

Inventory Mapping and Characterization of Landslides Using LiDAR: Kenton and Campbell Counties, Kentucky

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Introduction

Landslide identification and hazard mapping using light detection and ranging (LiDAR) have proven successful in Kentucky and other landslide prone areas of the United States, such as Oregon, Washington, and North Carolina (Burns and Madin, 2009; McKenna and others, 2008; Wooten and others, 2007). The purpose of this project was to develop a methodology for using LiDAR data to document preexisting landslides in Kenton and Campbell Counties, Kentucky (fig. 1). To do this, potential landslides were mapped and digitized that previously were not visible on existing maps or coarse digital elevation models (DEMs). Field verification of these mapped locations, where possible, also was conducted. Using high-resolution LiDAR to identify potential landslides provides a framework for analyzing landslide data that are crucial to understanding landslide susceptibility and reducing long-term losses.

Impact

Landslides have long been a problem in northern Kentucky. Steep topography, bedrock geology, and unconsolidated soils make many parts of northern Kentucky susceptible to landslides (Agnello, 2009; Potter, 2007). A 324-square-mile (mi²) area in Kenton and Campbell Counties consists of a heavily populated northern part close to Cincinnati and a more rural southern part (fig. 2). Many documented landslides have damaged roads, homes, and other infrastructure, thereby causing financial losses for property owners and making decisions difficult for government agencies and developers. Data obtained from the Kentucky Transportation Cabinet show that, from 2002 to 2010, landslide repair costs to roads

exceeded \$1.5 million in these counties (Overfield, 2014). From 2003 to 2013, the Kentucky State Emergency Management Office spent approximately \$5.3 million on acquisition of landslide-damaged homes (Esther White, University of Kentucky Hazard Mitigation Grant Program, written communication, 2011). In addition to direct costs, indirect costs such as commerce hindered by road closures, devalued property, and environmental effects may exceed direct costs. The slow nature of movement in some landslides, however, many of which are not related to roads, leads to incremental damage that can span several decades, often making people less aware of the problem. Many landslides go unreported and citizens do not take advantage of resources to become educated about how to recognize and mitigate the problems. This project will identify landslides not previously documented, provide insight into the distribution of landslides, and indicate areas of potential concern for future slope failure.

Methodology

The following steps were taken to identify landslides:

- Applied Imagery’s Quick Terrain Modeler software (<http://appliedimagery.com/>) was used to create DEM data sets from LiDAR LASer (LAS) files. LAS files are an industry standard binary file format capable of storing more information.
- DEMs were imported into Esri’s ArcMap for visualization, spatial analysis, and digitization.
- Digitized landslides were reexamined in 3D in Quick Terrain Modeler (v. 7.1.0).
- Locations were field checked.

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Introduction

Landslide identification and hazard mapping using LIDAR has proven successful in other landslide prone areas of the U.S. The purpose of this project was to develop a methodology using LIDAR data optimal for the geologic setting of Kenton and Campbell Counties and document landslides as part of an existing inventory. To do this, potential landslides were mapped and digitized that were previously not visible on existing maps or coarse digital elevation models. Field verification of these locations, where possible, also followed. Developing a methodology for viewing high resolution LIDAR to identify potential landslides provides a framework analyzing landslide data that is crucial to understanding the nature of the landslide prone areas and reducing long-term losses from landslide hazards.



KY 177: Slide above and below road, note old retaining wall.



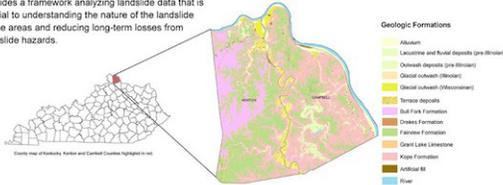
Licking Pike: Scarp and cracks in pavement, slide above and below road



KY 8: Leaning telephone poles on large slide above and below road



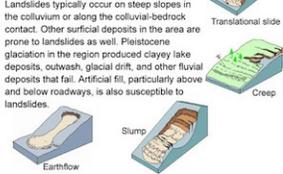
KY 1072: Old embankment failure



Geology & Common Landslide Types

Ordovician bedrock geology in Kenton and Campbell Counties consists of, in ascending order, the Kope Formation, Fairview Formation, Grant Lake Limestone, and Bull Fork Formation. Although landslides can occur in any of these units, the Kope Formation is especially problematic and is associated with many of the landslides in the area. The Kope shale weathers easily, slumping and producing colluvial soils of variable thickness. Composition of the colluvium ranges from clayey (predominantly illite) and silty to coarse with abundant limestone slabs. When clayey colluvium is mixed with large amounts of water, the soils pore-water pressure increases, which adds to the overall load on the slope.

