USGS Cooperative Landslide Hazard Mapping and Assessment Program - Final Technical Report

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Title: Developing a Comprehensive Landslide Inventory for Southeast Indiana Using Light Detection and Ranging (LiDAR) Data

Author(s) and affiliation(s) with address and zip code
Victoria Leffel
Indiana Geological and Water Survey
5001 N. State Road 37 Business
Bloomington, IN 47404

Nicholas Angelos
Indiana Geological and Water Survey
5001 N. State Road 37 Business
Bloomington, IN 47404

Author's telephone numbers and email address
812-855-1405, vleffel@iu.edu

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Abstract
Landslides represent a significant geological hazard in Indiana, yet detailed information on their distribution, characteristics, and impacts has been limited. To address this gap, the Indiana Geological and Water Survey (IGWS) conducted a systematic landslide inventory in southeastern Indiana using statewide Quality Level 2 (QL2) LiDAR data. Mapping was performed at 1:4,000 scale across five 1:100,000-scale quadrangles (Louisville, Madison, Greensburg, Cincinnati, and Falmouth), supplemented by targeted field investigations in the spring of 2025 for verification and documentation. Landslides were mapped according

to the methods described by Slaughter et al. (2017) and evaluated using multiple map products, including slope, orthoimagery, and hillshade topography.

Within the 11,000 km^2 project area, 6,810 landslide polygons were identified, substantially exceeding the 1,300 landslides originally anticipated. Each feature was assigned a confidence level following Burns and Madin (2009): 4,761 were labeled (low), 2,026 (moderate), and 23 (high). The predominance of low-confidence classifications reflects landslides characterized by hummocky topography lacking distinct scarps or flanks, suggesting many are older, shallow failures whose diagnostic features have degraded over time. Upcoming LiDAR acquisition in 2027 will facilitate difference-map analyses to further evaluate this hypothesis.

Field investigations confirmed the reliability of LiDAR-based mapping and yielded supplemental data, including photographs and field notes, which were archived in the IGWS digital collection portal. The inventory, publicly accessible through the *Indiana Journal of Earth Sciences* and IndianaMap, provides the first large-scale, high-resolution data set of landslides in southeastern Indiana. Findings indicate that landslides are far more numerous and spatially extensive than previously recognized, with important implications for hazard assessment, infrastructure planning, and risk mitigation.

Goals and Objectives

Project deliverables included the compilation of digital landslide photos and field notes, integration of landslide GIS data into the IGWS inventory, public access to the inventory through the IndianaMap website, and the production of state park landslide maps. Together, these products enhance accessibility to comprehensive landslide data for stakeholders (guidance criteria 1), supporting informed decision-making and risk management. They also improve understanding of landslide occurrences and characteristics, providing a foundation for more effective mitigation strategies and emergency response planning. Beyond technical outcomes, the project increased public awareness and engagement regarding landslide hazards, reinforcing the importance of safety and infrastructure resilience across southeastern Indiana.

Guidance Criteria Funded

This project fulfilled guidance criteria 1 by conducting landslide hazard mapping and assessment to enhance public and stakeholder access to critical data for informed decision-making. In addition, although not included in the original proposal, the project incorporated elements of guidance criteria 3 through education and outreach activities.

