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Reconnaissance of Landslides and Debris Flows Associated with the July 2022 Flooding in Eastern Kentucky

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Kentucky Geological Survey

Cover Photo: KGS geologist Matt Crawford surveys a debris flow that occurred in Breathitt County during the July 2022 eastern Kentucky flood event. Photo view looking upslope.

Kentucky Geological Survey
William C. Haneberg, State Geologist and Director
University of Kentucky, Lexington

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Our Mission

The Kentucky Geological Survey is a state-supported research center and public resource within the University of Kentucky. Our mission is to support sustainable prosperity of the commonwealth, the vitality of its flagship university, and the welfare of its people We do this by conducting research and providing unbiased information about geologic resources, environmental issues, and natural hazards affecting Kentucky.

Technical Level

Statement of Benefit to Kentucky

Exceptionally heavy rain during late July 2022 caused catastrophic flooding that killed 43 people and triggered thousands of landslides in eastern Kentucky. Scientists from the Kentucky Geological Survey used a combination of field observations and satellite image analysis to document the locations and types of landslides caused by the storms. The results of their work, which are described in this report, will provide data for future landslide hazard studies, help geologists to better understand how landslides in Kentucky are related to rainfall and climate change, and increase public awareness of landslide dangers.

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Abstract

Between July 25 and July 30, 2022, a series of convective storms generated approximately 14–16 inches of rainfall across parts of eastern Kentucky, predominately in Clay, Leslie, Perry, Breathitt, Knott, and Letcher Counties. The peak rainfall occurred on the evening of July 27 and the morning of July 28, with the hardest-hit areas experiencing more than 10 inches in a 24-hour period. The historic rainfall led to catastrophic flooding along many rivers and streams, but also triggered widespread landslides and debris flows that damaged roads, homes, property, and other infrastructure. Once initial relief and recovery efforts were established, the Kentucky Geological Survey (KGS) geohazard section conducted a preliminary field reconnaissance that observed and documented landslides and debris flows triggered by the July storm event. We documented landslides from late August to early November 2022 using (1) visual field inspection methods and (2) a remote sensing technique called normalized differencing vegetation index (NDVI). Visual field inspection occurred primarily along roads through documentation of landslide type and location. The NDVI technique allowed identification of larger landslides and debris flows not easily accessible in a vehicle. We identified more than 1,000 new landslides and debris flows triggered by the July event. The majority of landslides the team identified were shallow translational slides, supplemented by some rotational slides (slumps), and debris flows. Documenting landslides in the field before they perish is important for future hazard assessment modeling. Landslide inventories associated with large storm events, and large impact areas, will improve our understanding of landslide occurrence and rainfall rates, and potentially our ability to forecast landslides. The data is intended for use by both scientists and non-scientists, such as emergency managers and public safety decision-makers.

Introduction

Between July 25 and July 30, 2022, a series of convective storms generated approximately 14–16 inches of rainfall across parts of eastern Kentucky bringing catastrophic flash flooding and triggering landslides and debris flows. Convectional storm systems have cloud-forming mechanisms that often generate large amounts of rain with rapidly changing intensities in localized areas (NOAA National Severe Storms Laboratory, 2022). The highest rainfall totals occurred along a narrow band stretching east from Clay County into parts of Leslie, Perry, Breathitt, Knott, and Letcher Counties (Fig. 1). The historic rainfall led to flooding along many rivers and streams, including the Kentucky River and associated North, Middle, and South forks. Over the course of five days, multiple rounds of thunderstorm cells moved across eastern Kentucky generating intense swaths of heavy rainfall. The peak rainfall rates, up to 4 inches per hour, fell on the evening of July 27 and the morning of July 28 across an already saturated region. Rural communities located along forks of the Kentucky River and many tributary catchments and narrow hollows experienced devastating flood damage. Entire homes were destroyed, swept off their foundation, or ruined due to flood water damage inside the homes . Roads, bridges, and culverts were destroyed or washed away.

Flood Impacts

The July flood event damaged miles of roads, bridges, culverts, and water treatment and communications infrastructure (Figs. 2-3). Approximately 100 bridges require full replacement and thousands of others (including private crossings) require inspection or were deemed impassable (Kentucky Transportation Cabinet, 2022). As of early September, 225, 253 tons of debris in more than 5,000 truckload have been removed from state and county roads (Commonwealth of Kentucky, "Governor Beshear Provides Team Kentucky Update", 2022). A total of 1,334 rescues by boat and helicopter were completed between July 28 and August 2 by the Kentucky National Guard, the Tennessee National Guard, the West Virginia National Guard, the Kentucky State Police, and the Kentucky Department of Fish and Wildlife Resources (Commonwealth of Kentucky "Governor Beshear Provides Team Kentucky Update Focused on Flood Response", 2022). There are 43 confirmed fatalities across five counties including Breathitt, Knott, Clay, Letcher, and Perry.