Thickness of colluvial soils ranges, but is typically thicker at the toe of the slope. Landslides typically occur on steep slopes in the colluvium or along the colluvial-bedrock contact. Other surficial deposits in the area are prone to landslides as well. Pleistocene glaciation in the region produced clayey lake deposits, outwash, glacial drift, and other fluvial deposits that fail, particularly above and below roadways, is also susceptible to landslides.



Data Sets

- Standard LIDAR LAS files (provided by the Northern Ky Area Planning Commission)
 - Digital Elevation Models (DEM's)
 - Slope maps
 - Hillshade DEM's (bare earth)
 - Topographic contours (2 and 4 ft)
 - 1:24,000 scale geology
- 2-ft color aerial photography (leaf off)



Acknowledgements

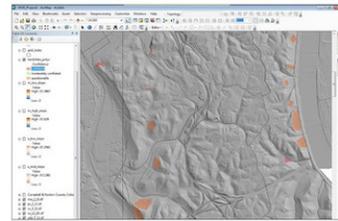
I would like to thank Paula Gorr and Peter Lytle with the U.S. Geological Survey Landslide Hazards program, which provided funding for this project. I also thank Sarah Johnson with Northern Kentucky University, who provided assistance with field work and valuable discussion of landslide activity in the area. Finally, I would like to thank William Andrews, Jerry Wassenfuh, Jackie Silvers, and Meg Smith of the Kentucky Geological Survey, who helped with the proposal, deliverable report, and making this project possible.

Project Methodology

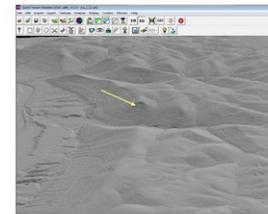
- Used Quick Terrain Modeler to create hillshade DEM's from the LAS files
- Imported DEM's to ESRI's ArcMap for visualization and spatial analysis
- Reexamined digitized landslides in Quick Terrain Modeler
- Performed field checking (example photos above)

Visualization

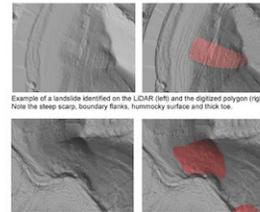
- Extents were digitized based on geomorphic signature: Scarp presence? Thick toeslope? Slope curvature? Hummocky?
- Systematic panning across the hillshade DEM's at various scales was used to identify and digitize the areal extent of potential landslides.
- A tiling scheme provided by the planning commission was used to help organize the visualization process
- Panning and zooming across the DEM's occurred: 1:10,000, 1:5,000, and 1:2,000
- Selected digitized features (25%) were reexamined in Quick Terrain Modeler with different azimuths, sun angles, and 3D
- For half of those, confidence was changed from questionable to moderately confident



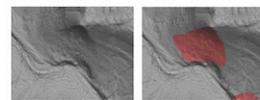
ESRI's ArcMap software program was used to map potential landslides. ArcMap allows for other data sets, contours, aerial photography, and geology to be used in conjunction with the LIDAR.



3D view in Quick Terrain Modeler. This software allows for creation of hillshade DEM's and rapid change of azimuths and sun angles.



Example of a landslide identified on the LIDAR (left) and the digitized polygon (right). Note the steep scarp, boundary flanks, hummocky surface and trunk line.



Example of a landslide identified on the LIDAR (left) and the digitized polygon (right). Note the steep scarp, boundary flanks, and hummocky surface. The steep scarp along the outbank of the stream probably contributed to the larger slide above.

Results

- 234 potential landslide extents digitized
- 10% initially attributed as confident
- Other slides attributed as moderately confident or questionable
- 15% of slide extents digitized were field checked. Of these, 43% were confirmed, 40% were likely, and 17% were not accessible.
- Types of landslides were not determined.

Figure 1. Page-size version of DMT'11 poster; see full-resolution image at <http://ngmdb.usgs.gov/Info/dmt/DMT11presentations.html>.

