Apr 25th, 9:00 AM - 11:00 AM

Preliminary site assessment for ground monitoring of a complex landslide along I-40 in Roane County, Tennessee

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Introduction

Borehole monitors are used to detect emerging slope hazards. Typically, monitoring is done with inclinometers, but time domain reflectometery (TDR) is a relatively new and cost-effective method (Figure 1) which has not yet been trialed in Tennessee for monitoring landslides near roads. ***The goal of this study is to assess landslide characteristics to optimize borehole installations at a TDR testing site.***

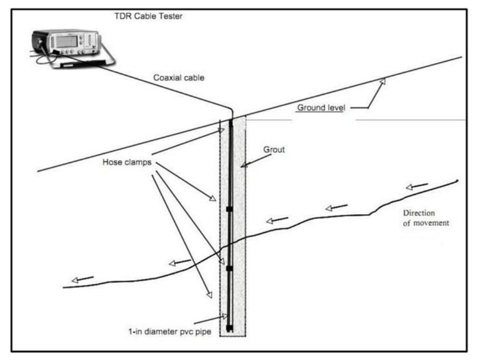

Figure 1. TDR system (Vinoth et al., 2016).

Site Description

- Half-mile section of I-40 north of Rockwood in Roane County (Figure 2).
- Slope instability problems began with initial highway construction in 1968.
- East-bound lane was constructed on a paleo landslide which failed during excavation (Figure 3).
- Slope stabilization and remediation include horizontal drains, groundwater pumping wells, and retaining walls.
- Site has been sporadically monitored with borehole inclinometers.
- Data from 13 inclinometers at the site indicated ongoing slope movement.

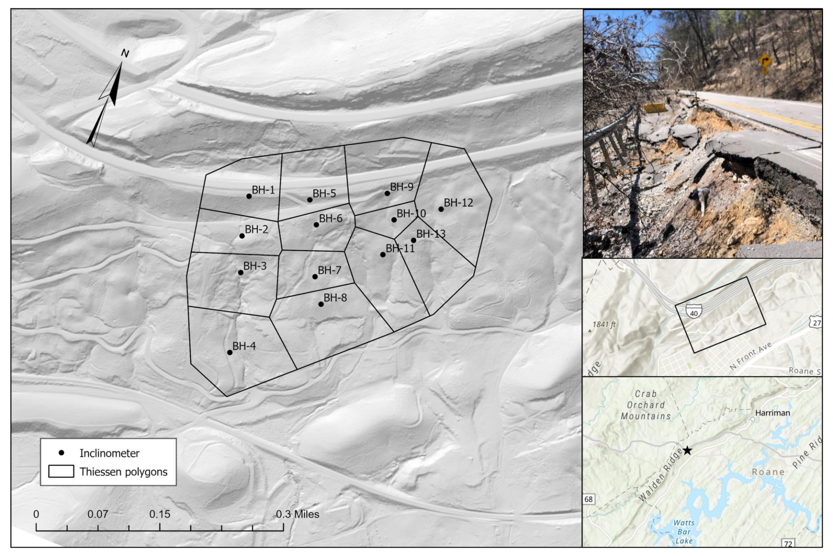

Figure 2. LiDAR hillshade map of the Rockwood landslide with inclinometer locations shown inside Thiessen polygons defining inclinometer areas. Inset maps on the right show site location.