Communities along Troublesome Creek which stretches east-southeast from Lost Creek in Breathitt County all the way to the town of Hindman in Knott County, were hit particularly hard, sustaining severe damage to homes and businesses (Fig. 4). Further southeast, the North Fork Kentucky River and Rockhouse Creek flooded the towns of Whitesburg and Fleming-Neon with 12-15 feet of floodwater. Many other small communities across the area were affected by the floods including Jackson, Isom, Oneida, Buckhorn, Hazard, Krypton, Martin, Prestonsburg, Garrett, and Paintsville.

Purpose

The purpose of this report is to present observations of landslides and debris flows triggered by the July storm event. We conducted a preliminary field reconnaissance effort that documented landslides and debris flows and related information such as landslide type and slope location. Starting approximately one month after the flooding, we compiled a landslide inventory containing locations and landslide type. We also conducted identification of landslides using a remote sensing technique called normalized differenced vegetation index (NDVI) to support identification of slides not observed along roads.

Most of our observations were made along roads, including landslides that initiated above roads, where soil and rock was deposited on the pavement, and pavement breaks and

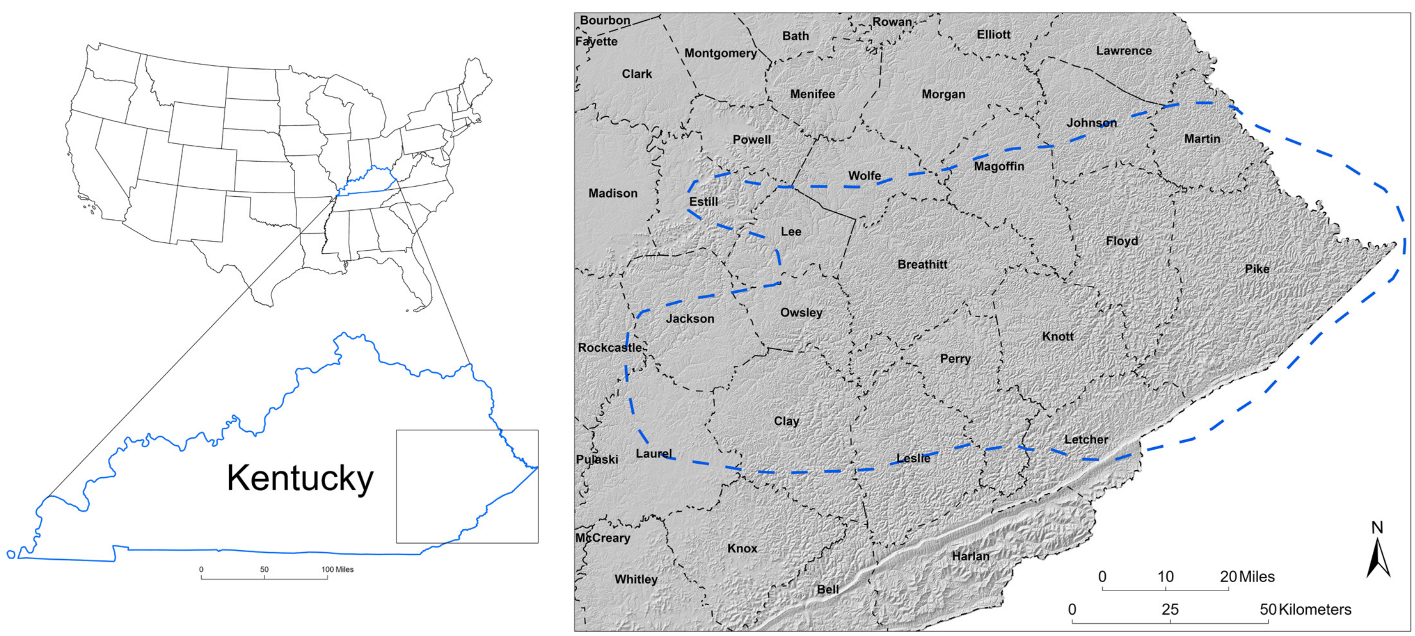

Figure 1. Map of the state of Kentucky and zoomed-in image of eastern Kentucky counties showing the areas most heavily impacted by the July 25-30 flooding (represented by a dashed line).

Figure 2. "Severe flash flooding caused extensive damage in downtown Whitesburg, KY." (NOAA National Weather Service, 2022).

