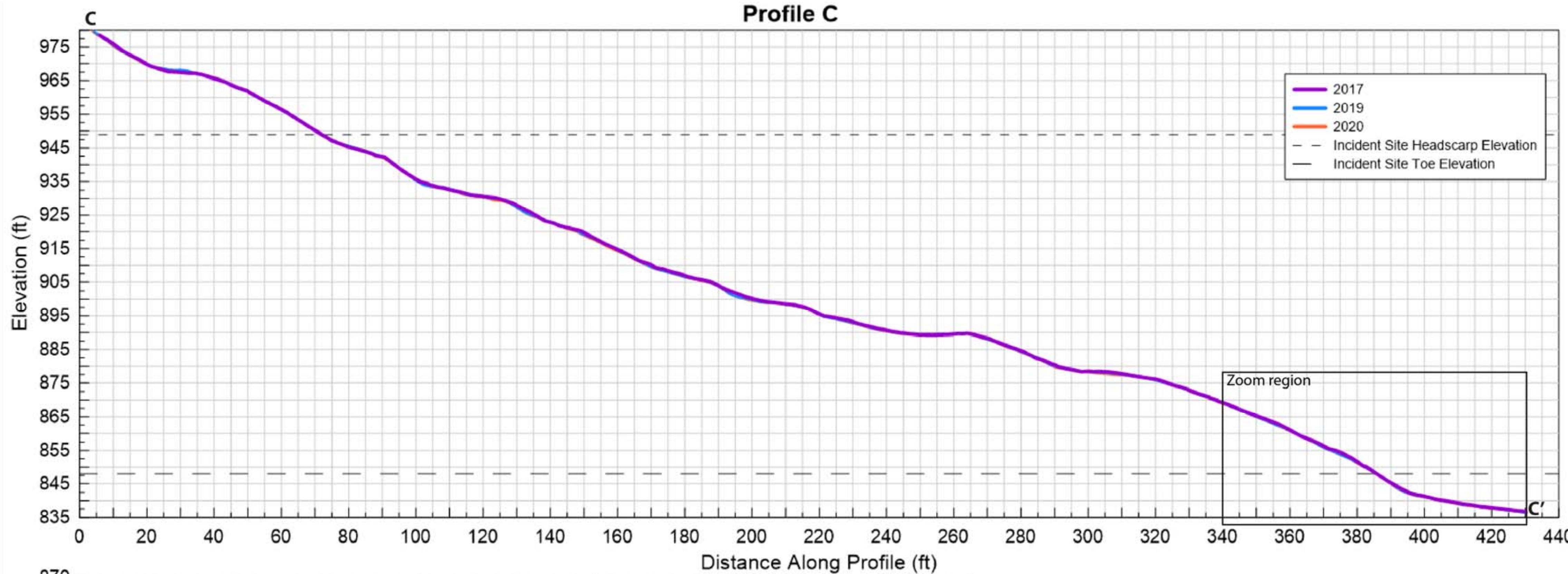
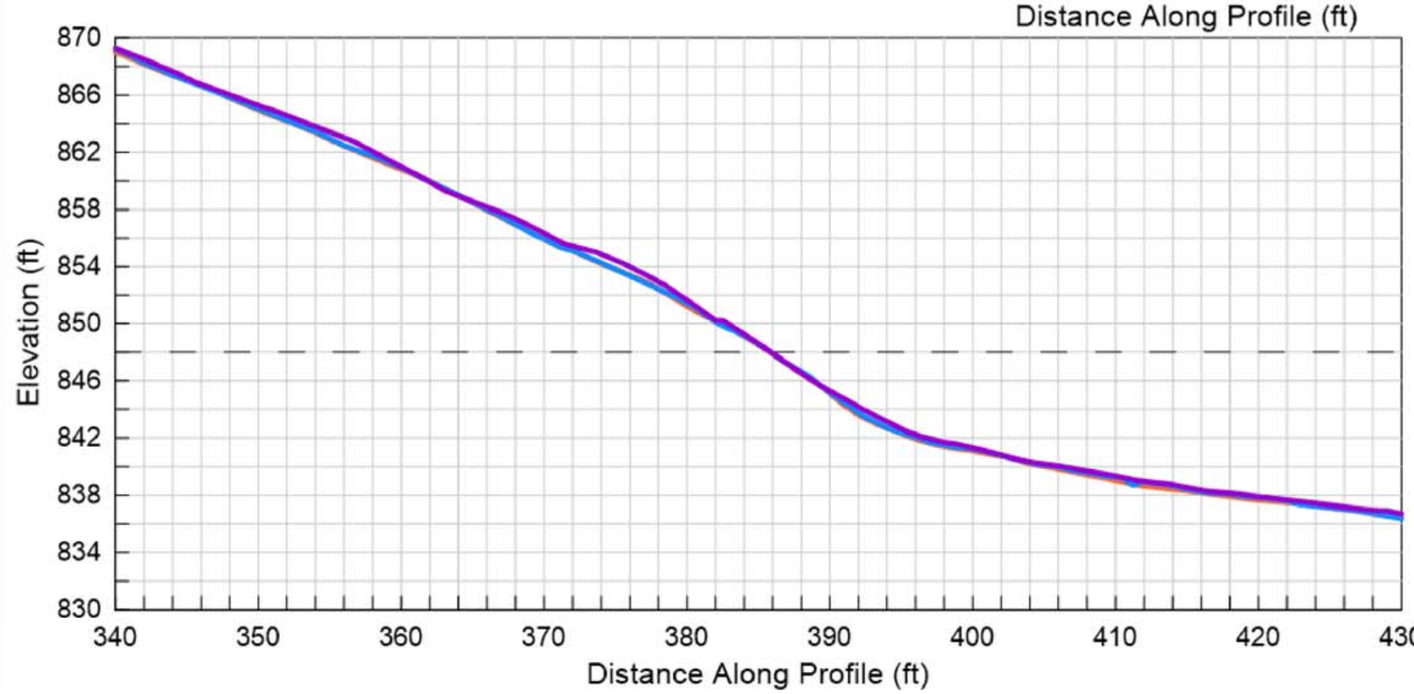