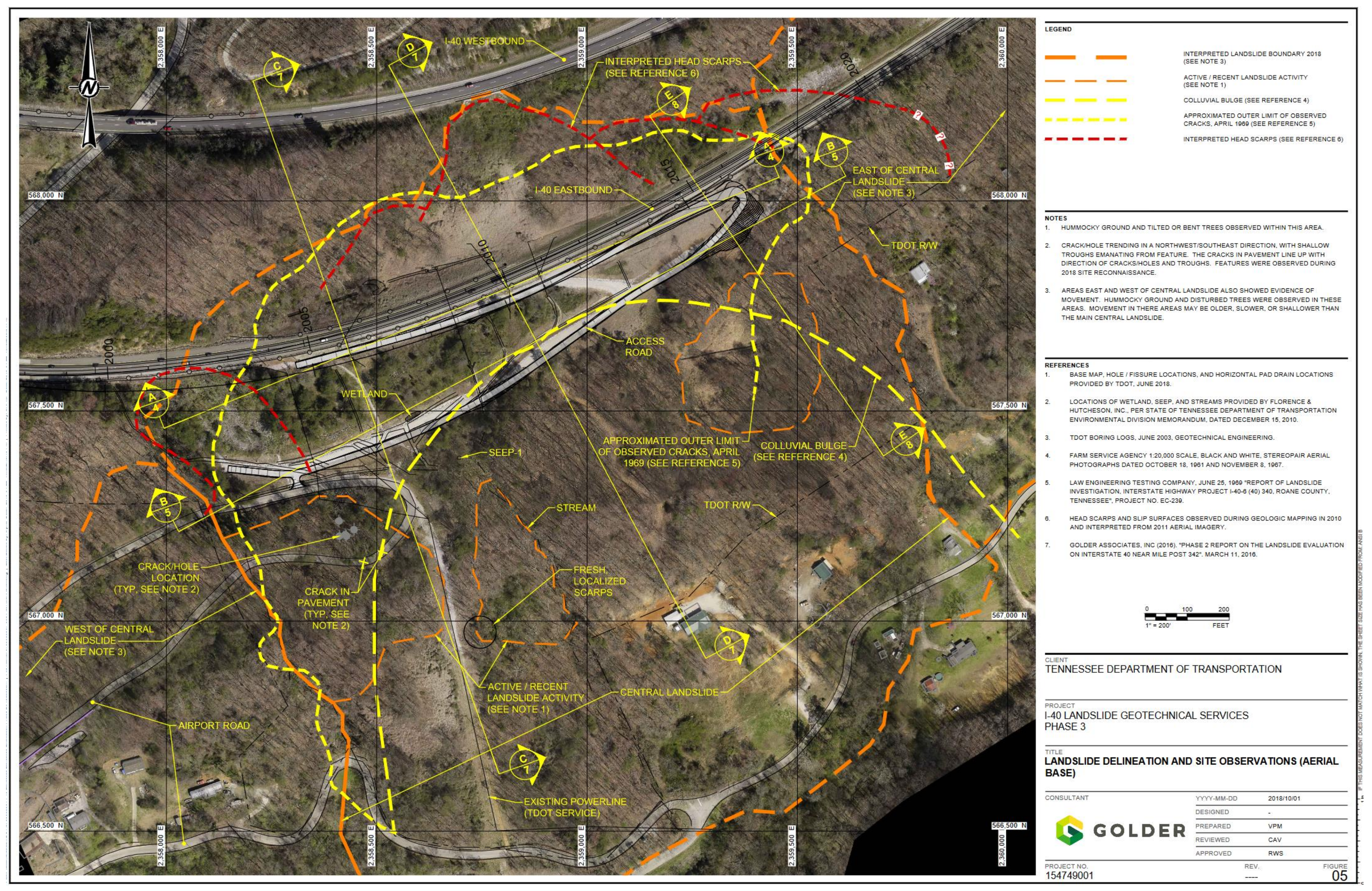

Figure 3. Site map by Golder Associates (2019) shows the outline of the slide area and suggests different slide bodies.

Methods

A dataset of monthly slope movements for 13 boreholes from 2018 to 2022 was analyzed for rate of movement and depth of slope failure (Figure 4). Preliminary data suggest the slope is sliding in two distinct units. Two approaches were used:

- Failure depth used to estimate morphology of the landslide slip surface
- Analysis of spatiotemporal trends in movements with space time cube (ArcGIS Pro)