Figure 3. "Flood waters over roads and surrounding houses in Hindman, KY." (NOAA National Weather Service, 2022).

landslides that initiated below the road. A rapid response involves a balance between time, data accuracy, and data quality. The important part of this field and inventory effort is the timely findings and documentation as landslides and debris flows are considered perishable field data after significant natural disasters. As time passes, hillslopes continue to weather or erode, making clear observations of landslide features associated with specific storms increasingly difficult. Documenting landslides before they become challenging to identify is important for future rainfall threshold and landslide occurrence studies. In general, documenting and mapping landslides as part of inventory databases is a critical foundation for hazard mitigation, hazard modeling, and awareness. This report is not intended to be a final, conclusive study of the landslides and debris flows associated with the July flooding, instead, it should be regarded as preliminary. Our primary aim is to release initial field observations and provide meteorological, geologic, and geomorphic context for these landslides and debris flows. To support our preliminary results, additional data collection and analysis is needed, particularly systematic field-checking of areas outside of the heavy rainfall bands in order to reduce bias of occurrence.

Geology and Landscape

The landscape in the impacted area of eastern Kentucky is highly dissected, characterized by narrow ridges, steep slopes, and sinuous-to-rectangular pattern alluvial valleys. Deeply incised stream drainages and variable hillslope morphologies range from long and narrow to bowl-shaped tributary valleys. Much of the landscape has been modified by surface coal mining, logging, and cut-and-fill practices for home and road construction. Mean slope angle across the areas of heaviest rainfall is approximately 22 degrees. Bedrock comprises relatively flat-lying sequences of Carboniferous (Pennsylvanian) sandstones, siltstones, shales, coals, and underclays (Greb and others, 2009). Shale beds, coals, and underclays weather easily and have complex porosities and permeabilities, which partially influences high landslide occurrence (Crawford 2014; Chapella and others, 2019). Slopes are mantled with colluvial soil of varying thickness, and mass wasting is a dominant process, moving soil and rock downslope by creep, sheetwash, landslides, and debris flows (McDowell, 1986). The colluvial soil is generally fine to coarse loam, typically poorly sorted, with grain sizes that range from clay to medium-coarse boulders up to perhaps a meter in diameter (Blair and McPherson, 1999).

Landslide Types, Occurrence, and Impact

A landslide is a general term for the downslope movement of rock, soil, or both under the influence of gravity. Colluvium is transported downslope as landslides ranges from imperceptible (creep) to rapid (catastrophic). Landslides that occur in colluvium are commonly thin (<3 m) translational

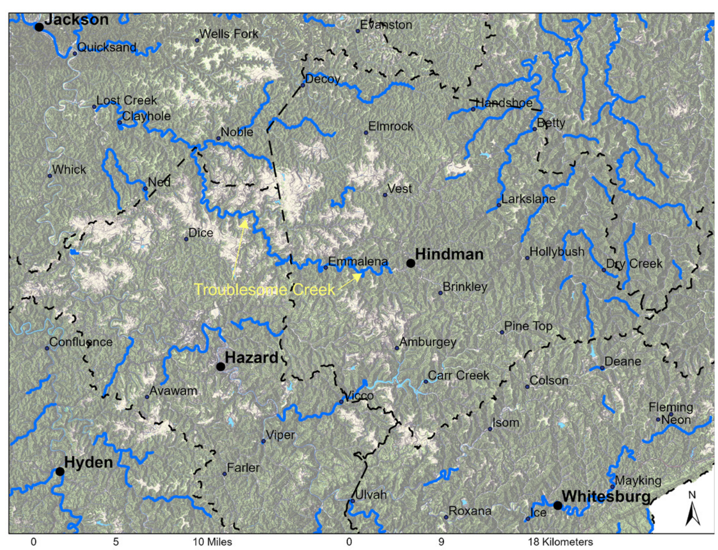

Figure 4. Map showing the eastern Kentucky communities in areas of the heaviest rainfall, many that incurred severe damage.

slides or thicker rotational slumps. While these types of slides typically cause only minor-to-moderate damage, they are each capable of developing into catastrophic debris flows or debris slides, especially on steep slopes (Turner, 1996; Crawford, 2014; Crawford and others, 2021). The classification of the type of movement, for example a fall, topple, slide, spread, and flow, distinguishes the behavior of how the landslide mass is displaced, which is important for determining the level of hazard (Fig. 5).

Slope shape, rock, and soil type, and how fast the rock and soil move influence the style of movement and resulting landslide extent or runout. Landslides occur when the strength of rocks or soil is exceeded by forces applied to those hillslope materials. An example of a driving force includes intense or prolonged rainfall that increases soil pore-water pressure.

are available for viewing and download through the [KGS Geologic Map Information Service](), which activates layers that display the locations of known landslides and areas susceptible to landslides in a geologic and geomorphic context (Fig. 6). The purpose of the inventory and associated map is to provide an overall view of landslide hazards across the state (Crawford, 2022). The landslide inventory database is also downloadable through [UKnowledge](), a digital collection of scholarship by University of Kentucky (UK) faculty, staff, students, departments, and research centers. KGS researchers have also used the inventory, and related geomorphic attributes, as the foundation for landslide susceptibility mapping. Five landslide susceptibility maps of Magoffin, Johnson, Martin, Floyd, and Pike counties in the Big Sandy Area Development District are available through the KGS online geologic map service.