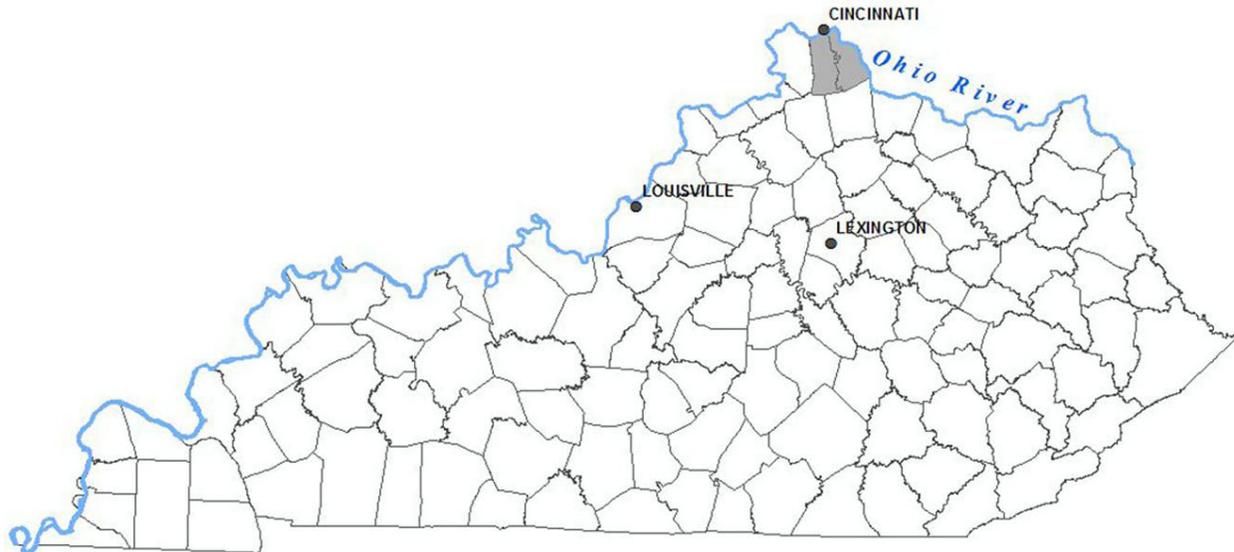


Figure 2. State of Kentucky showing (in gray) the location of Kenton and Campbell Counties (Kenton is to the west, Campbell to the east).

Data Sets

Standard LAS files from LiDAR were processed to create DEMs, slope maps, and hillshade DEMs. LAS files are binary files that contain the x, y, z data as well as the classifications of the multiple point returns (ground, trees, buildings, vehicles, power lines, and bridges). The ground classification points were used to create bare-earth, hillshade maps and were the primary data set used for visualization and landslide mapping. The horizontal resolution of the data was one meter. The LAS files were imported into Quick Terrain Modeler to create the hillshade, bare-earth DEMs. Hillshade DEMs of various extents were created, with a sun angle of 45° and an azimuth of 35° specified. The models were exported as hillshade DEMs (geo-referenced TIF files) that could be used in a geographic information system (GIS) with other spatial data sets. Other data sets used were topographic contours (2- and 4-foot (ft) intervals), 2-ft-resolution color aerial photography, and 1:24,000-scale geologic map data. The aerial photography was taken during a season without leaves on trees (referred to as “leaf-off”), allowing better views of the ground and structures.

Visualization and Analysis

Potential preexisting, previously undetected landslides were identified by visual examination of slope morphology at different scales. The bare-earth hillshade DEMs were used in ArcMap to map potential landslides (fig. 3). ArcMap allows for other data sets (contours, aerial photography, geology, and others) to be used in conjunction with the LiDAR. The hillshade DEMs were systematically panned at various scales to identify and digitize the areal extent of potential landslides. Draping the topographic contours over the hillshade was important for accentuating the slope geomorphology. A reference grid was used to help organize the panning and zooming across the DEMs. Examination was done at 1:10,000, 1:5,000, and 1:2,000 scales. All digitizing of potential landslide extents was done at a scale of 1:2,000. Potential landslides were primarily identified and mapped on the basis of geomorphic expression on the hillshade models. Steep scarps, hummocky terrain, concave and convex areas, and thick toeslopes were possible indicators of landslides. Changes in contour spacing helped accentuate thick toeslopes where the landslide deposits