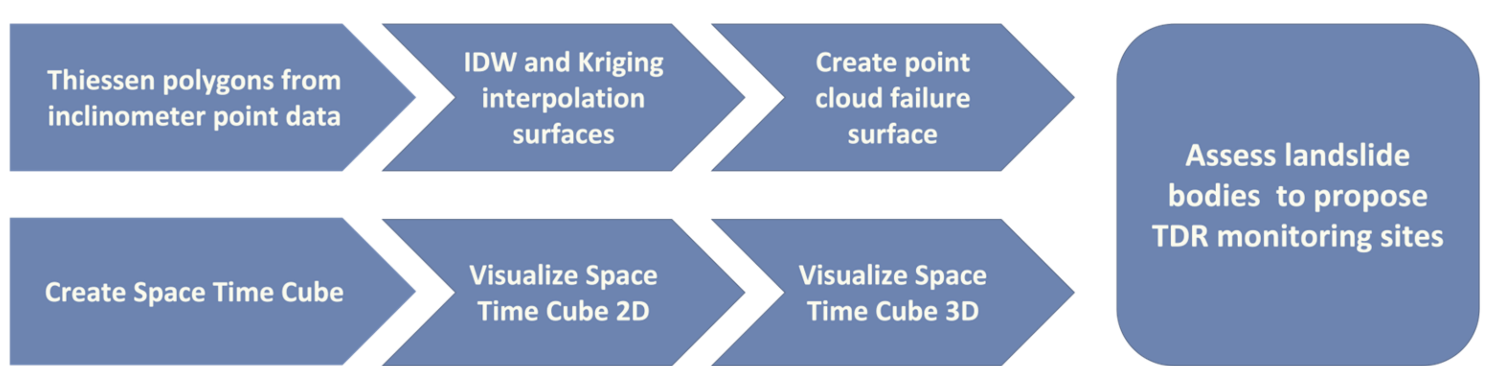

Figure 4. Methods flow chart

Abstract

In-ground slope monitoring is an essential part of landslide early warning systems. Precise movement data from borehole monitors can detect emerging hazards near critical infrastructure. Typically, monitoring is done with inclinometers, but lower-cost alternatives have emerged which have yet to be tested in Tennessee. Time domain reflectometry (TDR) records magnitudes and depths of slope movements along a buried coaxial cable. When paired with a remote data logger, TDR can wirelessly transmit high resolution movement data in real time, making it promising for landslide early warning systems. Tennessee Department of Transportation (TDOT) has proposed a one-year feasibility study to test TDR for use in unstable soil slopes near highways. The study area is a well-known landslide site along Interstate 40 in Roane County. Careful siting of borehole instrumentation is crucial for accurate monitoring; the goal of this study is to optimize TDR installation, with three specific aims: (i) evaluate landslide morphology, (ii) pinpoint locations and depths with greatest movement, and (iii) assess spatiotemporal patterns of movement across the site. Statistical analysis of prior data from 13 inclinometers showed ongoing slope movement over the 21-acre complex landslide. Spatial interpolation suggested an asymmetrical failure surface with both shallow and deep motion. Space-time cube analysis indicated varying movement rates and timing across the site, suggesting separate landslide bodies. Based on these results, optimal borehole depths and locations were proposed for three TDR instruments. This analysis will promote effective trials of TDR for early warning system feasibility in Tennessee.

Results - Failure surface

Based on observed depth of movement for each inclinometer, an estimated failure surface was created using Ordinary Kriging (Figure 5). When visualized in 3D with the failure surface overlaid with LiDAR elevation of the ground surface for visual interpretation (Figure 6), the landslide failure surface appears higher in the east (8 to 40 ft), while the side slip surface was deeper on the west side (75-122 feet). The irregular surface suggests a composite landslide with shallow translational and deep rotational components.