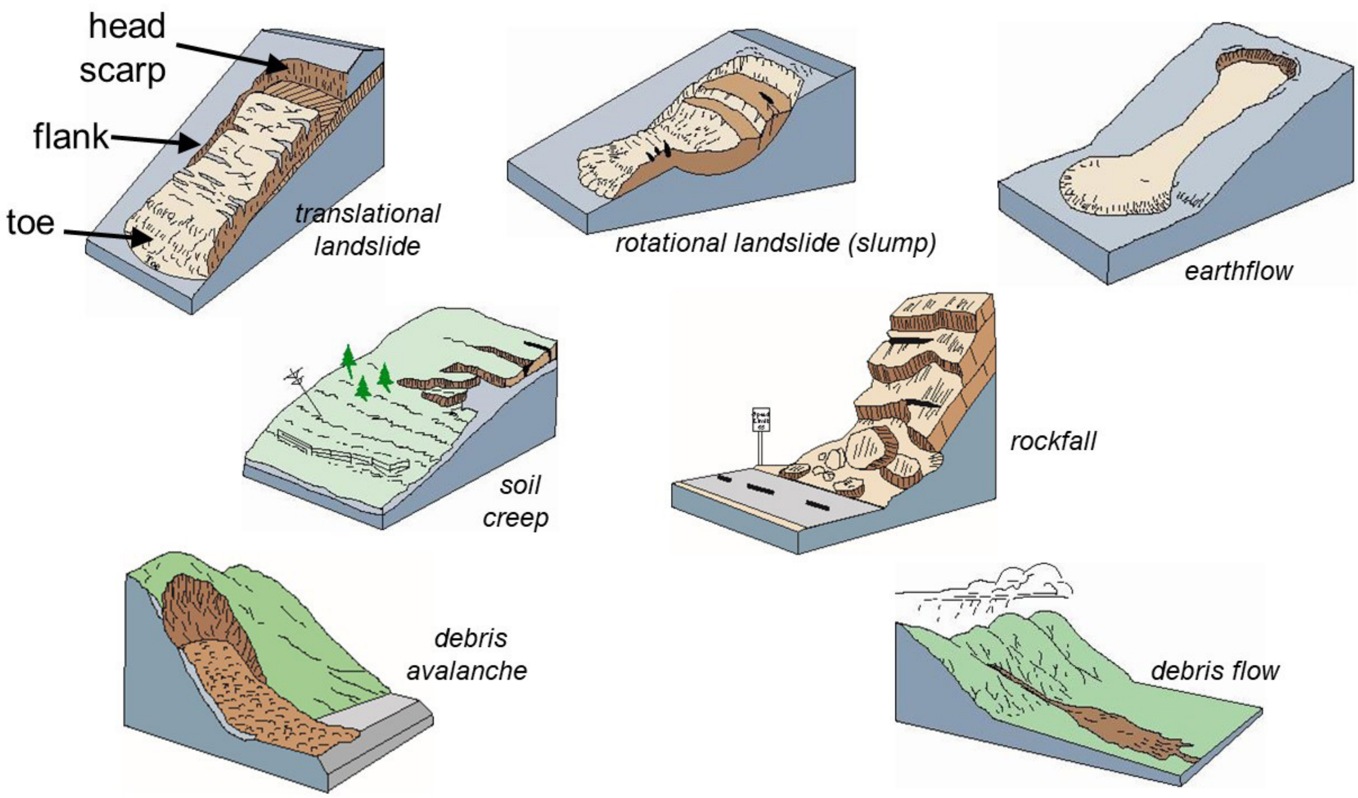

Figure 5. Types of landslides, which indicates the nature of rock and soil that is moving, as well as how fast the rock and soil move (modified from Highland and Bobrowsky, 2008). Some landslide types have distinct parts such as head scarps, flanks, and toes, which are labeled on the translational landslide.

Landslides occur across Kentucky, with direct costs of landslides conservatively estimated to be between $10 million and $20 million annually (Crawford, 2014; Crawford and Bryson, 2017). These costs result from damage to roads, buildings, private residences, and other infrastructure. Indirect costs such as road closures, utility interruption and decreased property value are also significant, but challenging to quantify.

The Kentucky Geological Survey maintains a landslide inventory database, where locations and associated data are compiled from KGS research, published maps, state and local government agencies, and the public. The data

Most landslides in Kentucky are rainfall-triggered, meaning that an increase in pore-water pressure (a force) occurs as rain infiltrates the soil and underlying rock. This force overcomes the strength of the soil and rock material, causing landslides. This relationship is demonstrated by the strong correlation between the number of landslides in Kentucky and the statewide average rainfall over the past 10 years (Fig. 7).