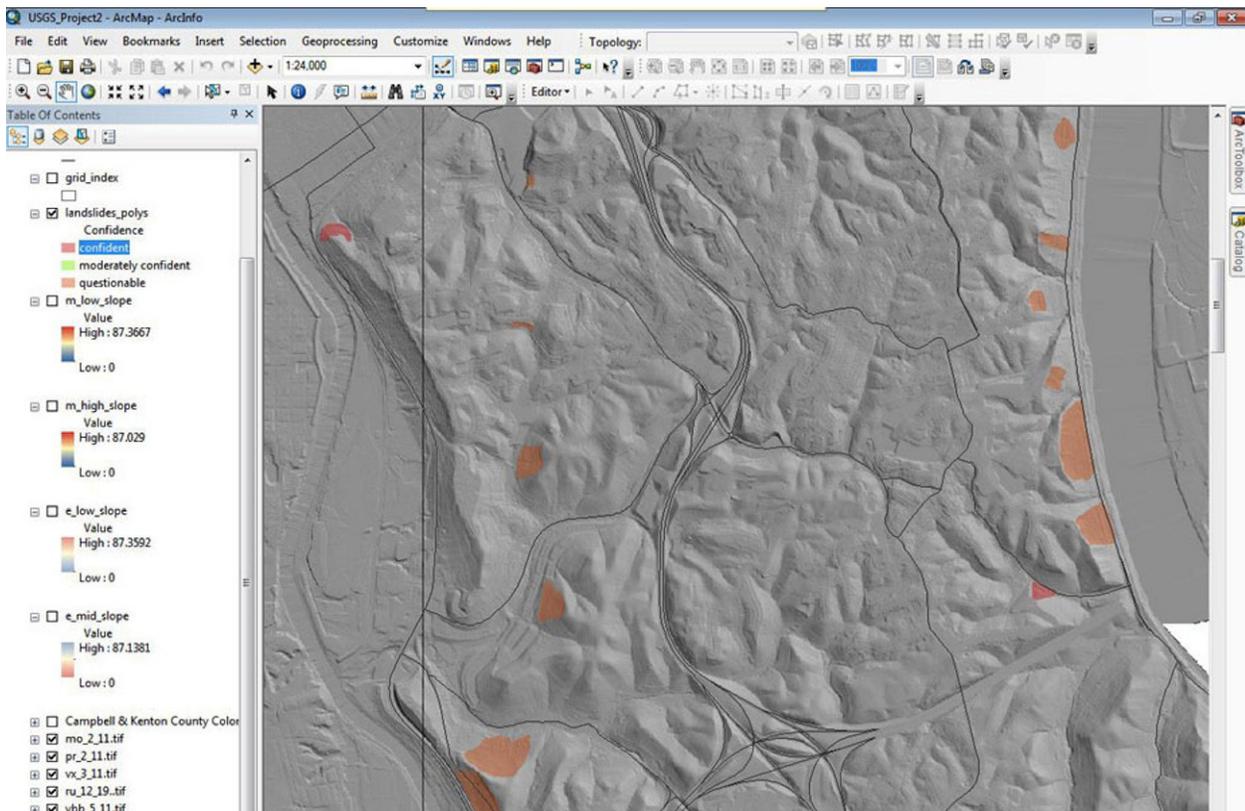


Figure 3. ArcMap project showing a bare-earth LiDAR hillshade DEM and mapped landslides.

had spread out, creating a gentler slope. The geology and leaf-off aerial photography also were used in the visualization and analysis processes. Evidence of landslides, such as repaired roads and leaning trees, occasionally was seen in the aerial imagery.

Potential landslide extents were digitized and assigned general confidence levels. Confidence levels assigned to digitized polygons were “confident,” “moderately confident,” and “questionable,” based on the visual clarity and geomorphic signature on the LiDAR hillshade model. Some of the questions dictating the confidence level included: How visible is the scarp? How visible is the toeslope? How much concavity or convexity is shown? Is the hummocky terrain actually a landslide or is it an otherwise modified surface that was forested? A standard rating system was not used to classify confidence; instead, it was a subjective decision made by the mapper.

Distinguishing between hummocky landslides and a general “roughness” in the LiDAR hillshade was a challenge. [“Roughness” refers to the hillshade quality and local landscape variability. The roughness may represent actual landscape ruggedness and discrete features, or a “false topography” because of sun angle, azimuth, resolution, and bare-earth derivation of actual landscape.] The data-processing algorithms that produce bare-earth hillshade models also can create false ground-surface roughness (McKenna and others, 2008). Roughness appears to be more prominent on forested slopes, particularly slopes with many cedar trees. Southwest-facing slopes also exhibited more roughness than slopes facing other directions and of similar land use. This would most likely change if hillshade DEMs were created with different azimuths. Mapping landslides in the more urban areas of Kenton and Campbell Counties also was a challenge. Densely populated neighborhoods with altered landscapes and abundant fill areas can be deceiving in a bare-earth surface model. Many of these areas appear to have landslides, but typically are artificially contoured terrain rather than a landslide. The color, leaf-off, 2-ft-resolution aerial photography helped clarify questionable geomorphology in urban areas.