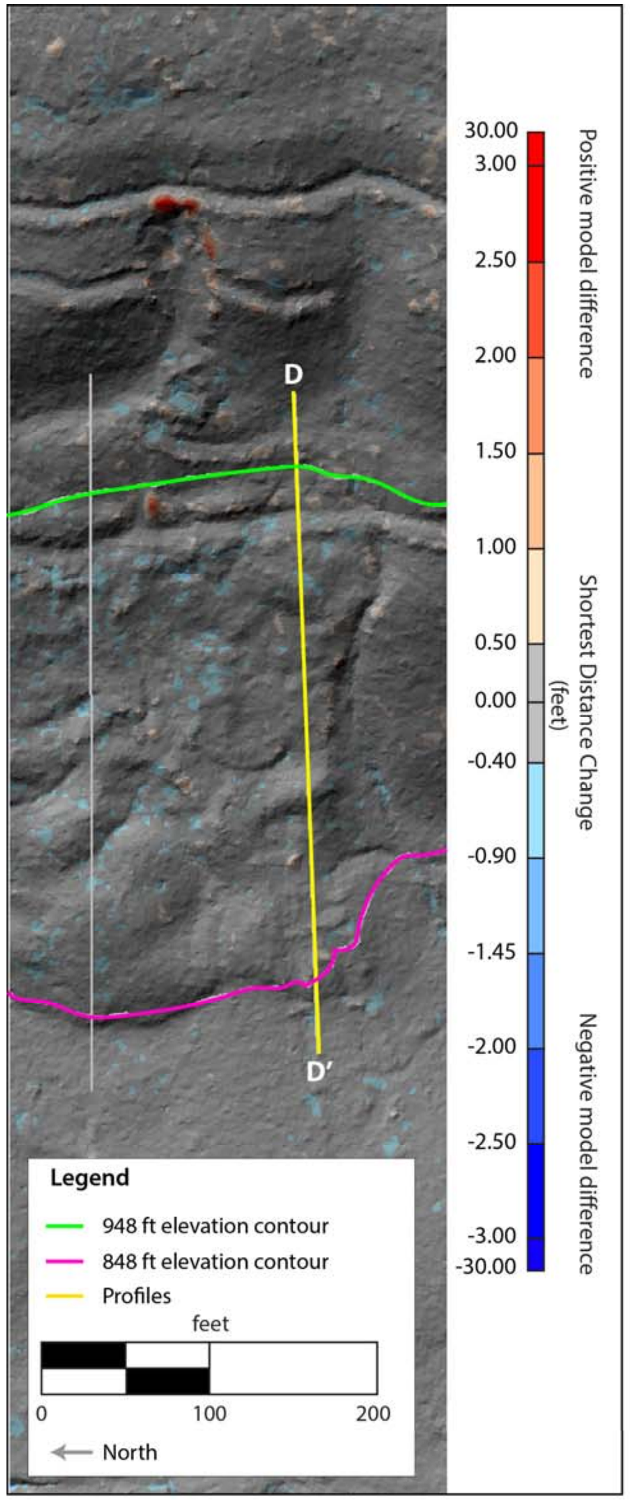


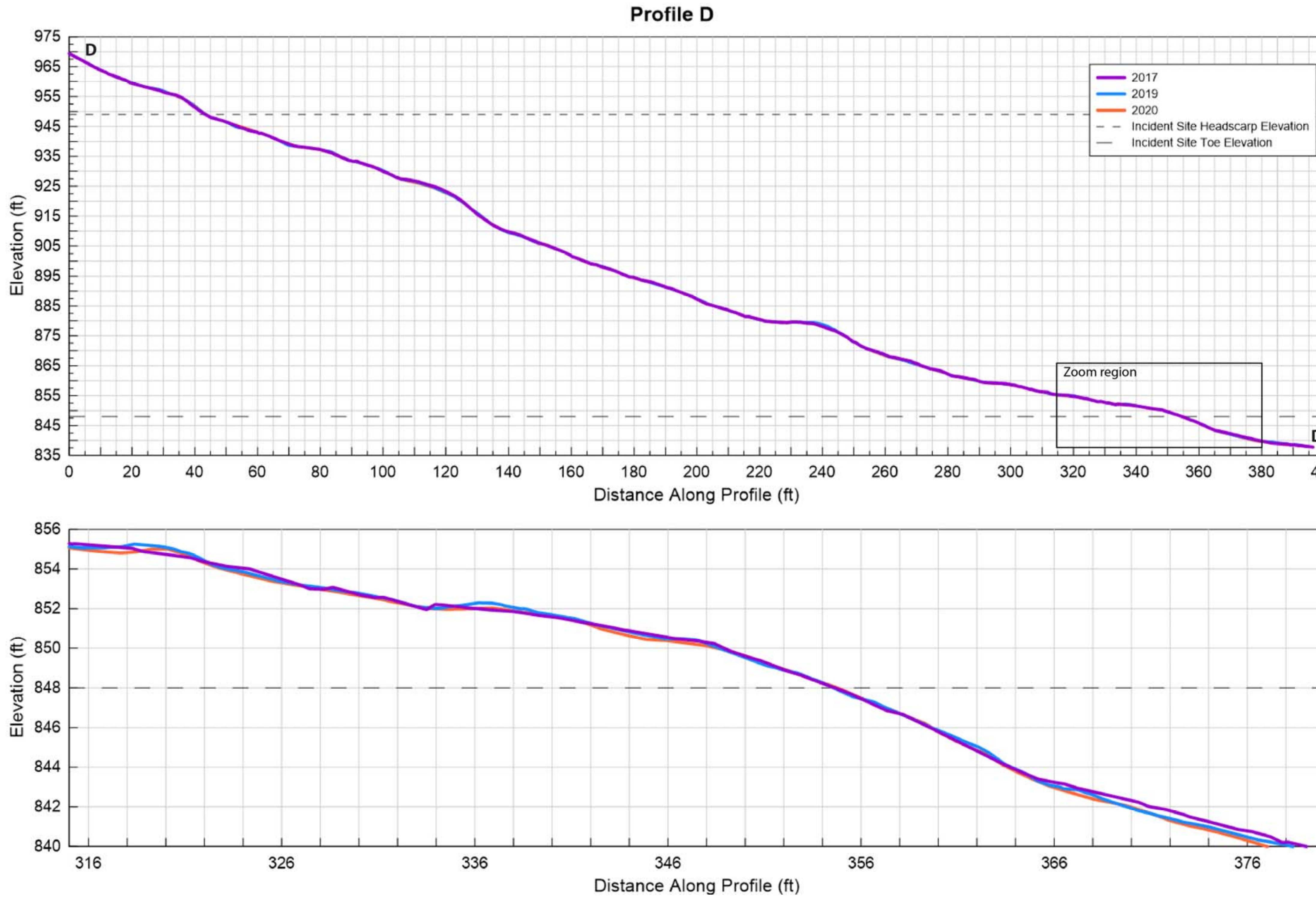
NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. 2017 ALS bare earth point data downloaded from Kentucky government portal (https://kygeonet.ky.gov/govmaps/).
3. November 2019 and May 2020 ALS point cloud data acquired by Quantum Spatial and provided to BGC by TETLP.
4. 2017 vs May 2020 shortest distance change detection analysis results represented on May 2020 ALS hillshade.
5. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: MJL	FIGURE TITLE: PROFILE C		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-17

0 5 10 mm in ANSI B sized paper

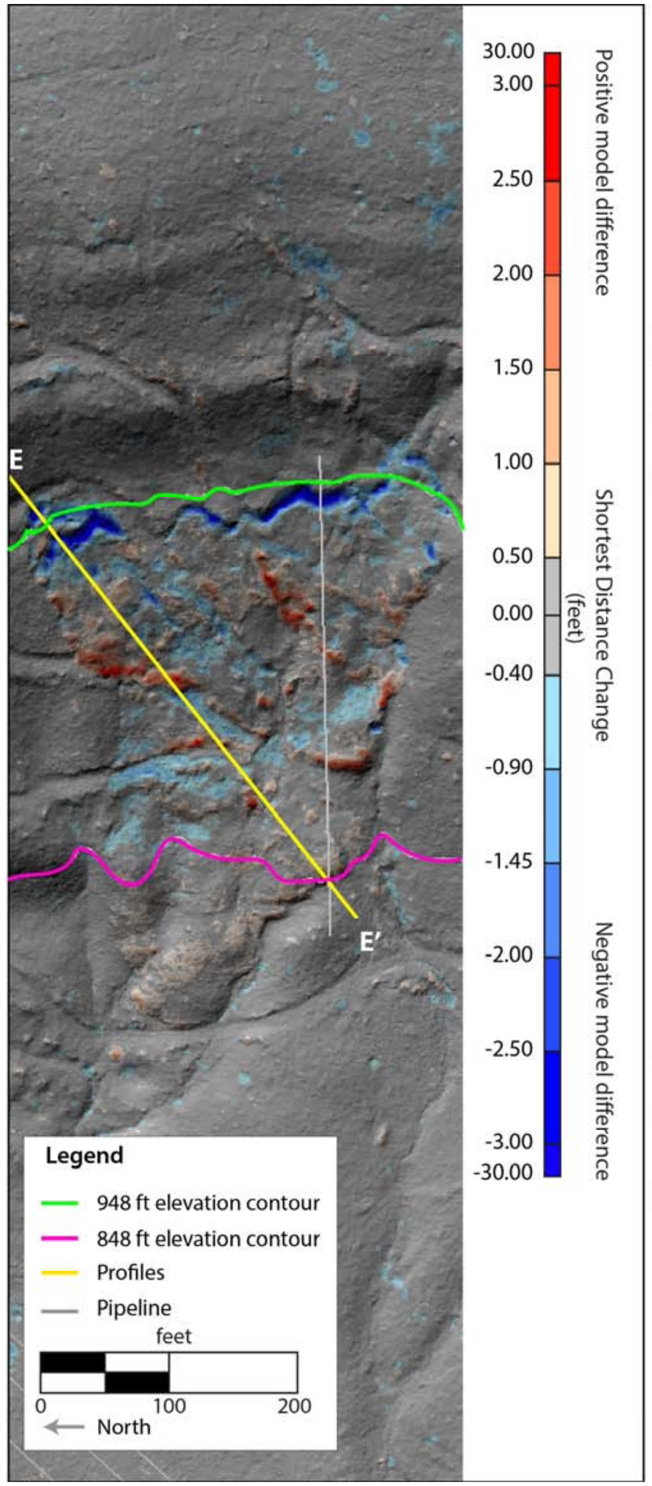


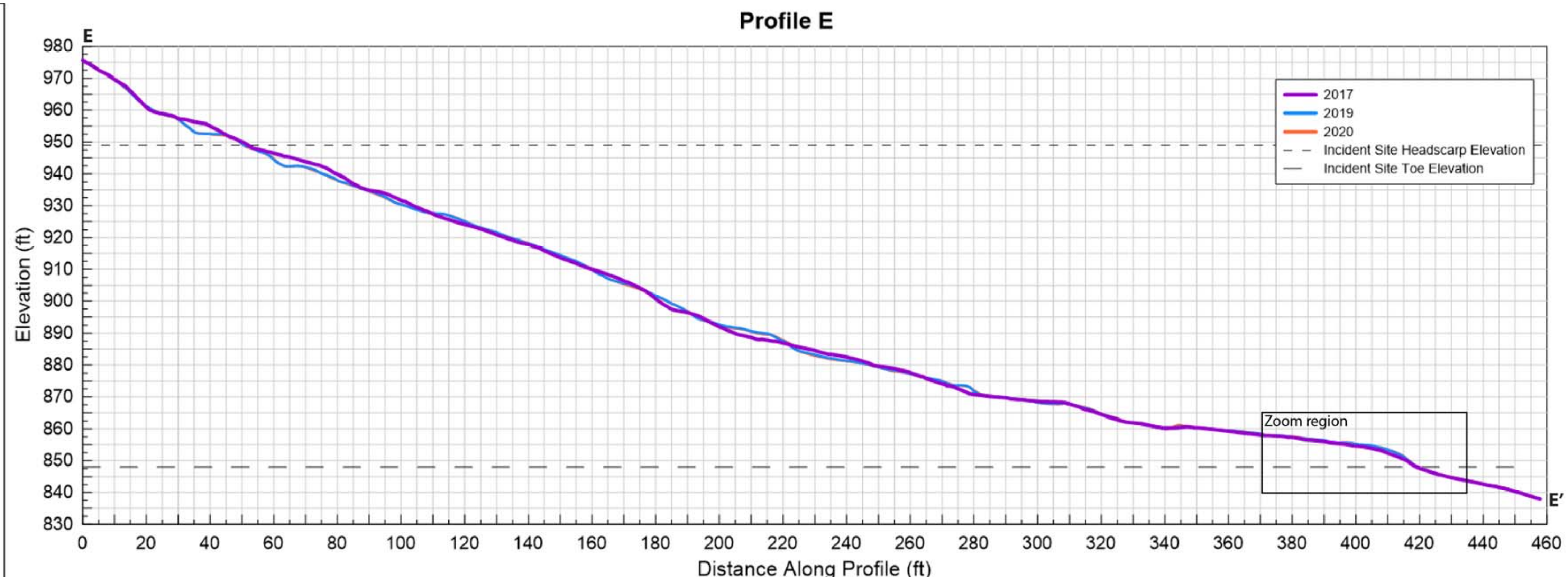


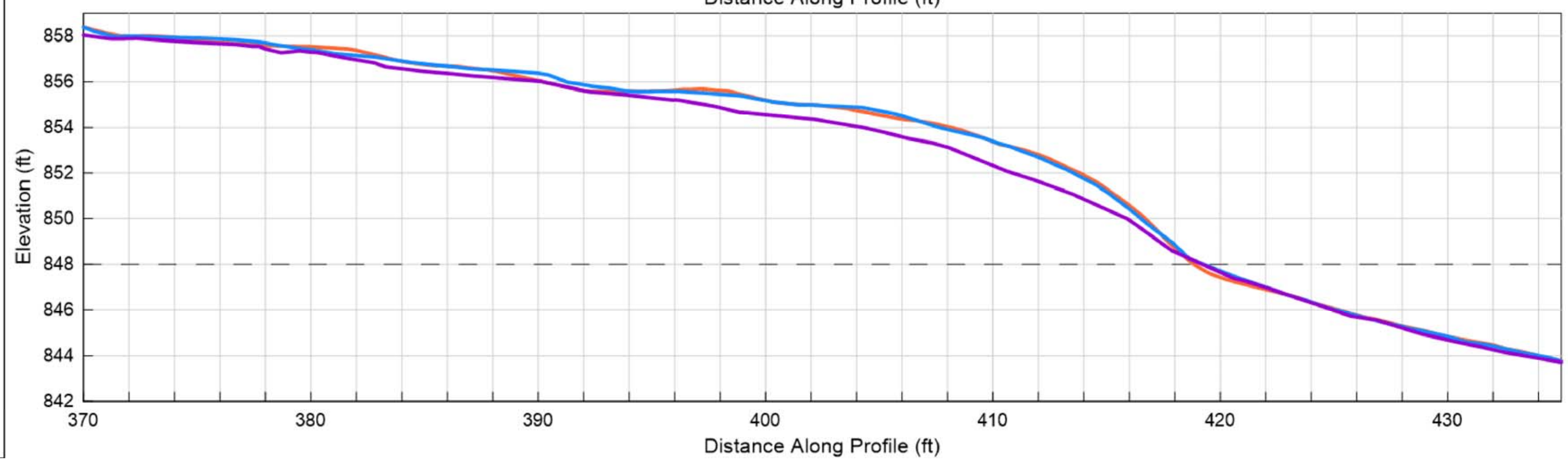
NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. 2017 ALS bare earth point data downloaded from Kentucky government portal (https://kygeonet.ky.gov/govmaps/).
3. November 2019 and May 2020 ALS point cloud data acquired by Quantum Spatial and provided to BGC by TETLP.
4. 2017 vs May 2020 shortest distance change detection analysis results represented on May 2020 ALS hillshade.
5. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: MJL	FIGURE TITLE: PROFILE D		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-18