Importantly, the National Oceanic and Atmospheric Administration (NOAA) has determined that Kentucky has experienced an increase in annual precipitation from 3%–12% in different parts of the state in the last 30 years (NOAA

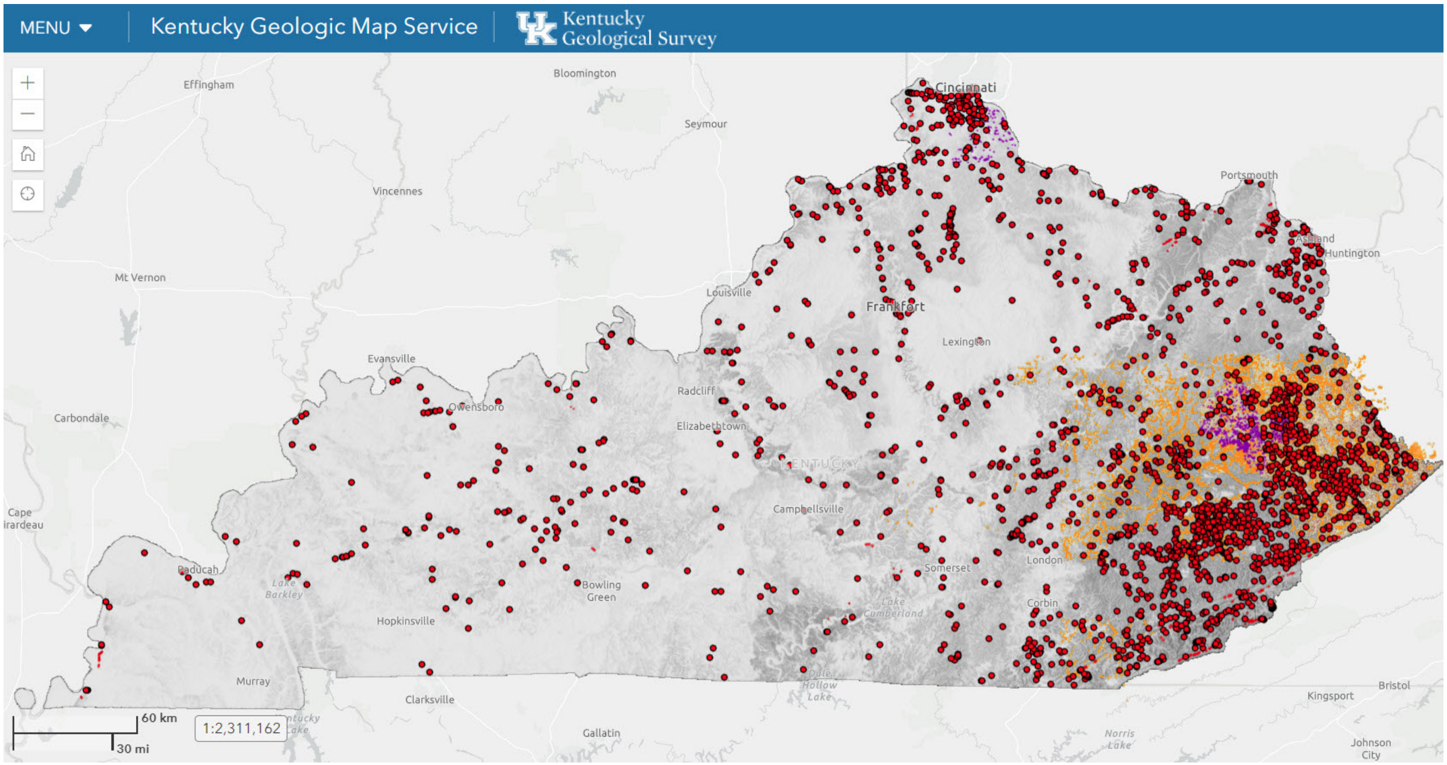

Figure 6. The KGS Landslide Inventory Map of Kentucky. The different colors and shapes (points and polygons) on the map represent different landslide types and states of activity, all compiled from different sources.

National Centers for Environmental Information, 2021). As an increase in landslides have occurred with increased precipitation, we anticipate future increases in precipitation will lead to more landslides in Kentucky.

Precipitation and the July 2022 Flood

The estimated rainfall totals of 14-16 inches for July 26 – 29, 2022 were over 600% of normal, an unprecedented amount in a short amount of time. (National Weather Service, Advanced Hydrologic Precipitation Service, 2022). Several rainfall 24-hour rainfall records were broken at the National Weather Service office in Jackson, Ky., a station at Buckhorn Lake, and a station at Carr Creek Lake. The peak rainfall occurred on the evening of July 27 and the morning of July 28, with the hardest-hit areas experiencing more than 10 inches in a 24-hour period.