Knowing where the geologic contacts between formations are located also helped in the analysis of slope geomorphology. Many places initially thought to be a landslide scarp or to have questionable geomorphology were actually the contact between the Fairview Formation and the underlying Kope Formation. The Fairview is interbedded limestone and shale with about 40 percent limestone near the base increasing to about 65 percent near the top. The Kope consists of approximately 80 percent shale with minor interbedded limestone. It is 200 to 250 feet thick, primarily cropping out along the lower parts of hills. The transition from a more resistant limestone to weaker shale shows up very well in the LiDAR hillshade. The breaks in slope in the Fairview are probably limestone beds that extend in a more continuous fashion along the slope than would a landslide scarp.

Reexamination of Surface Models

After initial identification of potential landslides in ArcMap, selected digitized features were reexamined in Quick Terrain Modeler for verification. This software allows for the rapid change of azimuths and sun angles (fig. 4). Different lighting and perspective on slope geomorphology and potential landslides help with assigning the confidence level. Scarps or concavity observed with one sun angle may appear completely different with other lighting orientations. In addition, Quick Terrain Modeler allows for 3D visualization, whereas ArcMap is best for 2D map view of data sets. Using rapid zooming and panning tools with 3D was very helpful in assigning confidence to the digitized landslide extents, confirming well-defined scarps, flanks, or thick toeslopes. Approximately 25 percent of the slides (about 50) identified using ArcMap were viewed in 3D with various lighting orientations. For about half of those, the confidence was changed from questionable to moderately confident, and the other half remained as questionable. Potential landslides that initially were attributed as questionable and not viewed in 3D were left as questionable.

Field Checking

Field checking was attempted for approximately 20 percent of the landslides whose extents were digitized. A strict project timeframe and inaccessibility controlled how much field verification was possible. Clusters of landslides were visited in an attempt to verify as many as possible. Separate attributes were assigned to the field-checked landslides: “confirmed”—landslide deposits and geomorphic features were observed in the field; “likely”—the actual deposit was not observed, but a landslide is likely based on proximity to other slides or other telling geomorphic features; “observed but could not determine”—the deposit was accessible but further field investigation was required; and “no access”—the landslide was on private property, on inaccessible terrain, or could not be seen.

Many of the confirmed landslides could be seen from the road, and road damage typically was associated with them (fig. 5). Recent scarps also were present in many slides, and deposition was active toward the toe of the slide. Determining the location of potential landslides was a subjective process. For example, a potential landslide might have been identified on a slope, and slumping in the road below it provided field verification, but it was not clear whether there was active sliding above the road or if there was geologic control on the geomorphology of the slope. Many of these slopes are creeping, but distinguishing between active creep and relict, non-active movement makes attribution difficult.