0 5 10 mm in ANSI B sized paper



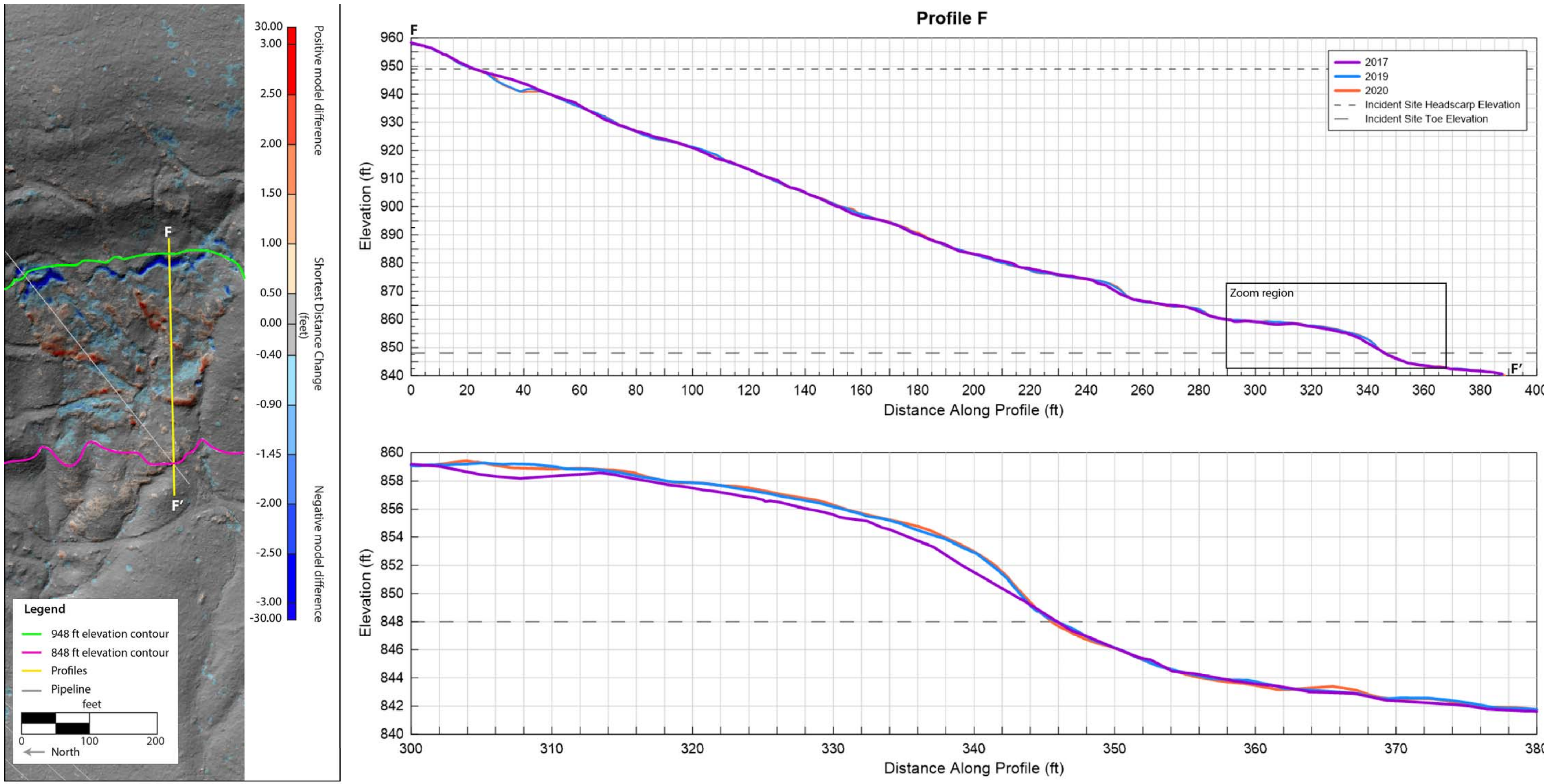




NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. 2017 ALS bare earth point data downloaded from Kentucky government portal (https://kygeonet.ky.gov/govmaps/).
3. November 2019 and May 2020 ALS point cloud data acquired by Quantum Spatial and provided to BGC by TETLP.
4. 2017 vs May 2020 shortest distance change detection analysis results represented on May 2020 ALS hillshade.
5. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: MJL	FIGURE TITLE: PROFILE E		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-19

0 5 10 mm in ANSI B sized paper

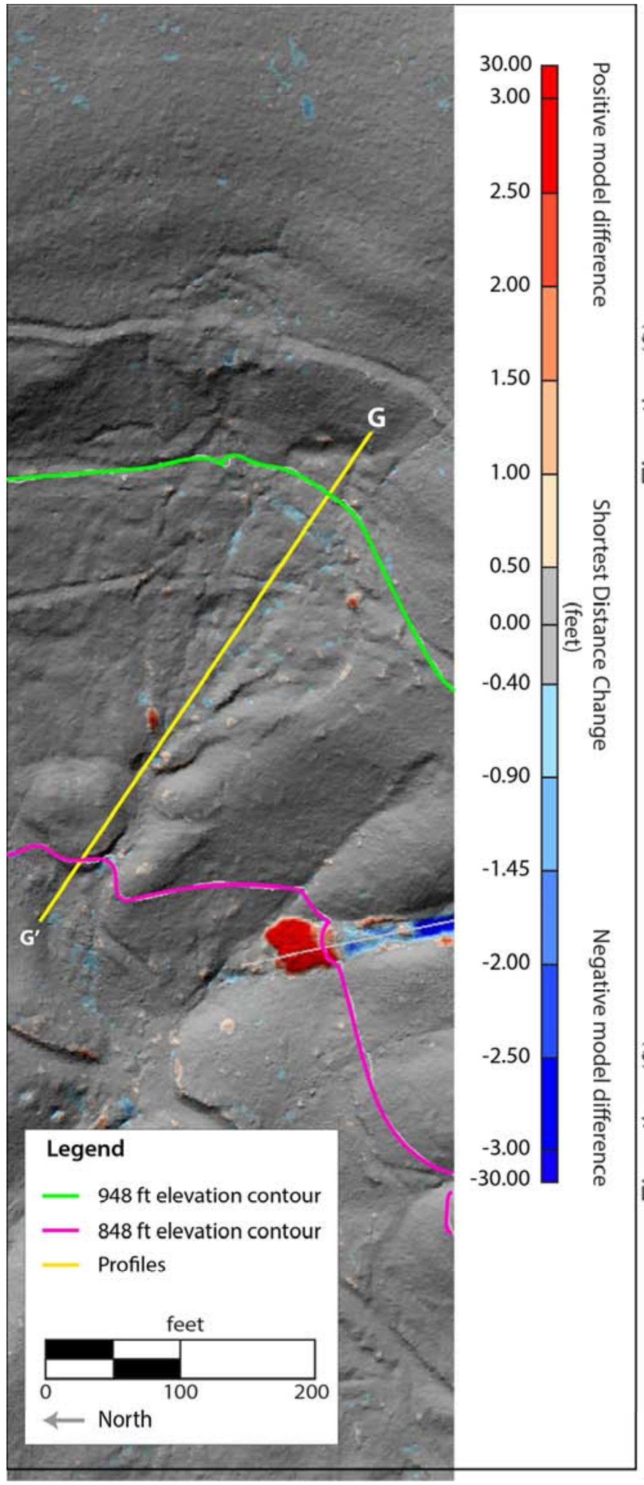


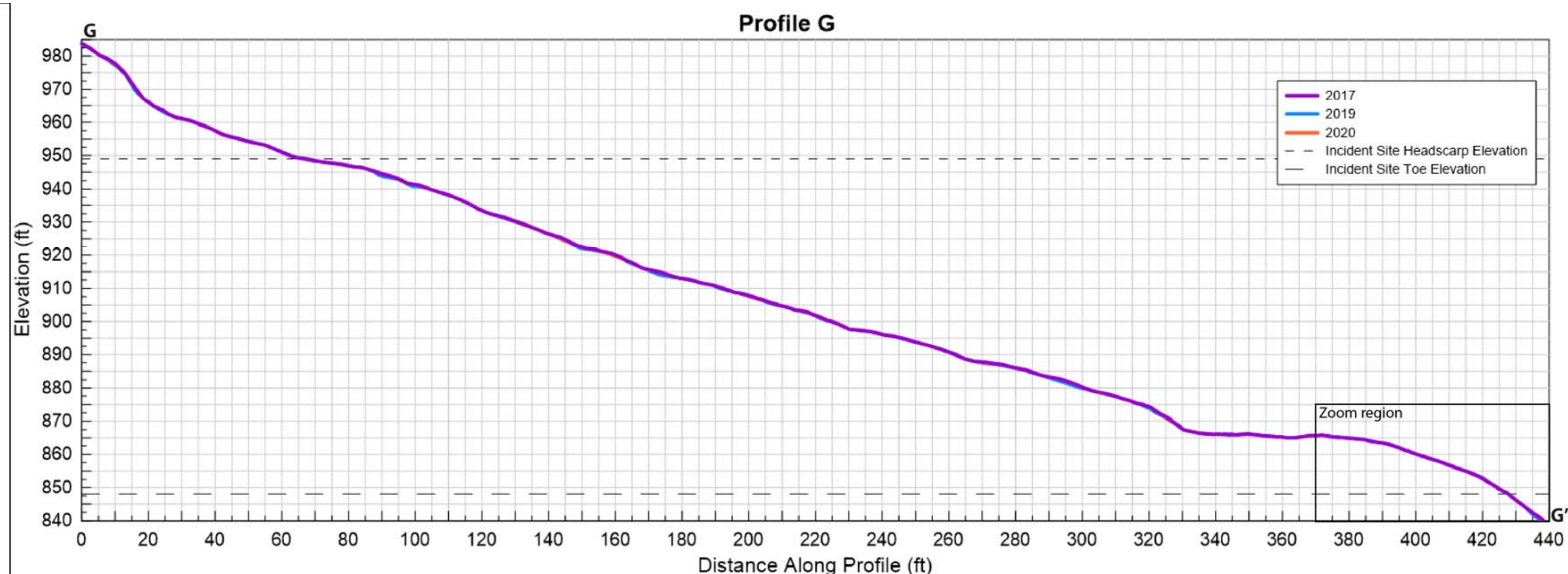
NOTES:

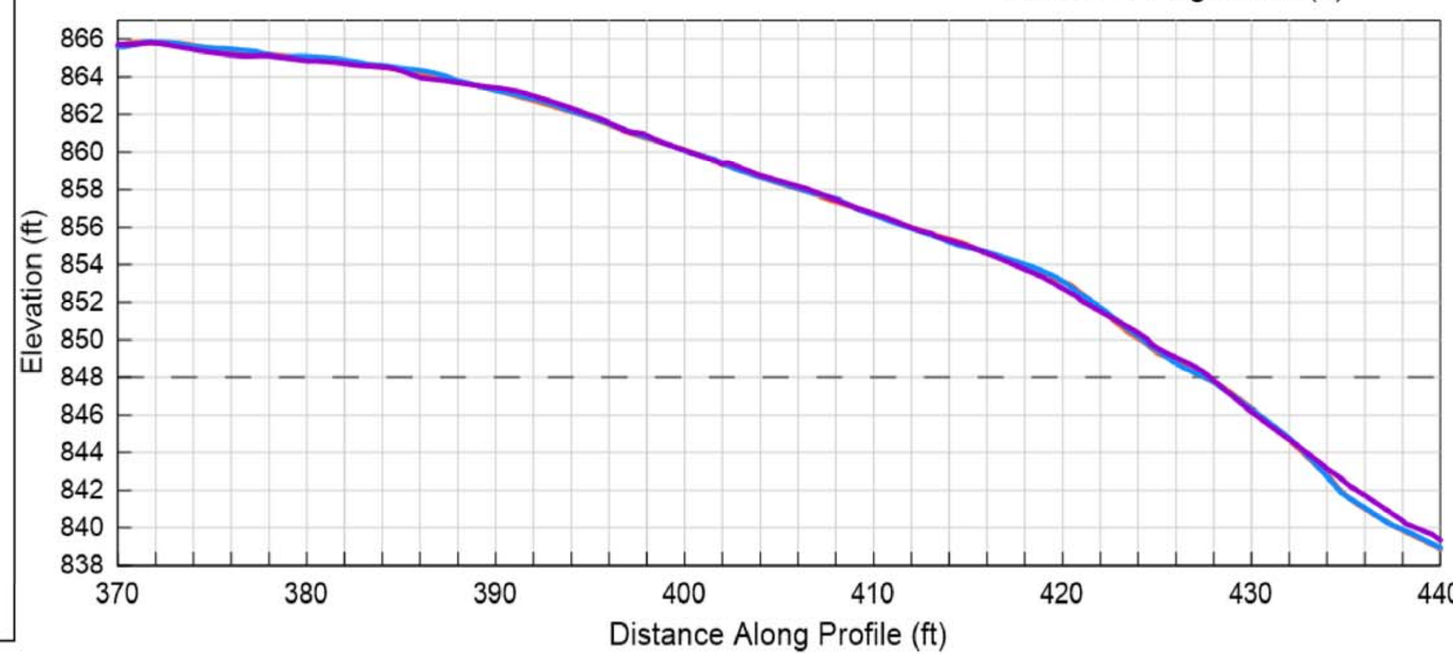
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. 2017 ALS bare earth point data downloaded from Kentucky government portal (https://kygeonet.ky.gov/govmaps/).
3. November 2019 and May 2020 ALS point cloud data acquired by Quantum Spatial and provided to BGC by TETLP.
4. 2017 vs May 2020 shortest distance change detection analysis results represented on May 2020 ALS hillshade.
5. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY:	FIGURE TITLE		
MJL	PROFILE F		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-20

0 5 10 mm in ANSI B sized paper



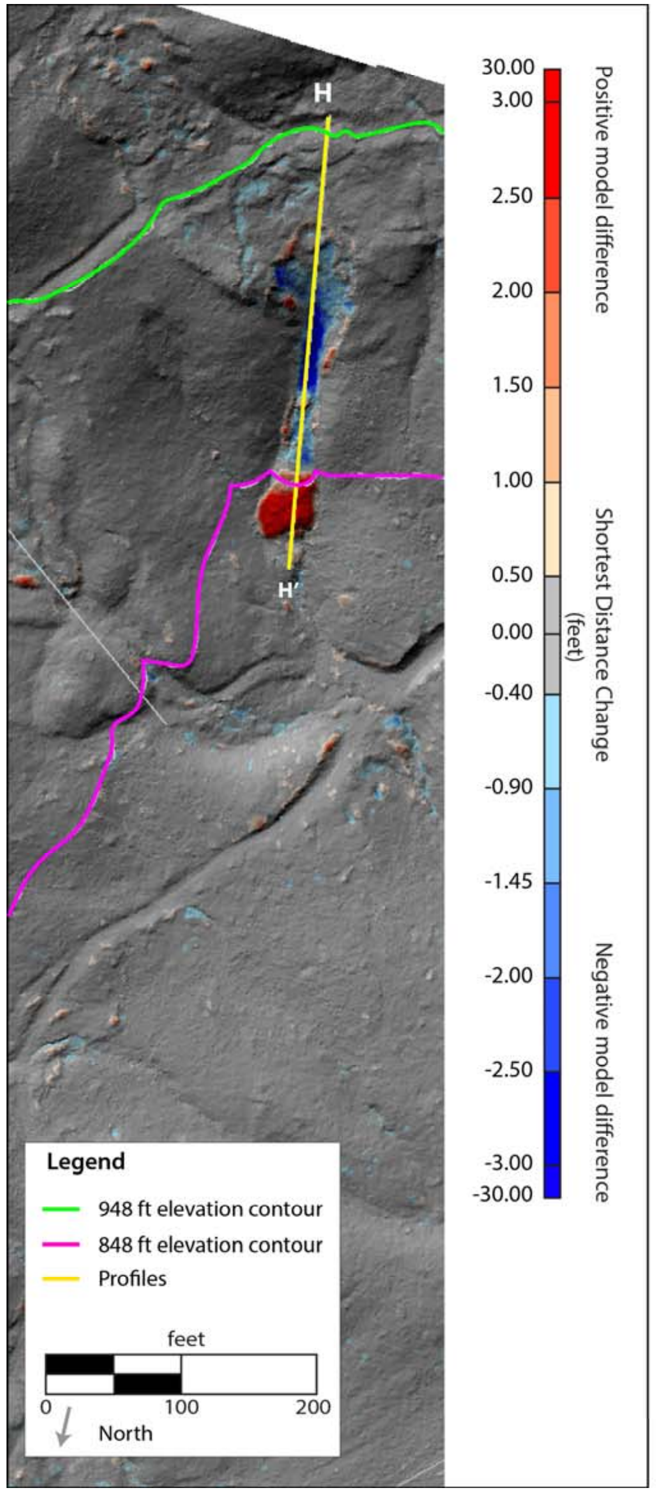


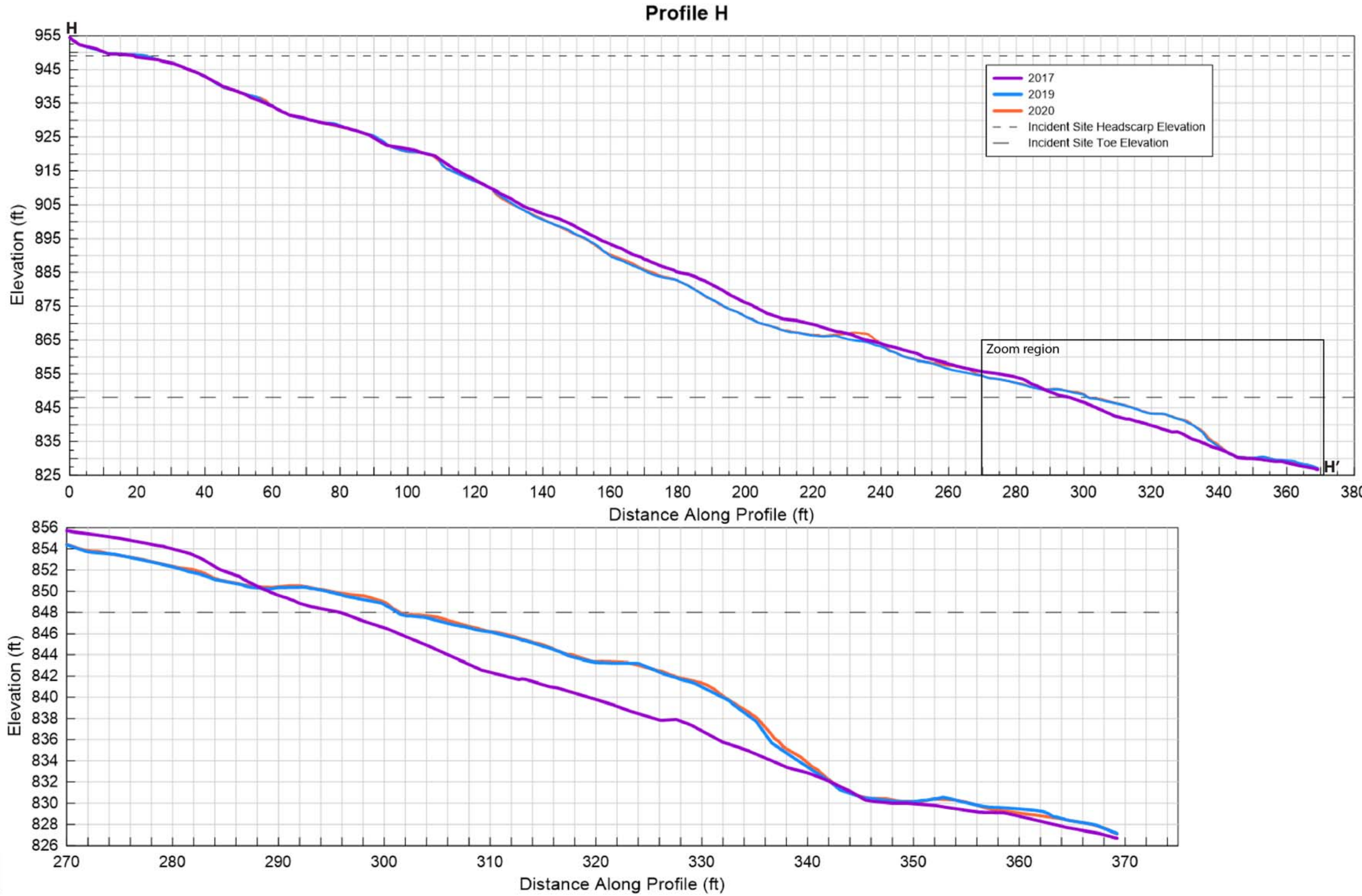


NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. 2017 ALS bare earth point data downloaded from Kentucky government portal (https://kygeonet.ky.gov/govmaps/).
3. November 2019 and May 2020 ALS point cloud data acquired by Quantum Spatial and provided to BGC by TETLP.
4. 2017 vs May 2020 shortest distance change detection analysis results represented on May 2020 ALS hillshade.
5. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY:	FIGURE TITLE		
MJL	PROFILE G		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-21

0 5 10 mm in ANSI B sized paper





NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. 2017 ALS bare earth point data downloaded from Kentucky government portal (https://kygeonet.ky.gov/govmaps/).
3. November 2019 and May 2020 ALS point cloud data acquired by Quantum Spatial and provided to BGC by TETLP.
4. 2017 vs May 2020 shortest distance change detection analysis results represented on May 2020 ALS hillshade.
5. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: MJL	FIGURE TITLE: PROFILE H		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: L-22