The Kentucky MESONET, a statewide weather monitoring network, generated a series of statewide precipitation maps showing 24-hour and one-week totals during the storm period (Figs. 8-9). Three of the top 20 monthly rainfalls recorded in Kentucky occurred in Breathitt County in July 2022. These were recordings at three separate gages measuring 17.6, 17.2, and 16.0 inches for the month (Interim Director of the Kentucky Climate Center and Kentucky Mesonet Manager, Megan Schargorodski, personal communication, 2022).

A site in Buckhorn Lake in Perry County measured 8.0 inches of rain in a 24-hour period. The four-day total from July 26 to July 30 at Buckhorn was 12.3 inches, which is a record (Fig 10). A site near Carr Creek Lake in Knott County reported 6.71 inches in the 24-hour period ending 7 AM on July 29, after receiving 6.5 inches in the previous 24-hour period ending on July 28. The 4-day total from July 25 to 29 was 14.0 inches.

The Kentucky River near Jackson, Ky. experienced a rise of about 25 feet in 24 hours, giving way to a river crest of 43.47 feet, breaking an old record 43.1 feet. Preliminary field evidence of observed debris in trees along roads suggests floodwater heights of 40 to 50 feet above normal stream levels, particularly in the heaviest rainfall areas. The North Fork Kentucky River at Whitesburg, Ky. rose about 18 feet within 10 hours (Fig. 11), breaking a flood stage record by about six feet and recording about 11 feet above flood stage (Weather Underground, 2022).

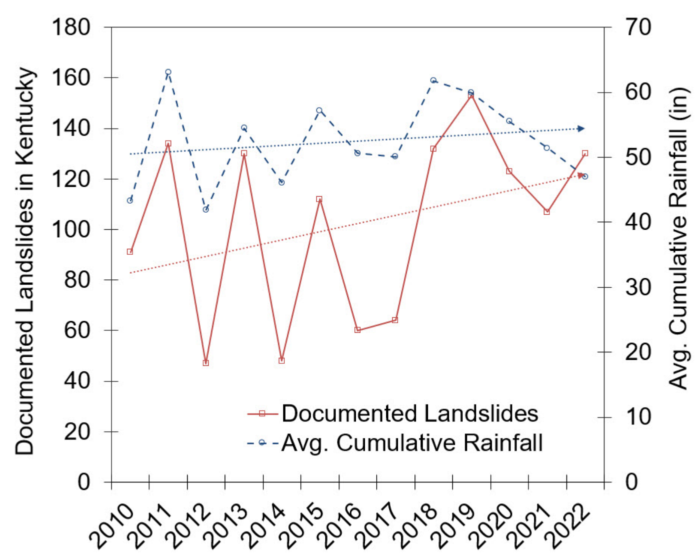

Figure 7. Annual documented landslides and annual statewide average rainfall in Kentucky. Landslides triggered by the July event are not included in this plot.