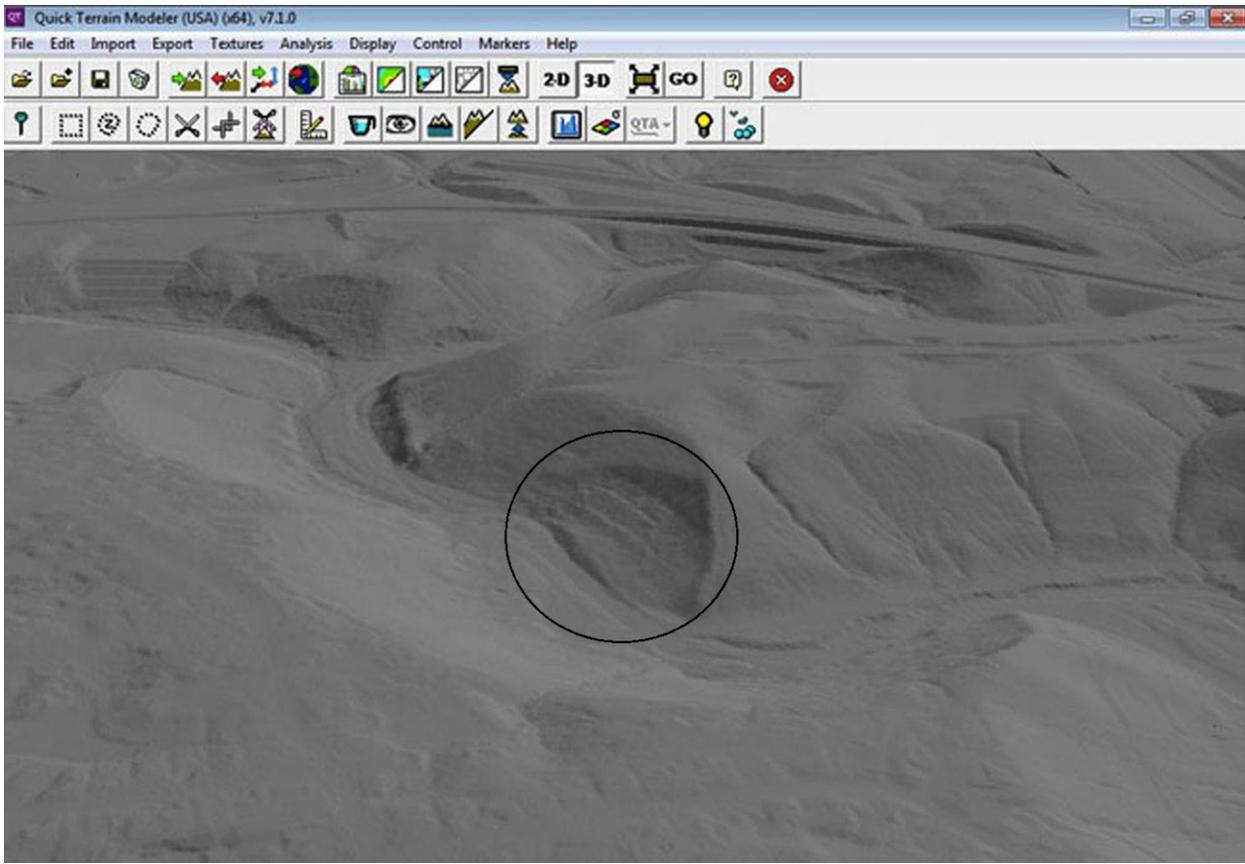


Figure 4. Rotated 3D view of LiDAR hillshade in Quick Terrain Modeler that accentuates the geomorphology when azimuth and sun angle are changed. Landslide is circled.

Figure 5. Photograph of landslide area along KY 8. Note leaning telephone pole.



Results

Two hundred thirty-four potential landslides were detected in Kenton and Campbell Counties, and their extents were digitized. Twenty landslides (approximately 9 percent) were initially attributed as confident (fig. 6). The other slides were attributed as questionable or moderately confident (fig. 7). The LiDAR hillshade geomorphology, geology, and proximity to urbanized areas dictated the initial classification. Reexamination in Quick Terrain Modeler changed the initial classification (that is, from questionable to confident, or vice versa) of some of the slides. Landslides were not deleted

from or added to the inventory after Quick Terrain Modeler was used. Forty-five landslides (approximately 20 percent) were field-checked. Of those, 20 were confirmed, 18 were likely or observed but could not be determined, and 7 were not accessible. Landslide type (translational or rotational) was not determined by LiDAR visualization. If landslide type could be determined in the field, then it was noted. Many of the landslides mapped are not associated with roadways and are in rural, wooded areas that are on private property. Using airborne LiDAR for detailed inventory mapping significantly improves awareness of landslide locations not previously known, especially in forested and suburban landscapes.