0 5 10 mm in ANSI B sized paper

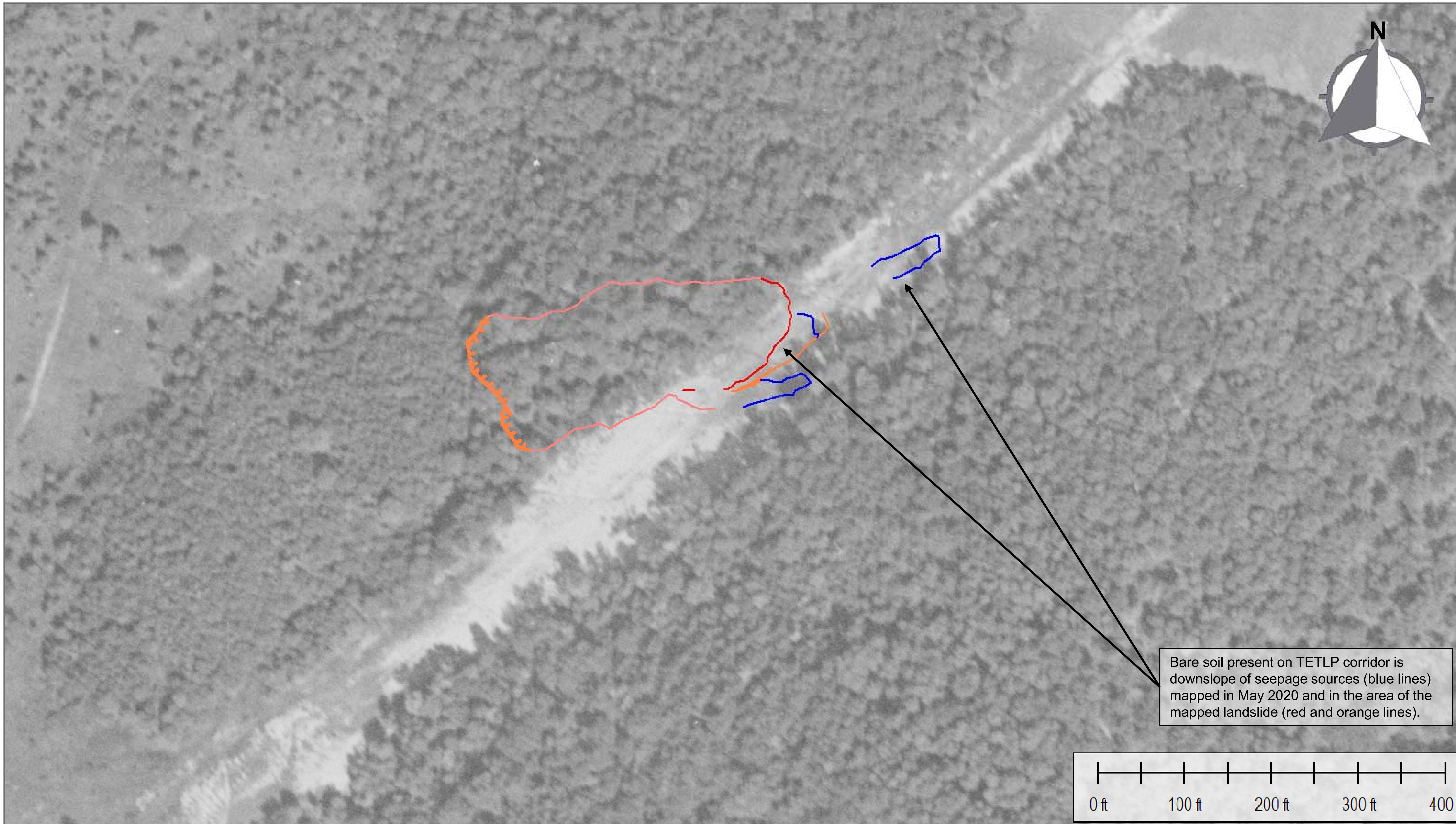
APPENDIX M
AIR PHOTOGRAPHY REVIEW

NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (1959). 2V, frame 166 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: CAD	FIGURE TITLE: FCI SEPTEMBER 12, 1959 AERIAL PHOTO			
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-1	

0 5 10 mm in ANSI B sized paper



NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (1959). 2V, frame 166 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: CAD	FIGURE TITLE: FCI SEPTEMBER 12, 1959 AERIAL PHOTO INSET		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-2

0 5 10 mm in ANSI B sized paper

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (1965). 4FF, frame 178 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: CAD	FIGURE TITLE: FCI OCTOBER 25, 1965 AERIAL PHOTO		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-3

0 5 10 mm in ANSI B sized paper

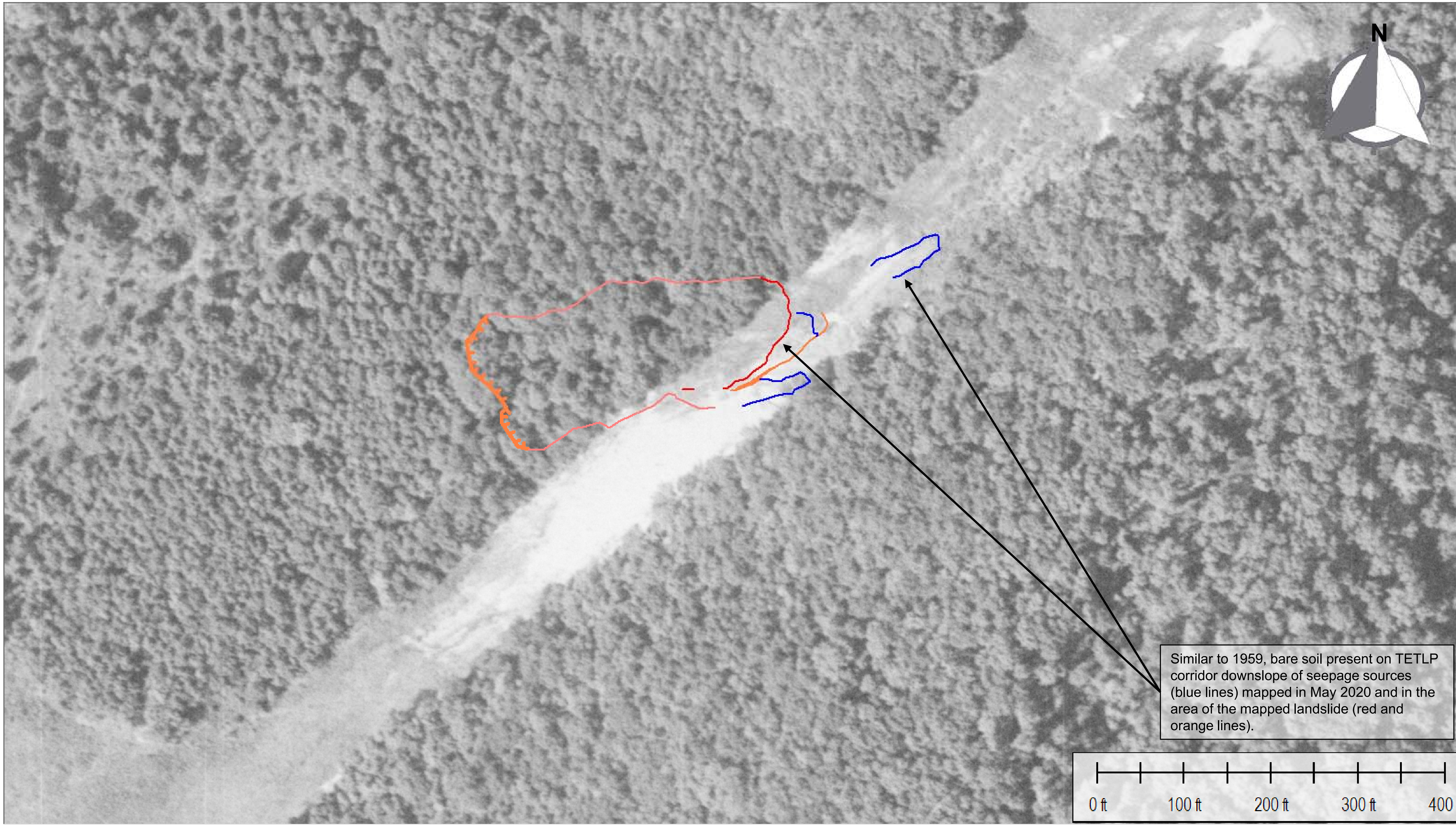
NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (1972). 172, frame 225 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: CAD	FIGURE TITLE: FCI SEPTEMBER 20, 1972 AERIAL PHOTO			
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-4	

0 5 10 mm in ANSI B sized paper

04-2021

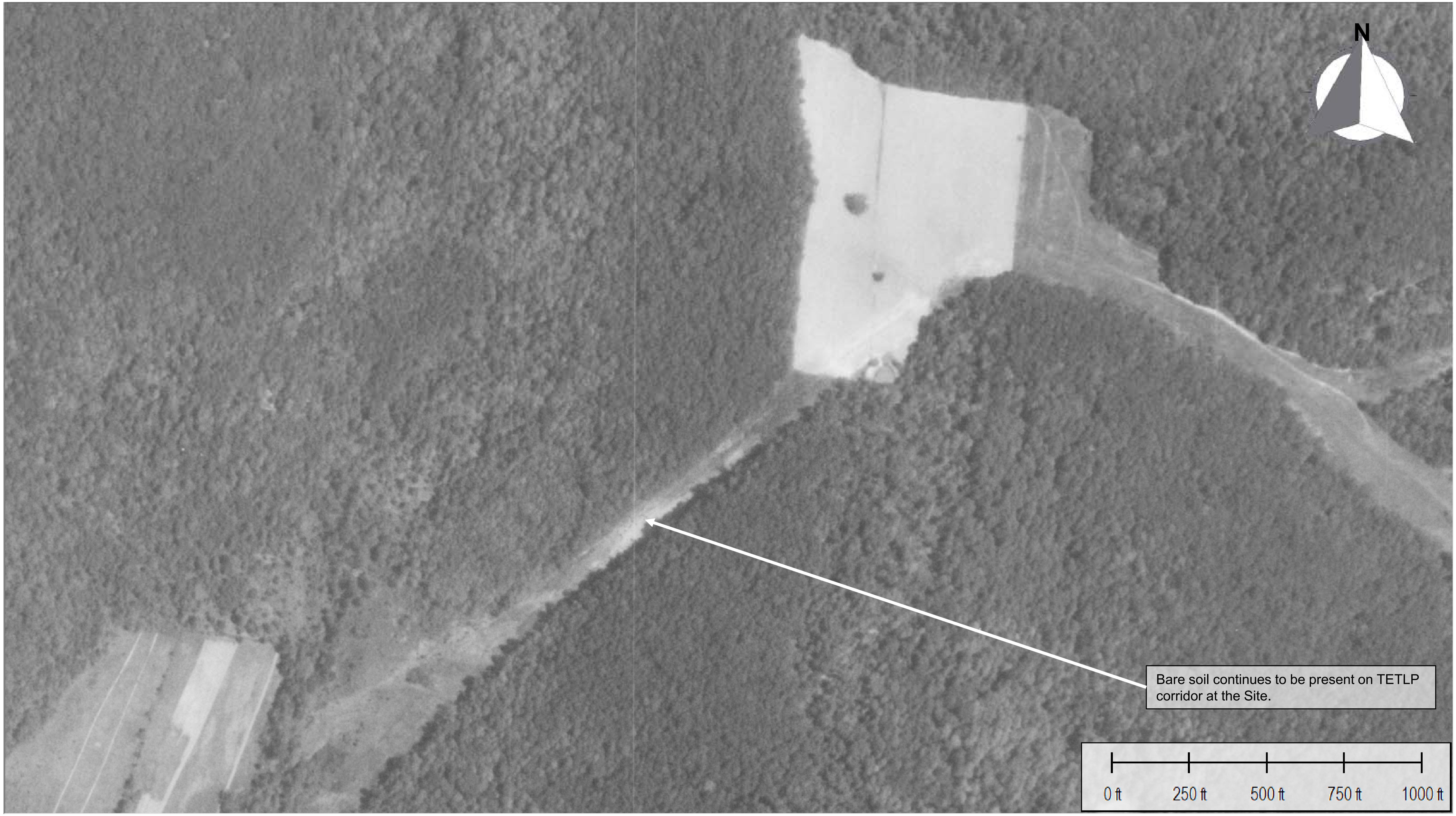


NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (1972). 172, frame 225 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: CAD	FIGURE TITLE: FCI SEPTEMBER 20, 1972 AERIAL PHOTO INSET			
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-5	

0 5 10 mm in ANSI B sized paper

BGC ENGINEERING INC.



NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (1981). 181, frame 39 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Fee
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: CAD	FIGURE TITLE: FCI MAY 22, 1981 AERIAL PHOTO		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-6

0 5 10 mm in ANSI B sized paper

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (1983). 319, frame 166 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY:	FIGURE TITLE		
CAD	FCI MARCH 18, 1983 AERIAL PHOTO		
CHECKED BY:	CLIENT:		
CRS	TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
CAD	AS SHOWN	1607024	M-7

0 5 10 mm in ANSI B sized paper

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (1983). 182, frame 66 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

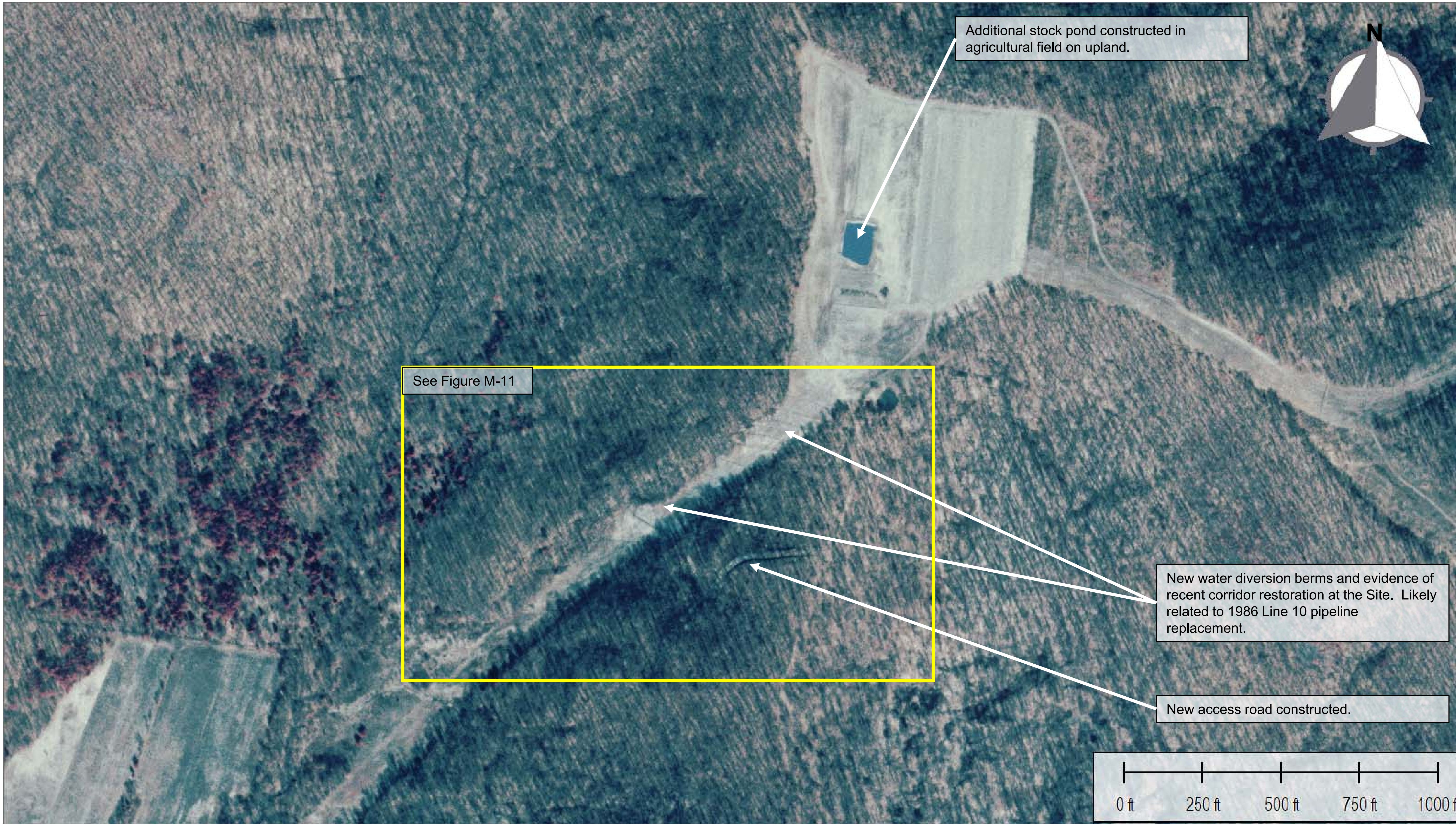
PREPARED BY: CAD	FIGURE TITLE: FCI JUNE 9, 1983 AERIAL PHOTO		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-8

0 5 10 mm in ANSI B sized paper

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (1985). 427, frame 40 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: CAD	FIGURE TITLE: FCI APRIL 17, 1985 AERIAL PHOTO		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-9

0 5 10 mm in ANSI B sized paper

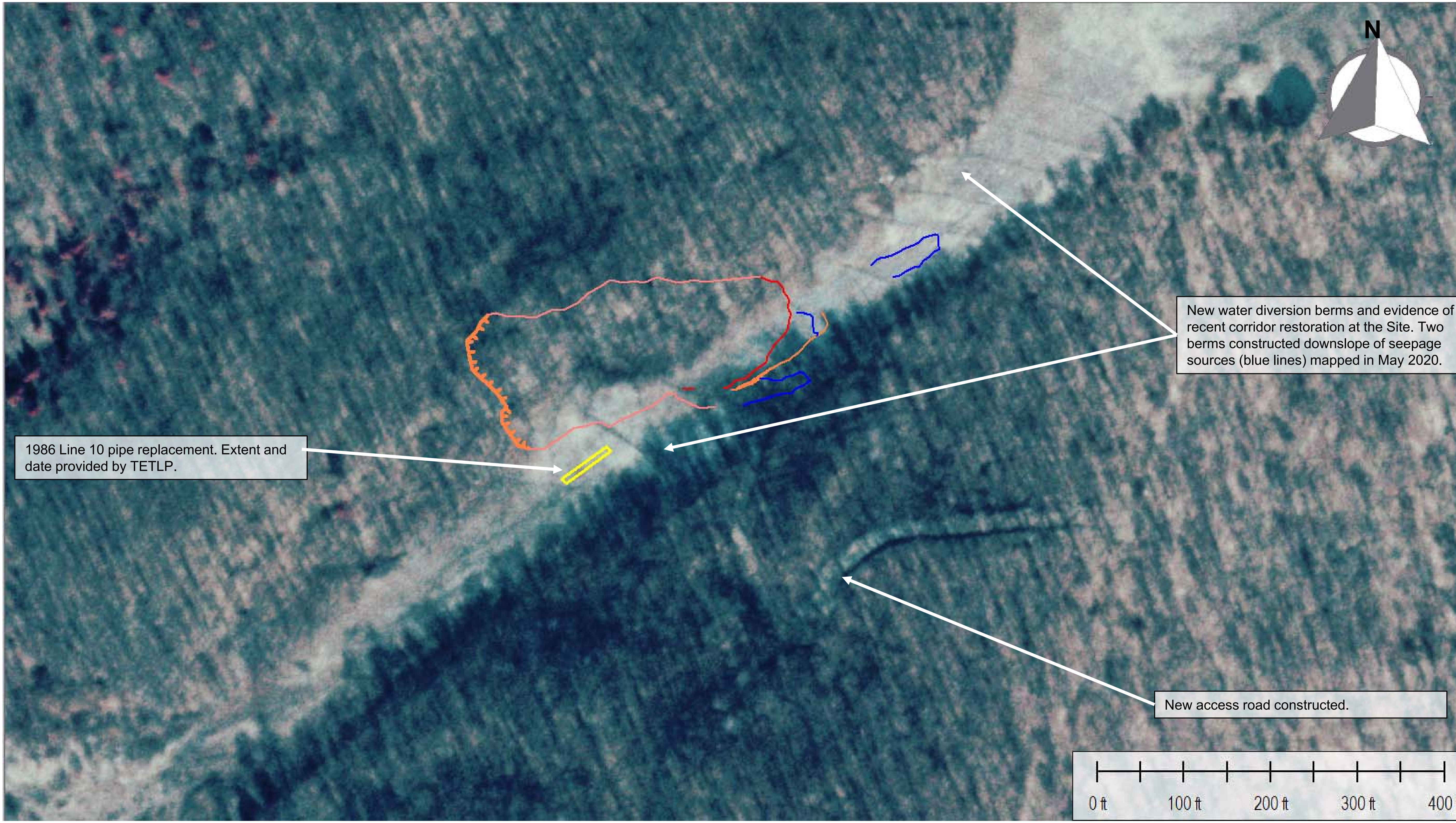


NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (1988). 29, frame 114 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: CAD	FIGURE TITLE: FCI MARCH 11, 1988 AERIAL PHOTO		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-10

0 5 10 mm in ANSI B sized paper



NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (1988). 29, frame 114 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
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PREPARED BY: CAD	FIGURE TITLE: FCI MARCH 11, 1988 AERIAL PHOTO INSET			
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-11	

0 5 10 mm in ANSI B sized paper

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (1995). 6030, frame 37 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
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PREPARED BY: CAD	FIGURE TITLE: FCI FEBRUARY 18, 1995 AERIAL PHOTO			
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-12	

0 5 10 mm in ANSI B sized paper

NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (2004). 03260, frame 83 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