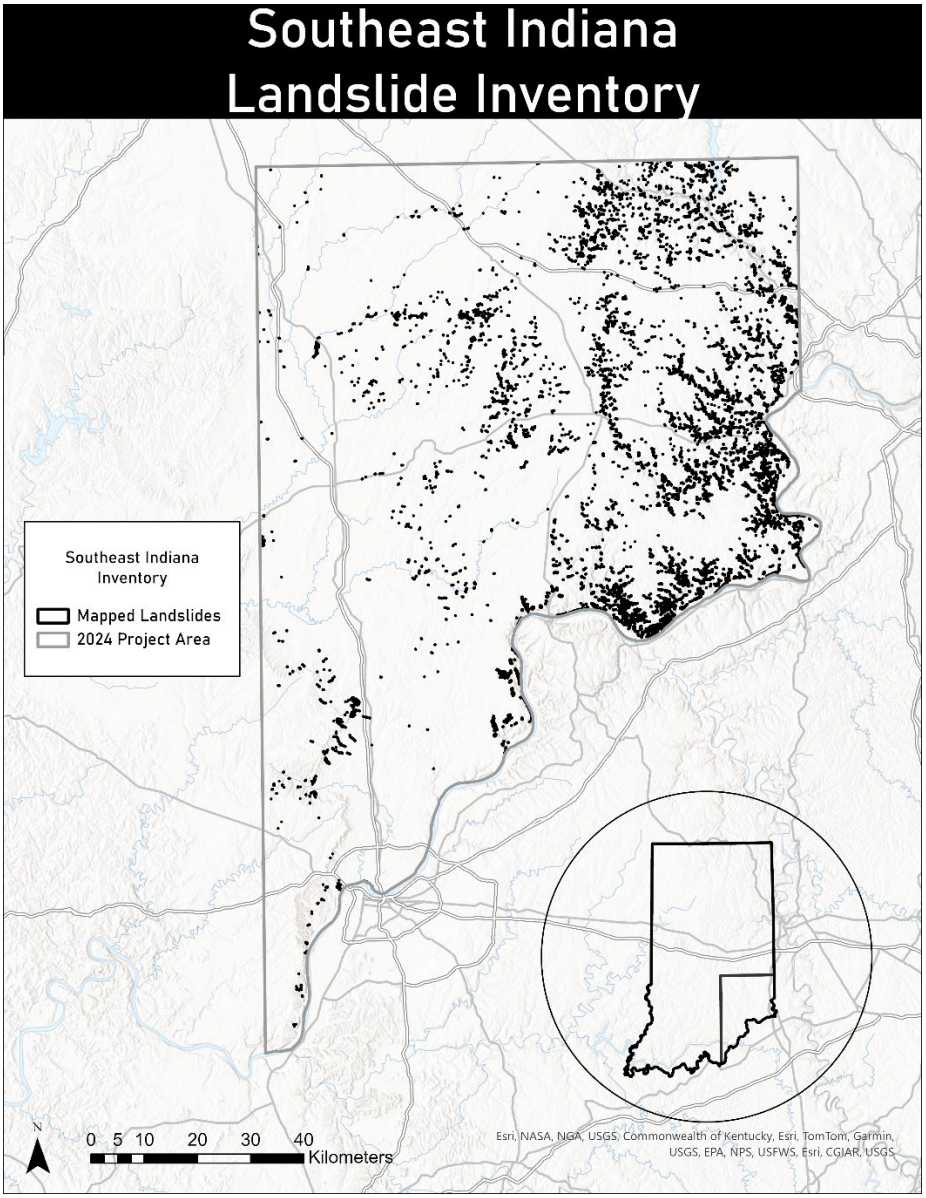
Accomplishments

Guidance criteria 1:

Mapped 6,810 landslides across an 11,000 km^2 area in southeastern Indiana (Figure 1), home to an estimated 620,000 people, and compiled detailed attributes including identifiers, slope characteristics, landslide type, area size, status, confidence levels, roadway information, data sources, earliest reported failures, corrective actions, photos,

and field notes. Metadata for the inventory was published in the online, open-access *Indiana Journal of Earth Sciences* and made publicly accessible through the IndianaMap website. (https://portal.igs.indiana.edu/portal/home/item.html?id=e8914605d3954ea18ef0da9282532297).

Figure 1. Map showing landslides in southeast Indiana.



Between February and May 2025, fieldwork was completed at 119 sites across three state parks and one state forest (Clifty Falls, Versailles, Brookville Lake, Clark State Forest) and along highway corridors. Field notes, photographs, and GPS data were integrated into GIS attribute tables and IGWS digital collections, with documentation from 121 total sites

(including pre-project records) published online in IGWS Digital Collections (https://data.igws.indiana.edu/pages/search.php?search=%21collection1586127).