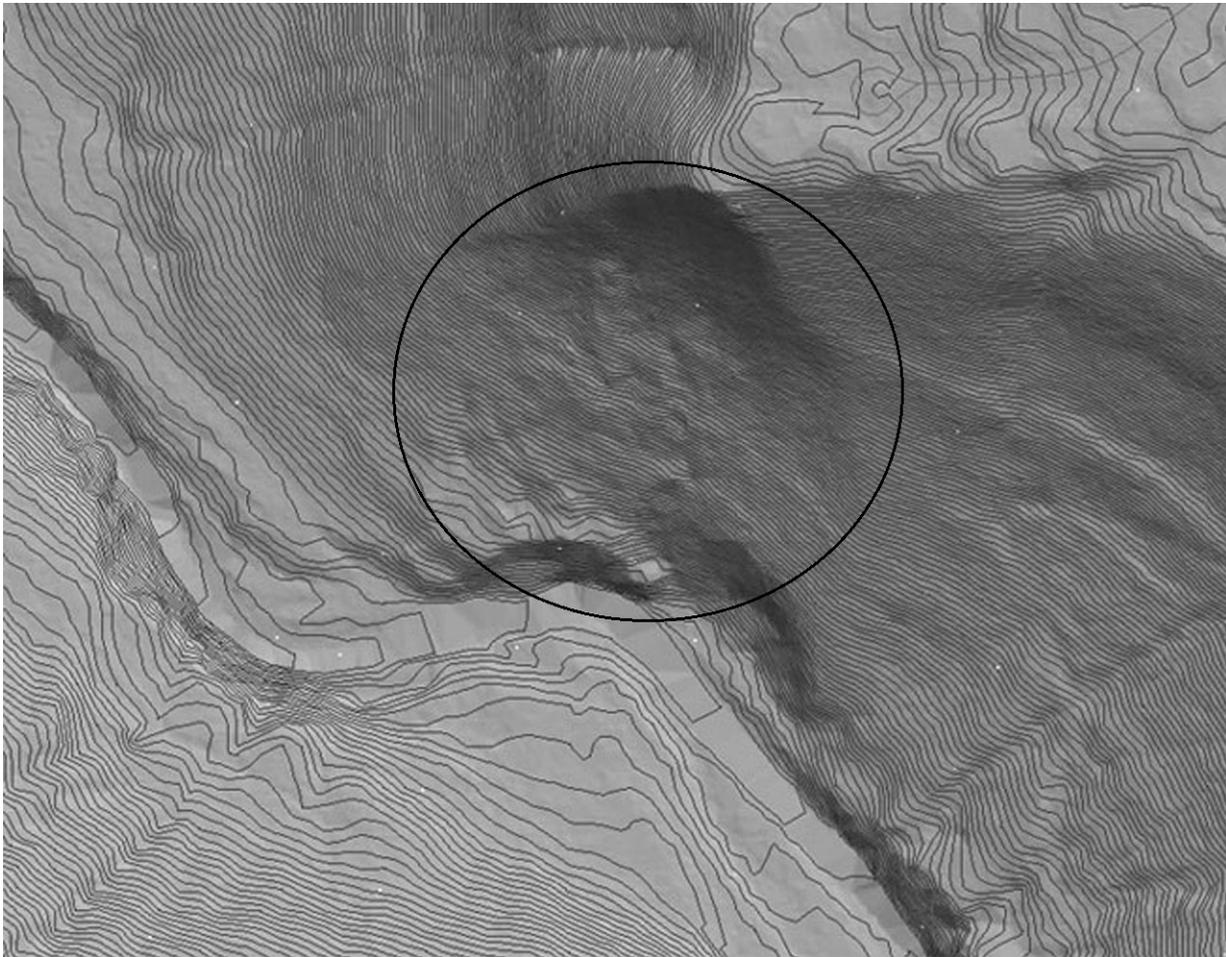


Figure 6. Mapped landslide on LiDAR hillshade draped with topographic contours (2 ft). Slide occurs at cutbank in a stream at the toe and is approximately 455 ft long down the axis of the slide. Note hummocky surface of slide area, slide flanks, and steep scarp area near the top of the slope.