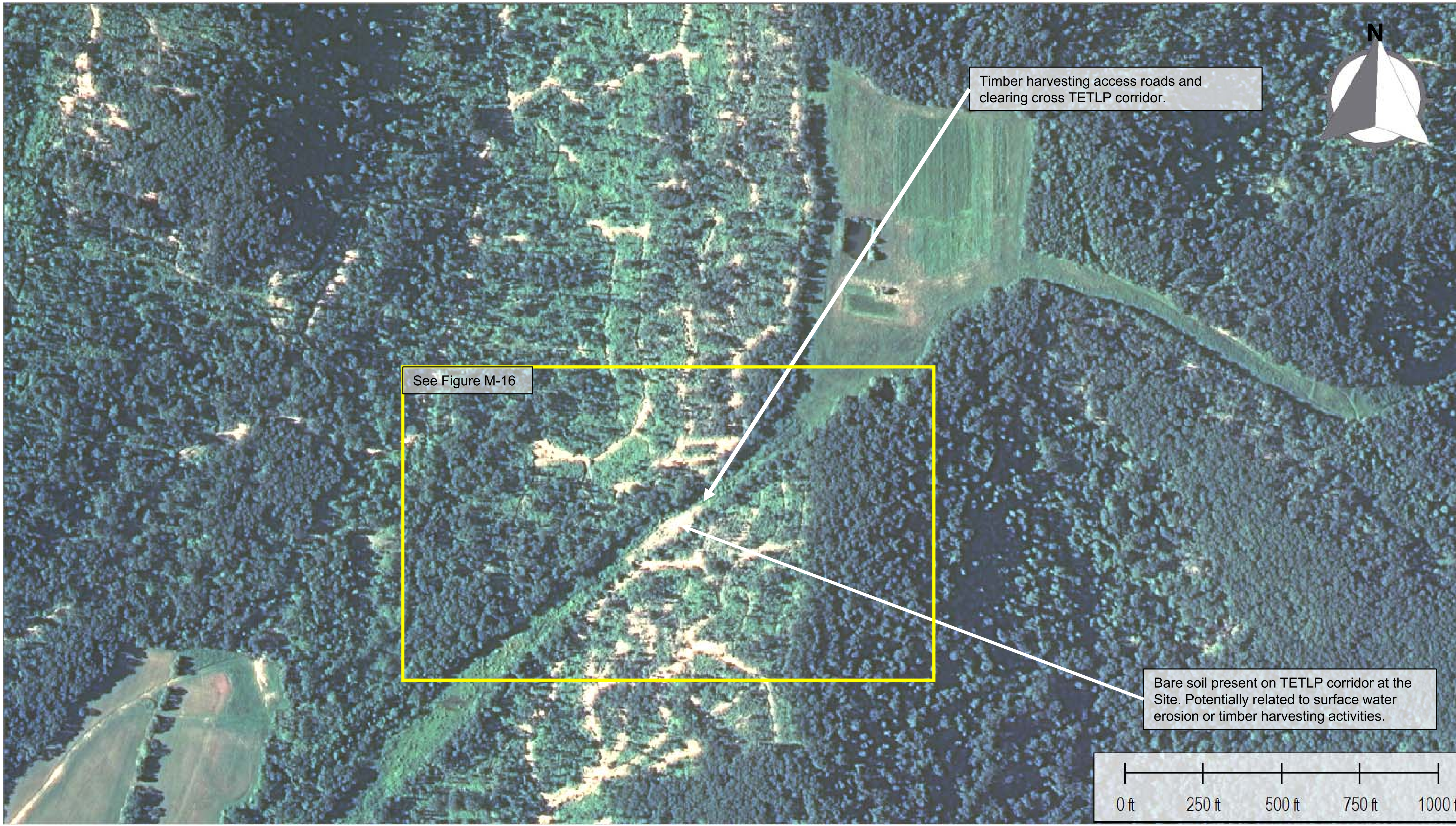
PREPARED BY: CAD	FIGURE TITLE: FCI SEPTEMBER 21, 2004 AERIAL PHOTO		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-13

0 5 10 mm in ANSI B sized paper

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (2006). NAIP06, frame 1-1 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: CAD	FIGURE TITLE: FCI JULY 27, 2006 AERIAL PHOTO			
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-14	

0 5 10 mm in ANSI B sized paper



NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (2008). NAIP08, frame 1-1 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
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PREPARED BY:	FIGURE TITLE		
CAD	FCI JULY 11, 2008 AERIAL PHOTO		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-15

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NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (2008). NAIP08, frame 1-1 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: CAD	FIGURE TITLE: FCI JULY 11, 2008 AERIAL PHOTO INSET		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-16

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04-2021

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (2010). NAIP10, frame 1-1 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
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PREPARED BY: CAD	FIGURE TITLE: FCI JULY 11, 2010 AERIAL PHOTO		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-17

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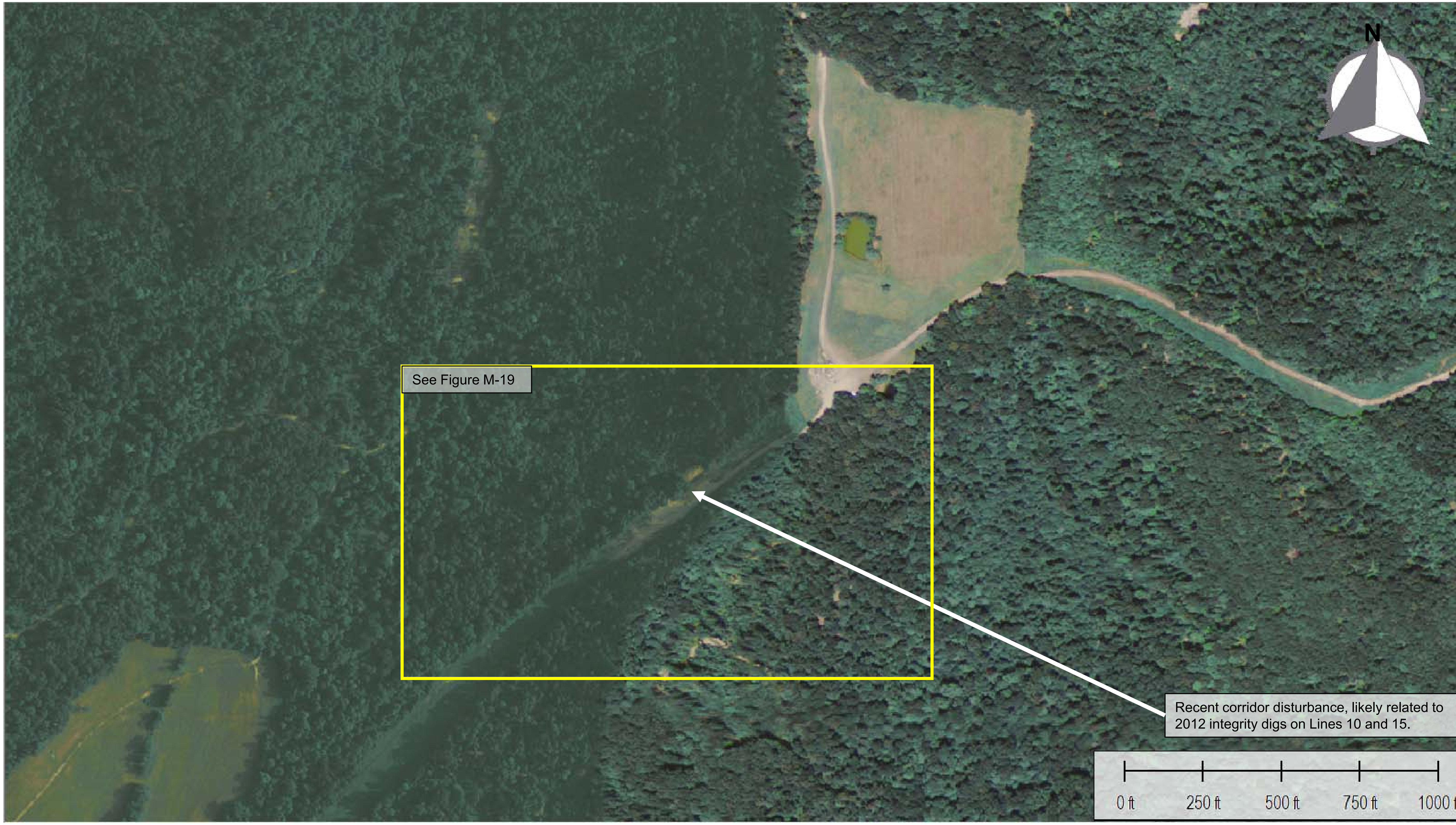

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (2012). NAIP12, frame 1-1 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
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PREPARED BY: CAD	FIGURE TITLE: FCI JULY 5, 2012 AERIAL PHOTO		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-18

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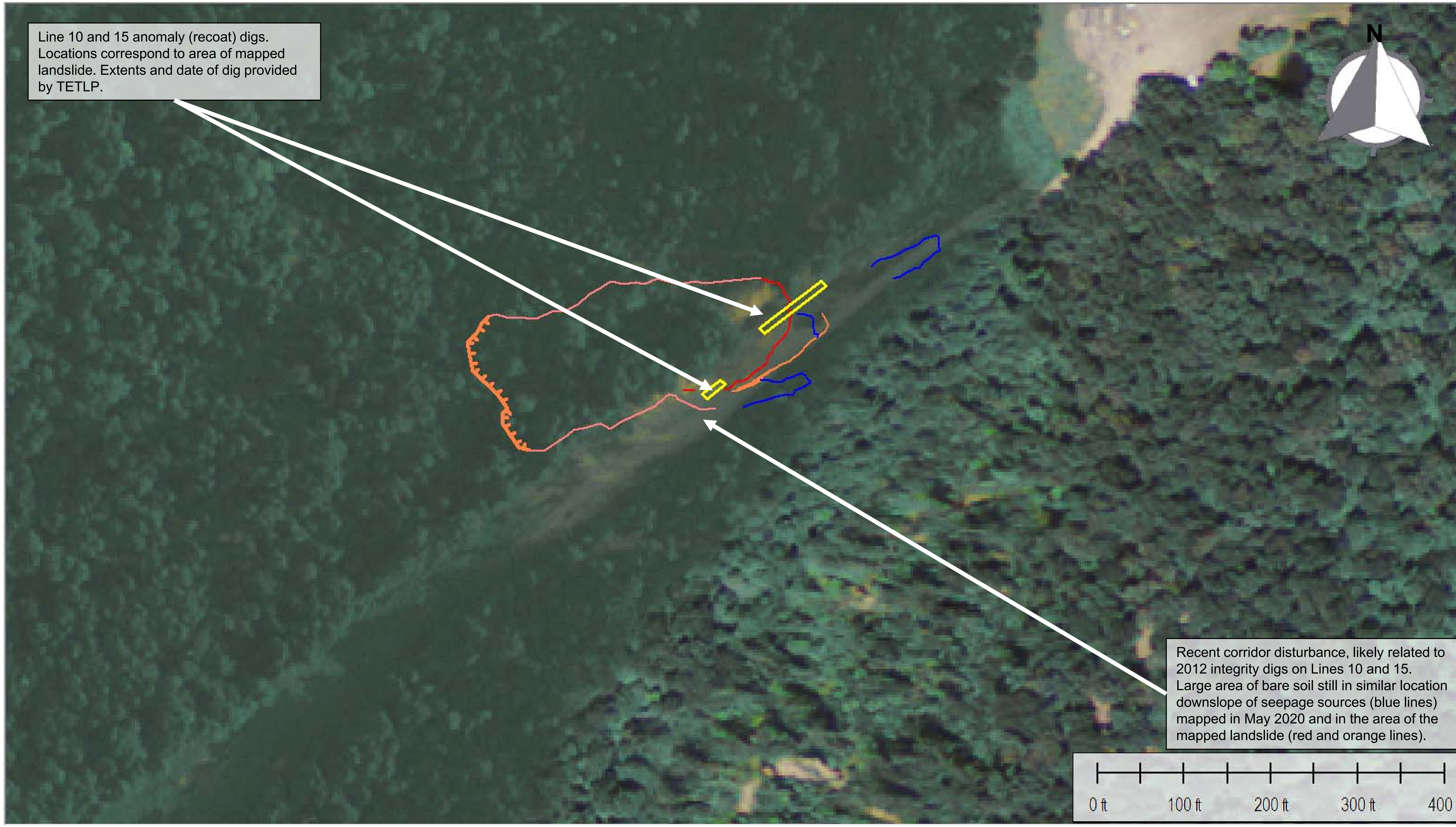