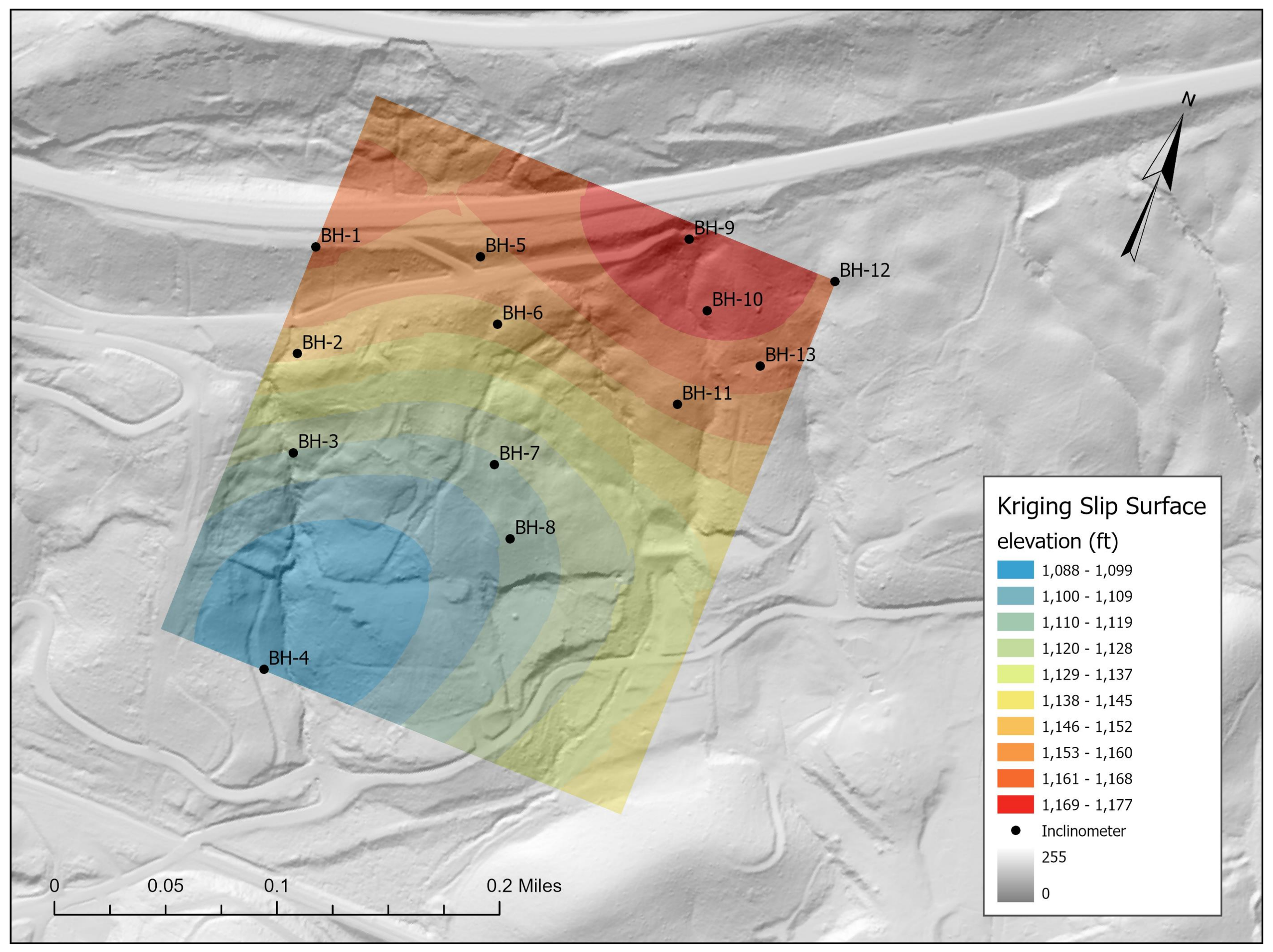

Figure 5. Kriging interpolation surface predicting depth of landslide failure surface across the slide area based on observed failure depths from the 13 borehole inclinometers.