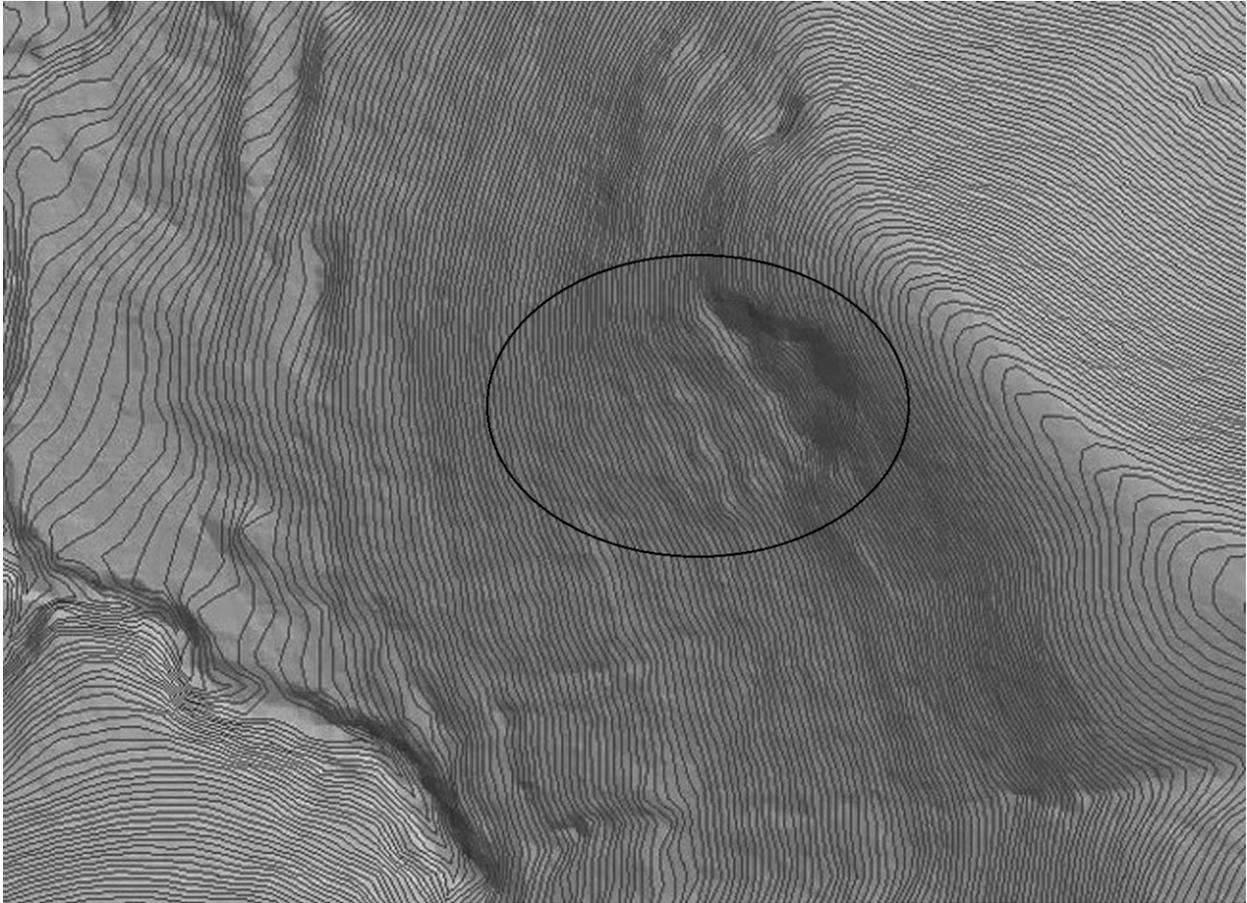


Figure 7. Mapped landslide on LiDAR hillshade draped with topographic contours (2 ft). Slide occurs mid-slope and is approximately 280 ft long down the axis of the slide. Note hummocky surface of slide area and steep scarp. This slide occurs in a wooded area that otherwise would not have been recognized.

Conclusion

This study successfully used LiDAR to map landslides in Kenton and Campbell Counties. The landslides were added to an existing inventory database, approximately doubling the number of documented landslides for the area. Although there were some limitations, the methodology provided here can be a precedent for future studies. Potential landslides were identified that would not have been identified with traditional, lower-resolution GIS data. This method documents landslides for which researchers have not had the resources to identify in the field, thereby saving time and funding. One of the strengths of using LiDAR is being able to map potential landslides in areas not accessible by roads. Much of the landslide data in the existing Kentucky Geological Survey (KGS) landslide inventory is from road-related slide activity, and these landslides are too small to detect using LiDAR or were repaired before the LiDAR was flown. Mapping landslide locations on slopes unrelated to roads or other human activity can provide a better understanding of landslide activity within a natural geologic and geomorphic context.

In addition to revealing inaccessible and small slides, this methodology can indicate future failures. Many of the landslides mapped are old, creeping slides that may not yet have become a problem. A heavy rain or other trigger could cause these existing landslides to move again, potentially quickly and unexpectedly. Hazard mitigation efforts continue across the State to help citizens facing landslide problems. Although mitigation projects provide solutions, obtaining funding is often difficult, and the process can take years to implement.

This study was limited by time and ability to field-check identified landslides. Urbanization in parts of Kenton and Campbell Counties also made it challenging to identify landslides using LiDAR. Extensive neighborhoods, large industrial areas, and Interstate highways can mask the natural slope geomorphology. The use of Quick Terrain Modeler helped with setting the initial confidence level for landslide identification. Using software specifically designed for processing large amounts of LiDAR data and having the capability to view the data in 3D is very effective. Although ArcMap was effective for 2D mapping, many traditional GIS programs cannot process large data sets with the speed needed for detailed slope visualization.

The amount of LiDAR data available for Kentucky will increase in the future. High-resolution data sets will become available for other landslide prone counties, and studies similar to this one can provide precedent for future landslide inventory mapping. An automated program that completes the image analysis part of landslide mapping would be very beneficial. Future mapping will greatly enhance the existing KGS landslide inventory, which is a foundation for effective hazard and risk analysis.

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