Four landslide maps were produced, covering Brookville Lake and Whitewater Memorial State Parks, Clark State Forest, Clifty Falls State Park, and Versailles State Park. The park maps are published in the *Indiana Journal of Earth Sciences for free download. A PDF version of the maps is here:* *https://scholarworks.iu.edu/journals/index.php/IJES/article/view/42198/43966*

Guidance criteria 3:
Outreach efforts included presentations at the 2025 Indiana Professional Soil Classifiers Meeting (70 attendees), the 2025 Indiana Academy of Science (30 attendees), and an online session with the U.S. Forest Service (30 attendees). Media coverage further broadened awareness through articles in the *Indiana Daily Student* (January 2025) and *Indiana University Research* (January 2025).

Collaboration involved the Indiana Department of Natural Resources (DNR), Indiana Department of Transportation (INDOT), and Indiana Department of Homeland Security (IDHS). DNR staff, property managers, and geologists participated in field visits to gain hands-on experience in landslide recognition and mapping, while an IGWS GIS analyst was trained as an early-career professional in landslide assessment. Mapped landslide locations along state highways were shared with INDOT to support field reviews and prioritize repairs. After spring 2025 flooding, the IDHS applied IGWS mapping guidance to evaluate reported slope failures.

Unmet Results
None

Summary
Within the 11,000 km^2 project area, 6,810 landslides were mapped—more than five times the 1,300 anticipated. This discovery highlights both the widespread nature of slope failures in southeastern Indiana and the effectiveness of LiDAR for detecting geomorphic evidence of landslides. Confidence levels assigned using Burns and Madin criteria (2009) show that most landslides were classified as low confidence (4,761), reflecting older, shallow slides with degraded diagnostic features. Field investigations confirmed the accuracy of LiDAR-based mapping and contributed supplemental notes and photographs, archived in IGWS Digital Collections. Together, these findings demonstrate that landslides are far more numerous and spatially extensive than previously recognized. The project produced the first high-resolution, systematically mapped landslide inventory for the region, directly supporting USGS objectives. Data shared with INDOT and IDHS informed roadway safety reviews, while public release via IndianaMap increases accessibility for planners, engineers, and stakeholders. The methodology, integrating LiDAR, confidence classification, and field validation, is transferable to other regions in the state and will be

strengthened by upcoming 2027 LiDAR updates, enabling temporal monitoring and difference-map analyses.

Despite these advances, the project faced limitations. The method proved highly effective for detecting large landslides but less so for smaller failures along roadways, underscoring the need to integrate LiDAR with ground surveys. Additionally, LiDAR captures only static conditions; spring 2025 flooding triggered new slope failures not visible in earlier imagery, leaving some events unmapped. Structural limitations of the IGWS database also became evident, as the initial inventory was based on highway records and was not originally designed to accommodate the expanded LiDAR-based data set. Future efforts will restructure the database, extend mapping into south-central Indiana, and add detailed attributes to support a regional susceptibility map. Continued collaboration with state agencies will ensure that the inventory advances scientific understanding while also strengthening infrastructure management, hazard planning, and long-term risk reduction.

References

Burns, W. J., and Madin, I. P., 2009, Protocol for inventory mapping of landslide deposits from light detection and ranging (LIDAR) imagery: Oregon Department of Geology and Mineral Industries Special Paper 42, 30 p.

Slaughter, S. L., Burns, W. J., Mickleson, K. A., Jacobacci, K. E., Biel, A., and Contreras, T. A., 2017, Protocol for landslide inventory mapping from lidar data in Washington State: Washington Geological Survey Bulletin 82.

Bibliography

Leffel, V. A., and Angelos, N. P., 2025, Southeast Indiana landslides: Indiana Geological and Water Survey, Indiana Journal of Earth Sciences, v. 7, scale 1:100,000. doi: 10.14434/ijes.v7i1.42198

Indiana Geological and Water Survey, 2024, Indiana landslide inventory—landslide areas of Indiana [GIS feature service], downloaded from Indiana Geological and Water Survey Portal, <https://portal.igs.indiana.edu/portal/home/item.html?id=e8914605d3954ea18ef0da9282532297> date accessed, September 2, 2025.

Indiana Geological and Water Survey, 2025, 2024-USGS-SE-IN-SLIDES [photograph collection], <https://data.igws.indiana.edu/pages/search.php?search=%21collection1586127>, date accessed, September 2, 2025.