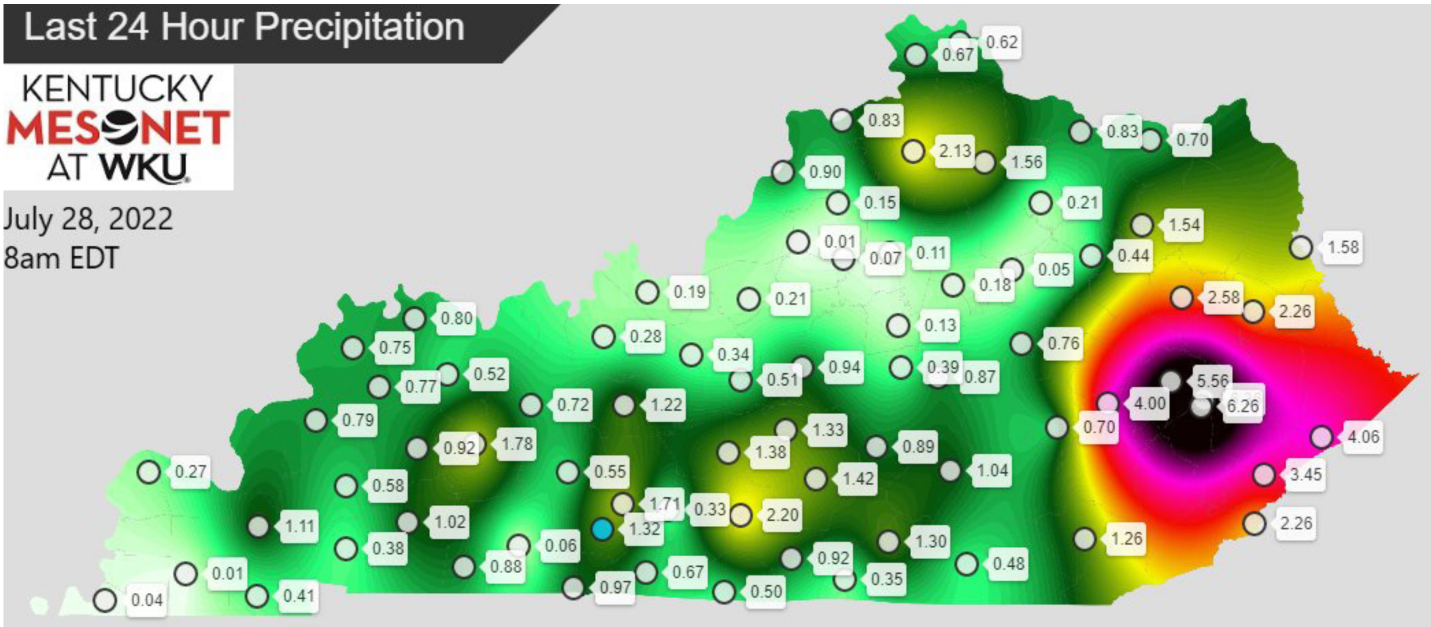

Figure 8. Kentucky MESONET (2022) map showing 24-hour precipitation ending July 28, 2022 at 8am.

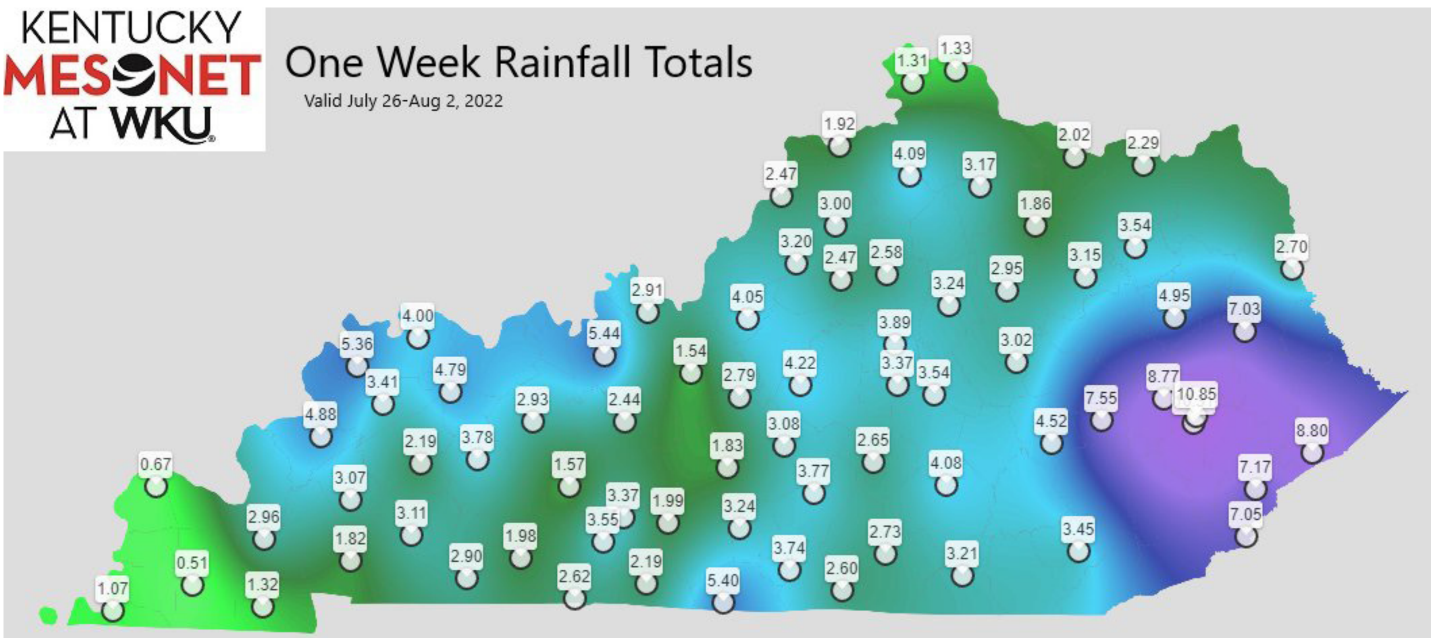

Figure 9. Kentucky MESONET (2022) map showing one week precipitation valid from July 26 to August 2, 2022.

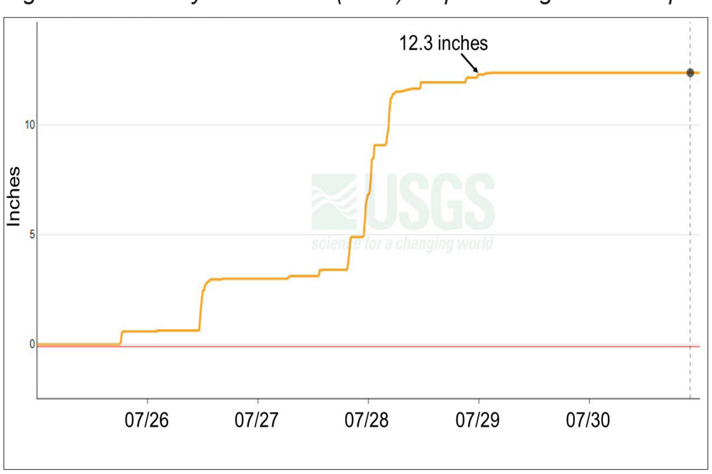

Figure 10. Total precipitation at Buckhorn Lake from July 26 through July 30. Plot modified from U.S. Geological Survey stream gage monitoring location 03280800 at Buckhorn Lake, Perry County.