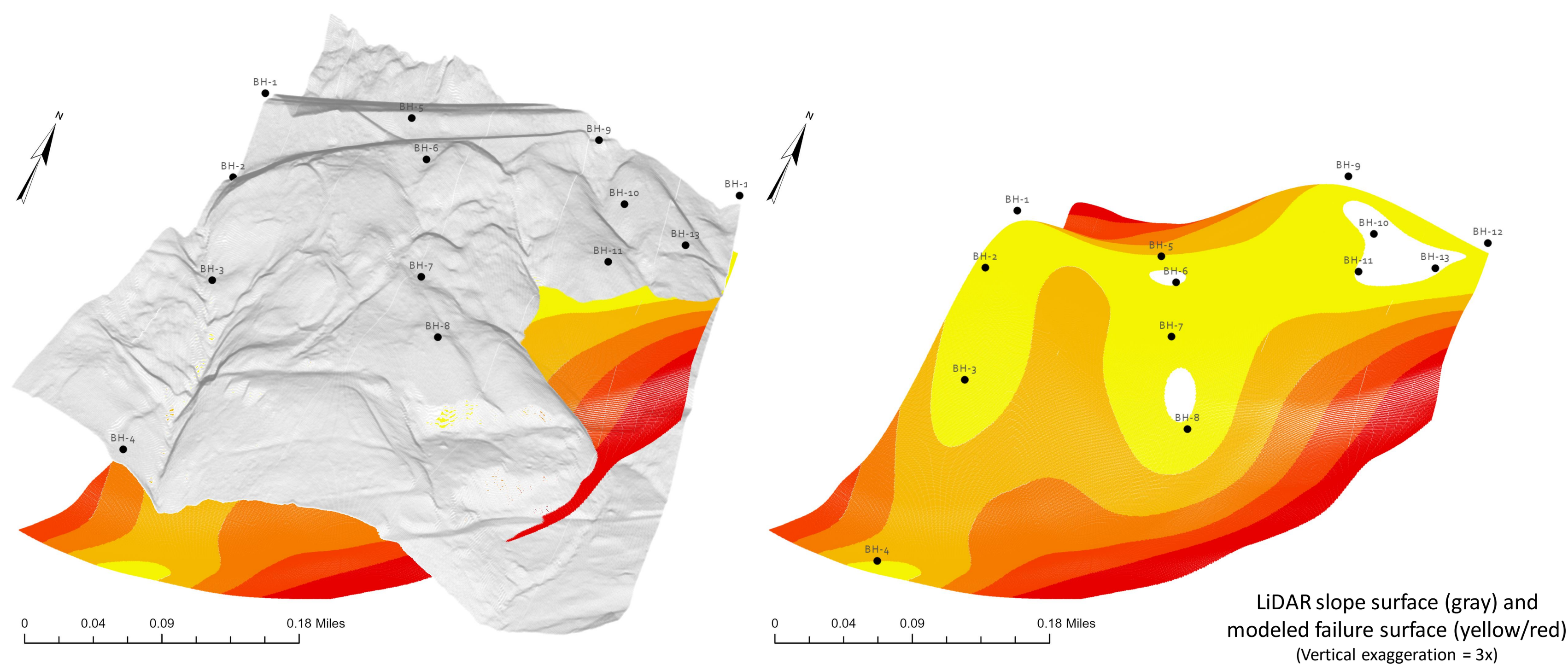

Figure 6. 3D point layers extracted from state LiDAR elevation raster overlaid on an estimated landslide failure surface point cloud based on kriging results. These show an irregular failure surface with shallow sliding in the east and deep failure in the western landslide area. The symbology shows kriging error results: low standard error of prediction = yellow and high standard error = red.

Results – Landslide movement rates

Thiessen polygons show average rate of sliding over the 4-year period (Figure 7) show highest rates of slip in the eastern side. Space time cube 3D visualization (Figure 8) indicates a period of increased sliding in the western area in 2019-2020, followed by more recent sliding for the eastern slide area.