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (2012). NAIP12, frame 1-1 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
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PREPARED BY: CAD	FIGURE TITLE: FCI JULY 5, 2012 AERIAL PHOTO INSET			
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-19	

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04-2021

NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (2014). NAIP14, frame 1-1 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
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PREPARED BY: CAD	FIGURE TITLE: FCI JUNE 15, 2014 AERIAL PHOTO		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-20

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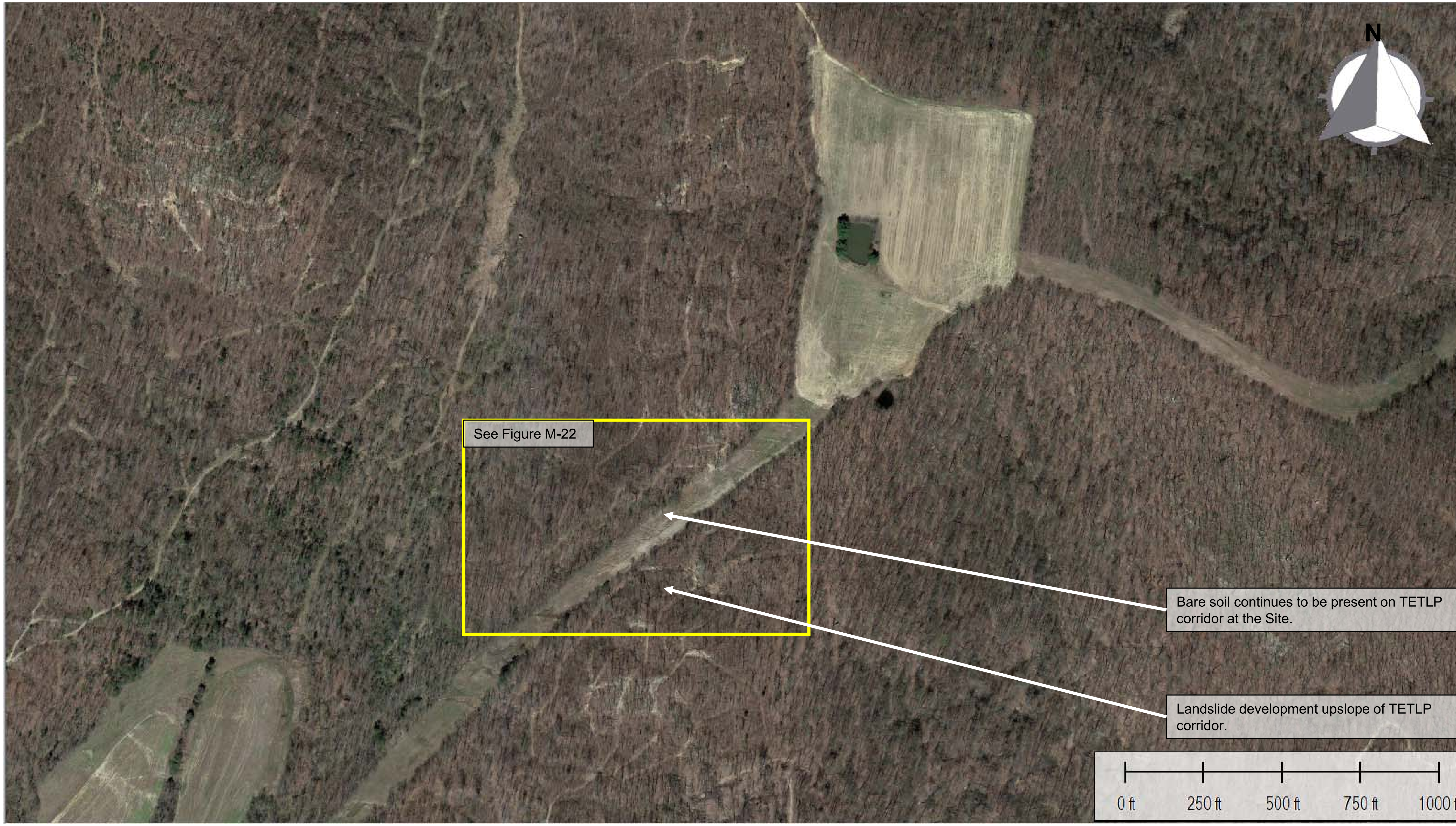


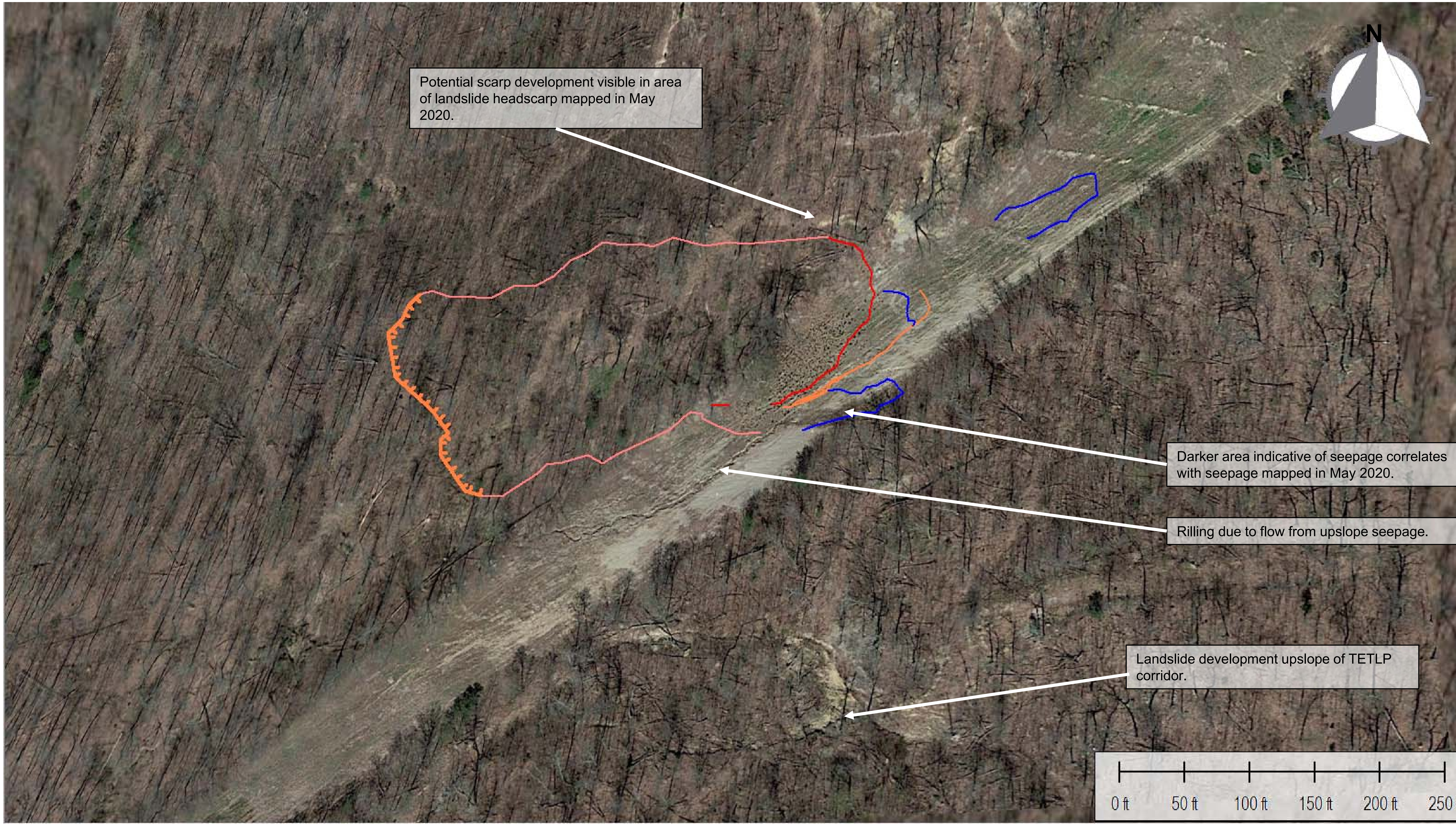
NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: Google Earth Pro 7.3.3.7699. (2020, May 7). Fleming County, Kentucky [Satellite Imagery]. Retrieved from http://www.google.com/earth.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY:	FIGURE TITLE		
CAD	FCI APRIL 4, 2016 AERIAL PHOTO		
CHECKED BY:	CLIENT:		
CRS	TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
CAD	AS SHOWN	1607024	M-21

0 5 10 mm in ANSI B sized paper

BGC ENGINEERING INC.



NOTES:
1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: Google Earth Pro 7.3.3.7699. (2020, May 7). Fleming County, Kentucky [Satellite Imagery]. Retrieved from http://www.google.com/earth
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: CAD	FIGURE TITLE: FCI APRIL 4, 2016 AERIAL PHOTO INSET			
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP			
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-22	

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NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (2016). NAIP16, frame 1-1 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
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PREPARED BY:	FIGURE TITLE		
CAD	FCI JUNE 9, 2016 AERIAL PHOTO		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-23

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NOTES:

1. This Figure should be read in conjunction with BGC's report titled "May 4, 2020 Fleming County Incident Geotechnical Causation" and dated April 2021.
2. Reference: USDA. (2018). NAIP18, frame 1-1 [Aerial photograph]. Salt Lake City, Utah: USDA Farm Service Agency – Aerial Photography Field Office.
3. Air Photos have been orthorectified to UTM Zone 17N NAD83 US Survey Feet.
4. Unless BGC agrees otherwise in writing, this figure shall not be modified or used for any purpose other than the purpose for which BGC generated it. BGC shall have no liability for any damages or loss arising in any way from any use or modification of this document not authorized by BGC. Any use of or reliance upon this document or its content by third parties shall be at such third parties' sole risk.

PREPARED BY: CAD	FIGURE TITLE: FCI OCTOBER 22, 2018 AERIAL PHOTO		
CHECKED BY: CRS	CLIENT: TEXAS EASTERN TRANSMISSION, LP		
APPROVED BY: CAD	SCALE: AS SHOWN	PROJECT NO: 1607024	FIGURE NO: M-24

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