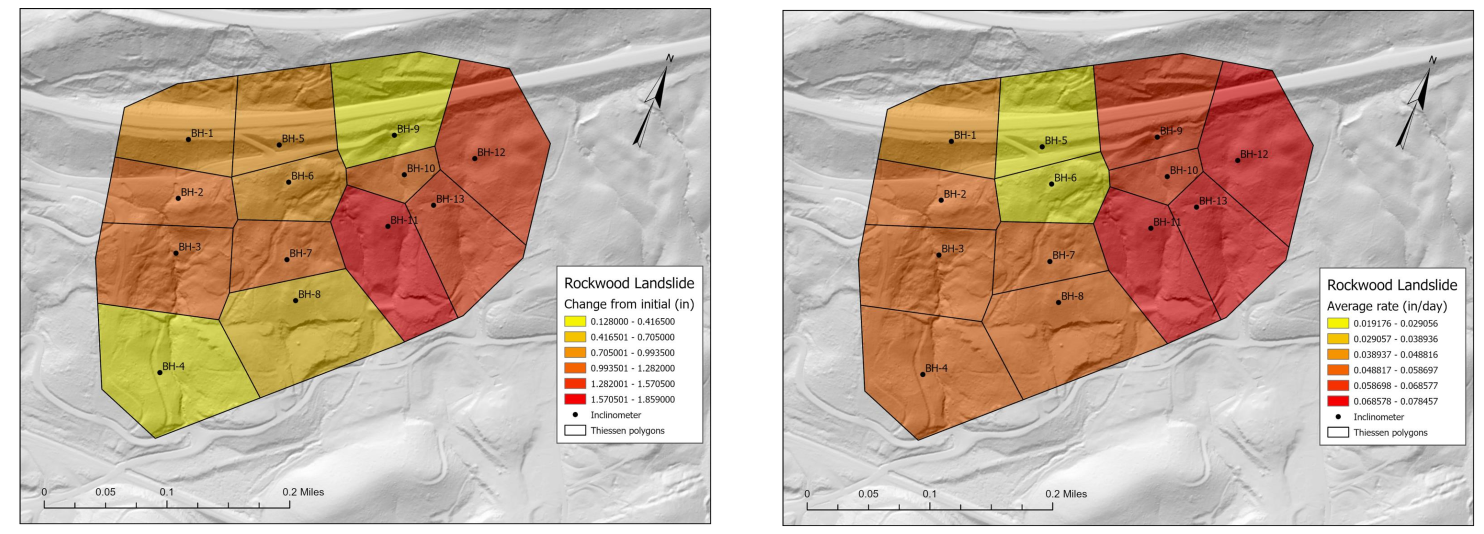

Figure 7. Thiessen polygon maps show differences across site for (i) overall movement per borehole for the 4-year period (left image) and (ii) daily average movement (right).

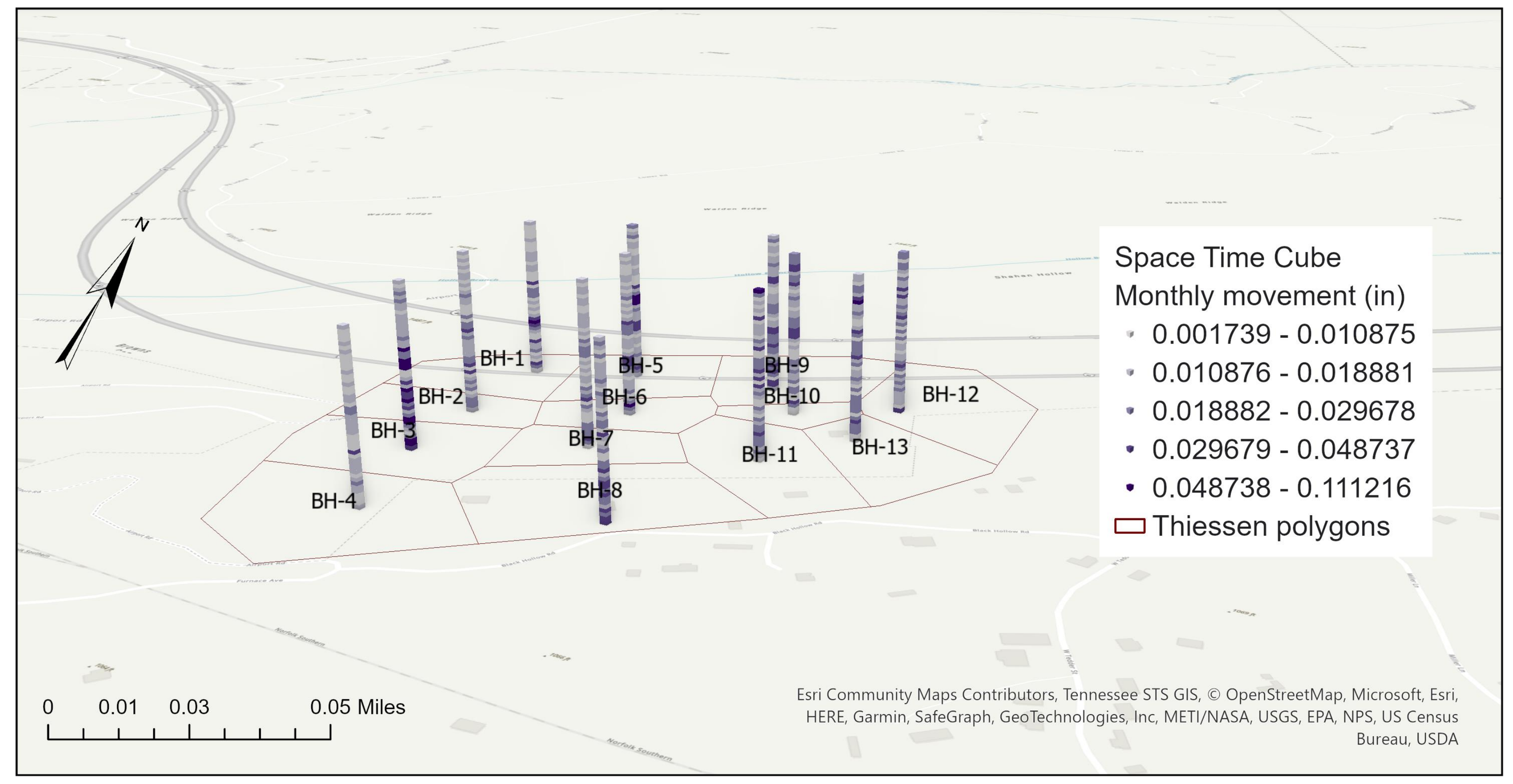

Figure 8. Visualization of space time cube for average movement by month. Thiessen polygons for each borehole are shown with the time series data (white and purple stacks) of monthly movements for the 4-year measurement period.

Conclusion and recommendation

- Two landslide masses were inferred: deep-seated western rotational landslide with moderate slippage, failure surface at 75 to 122 ft depth.
- Shallower but more mobile slide with recent motion, 8 to 41 ft.
- Greatest threat to I-40 appears to be from the western deep slide.
- 3 borehole locations were selected in upslope, mid-slope, and lower slope positions of the western slide mass for TDR monitoring (Figure 9).
- Feasibility tests for early warning system with TDR will improve safety (Figure 10) and maintenance (Figure 11) along I-40.

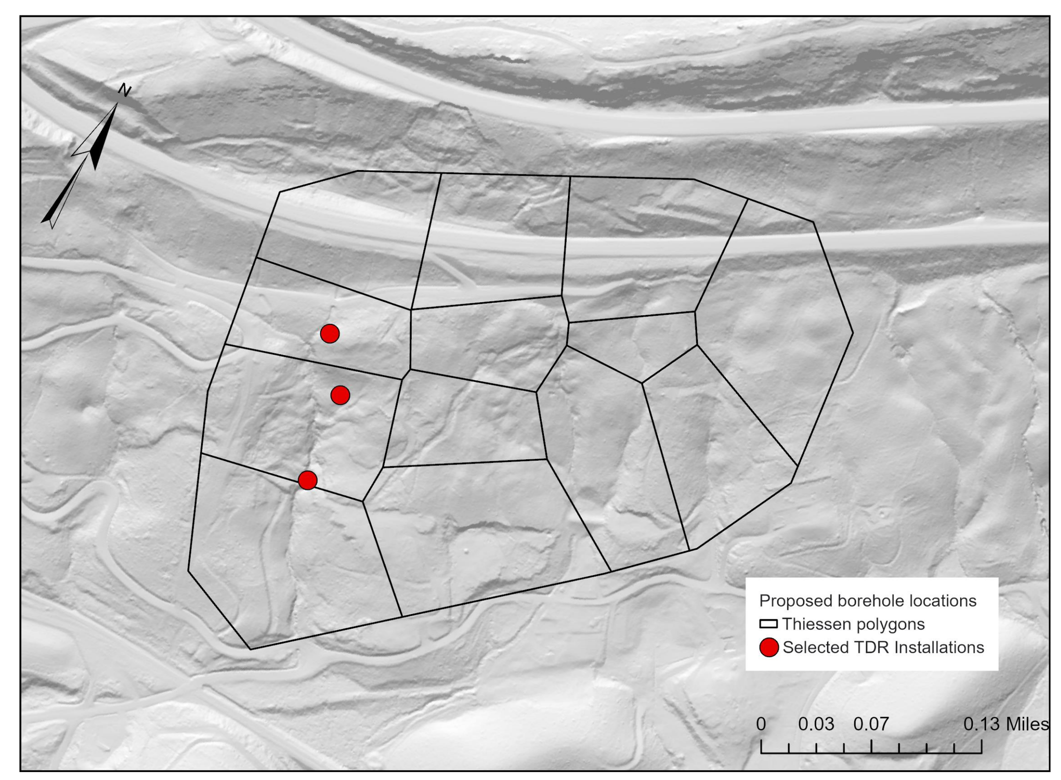

Figure 9. Proposed TDR boreholes

Figure 10. Field work on site.

Figure 11. borehole inclinometer.

Acknowledgements: TDOT, Golder Inc.