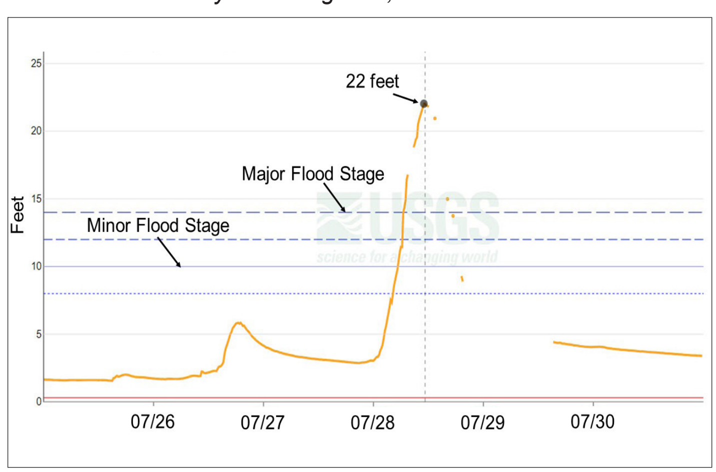

Figure 11. Water elevation gain from July 26 to July 30 at the North Fork of the Kentucky River near Whitesburg. Plot modified from U.S. Geological Survey monitoring location 03277300.

The National Weather Service Advanced Hydrologic Prediction Service can generate observed precipitation maps integrated from radar and on-the-ground rain gages within a defined time frames. Figures 12 and 13 show 1-day observed precipitation across the hardest hit areas. These maps, along with other radar loops show the amount of precipitation over the course of two days, but also note how the heaviest convective rainfall cells shifted from one area to another, making this a very widespread event. A National Weather Service four-day radar (integrated with gage observation) shows precipitation totals generated over 12 inches across many parts of the storm area (Fig. 14).

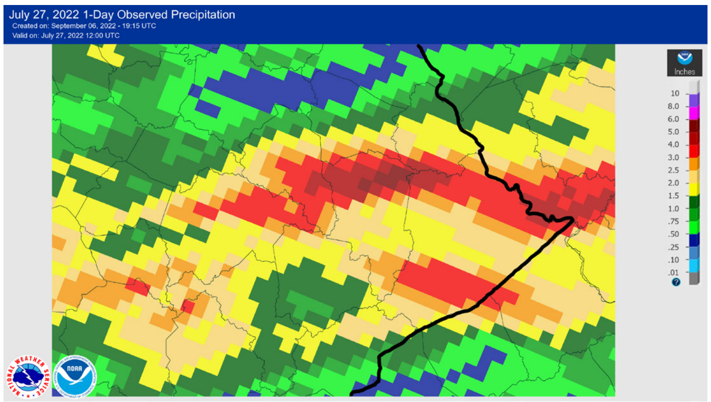

Figure 12. One day observed precipitation on July 27, 2022. County outlines are thin gray lines. The state line is the bold, black line. Generated from the NOAA National Weather Service Advanced Hydrologic Prediction Service (2022).

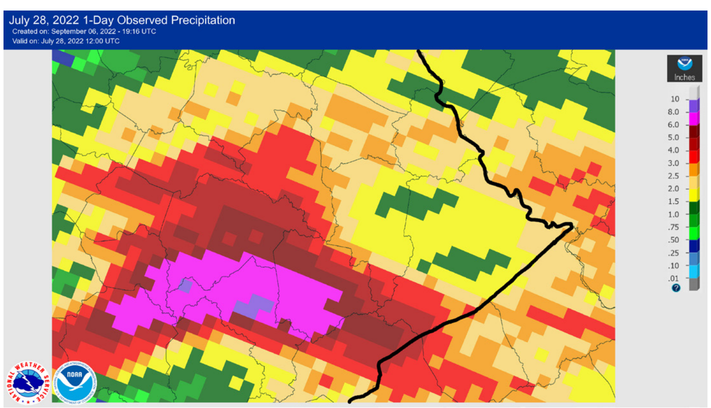

Figure 13. One day observed precipitation on d July 28, 2022. County outlines are thin gray lines. The state line is the bold, black line. Generated from the NOAA National Weather Service Advanced Hydrologic Prediction Service (2022).

Field Reconnaissance and Landslide Inventory

The KGS geologists documented landslides by (1) visual field inspection and (2) using a remote sensing vegetation differencing technique called relative difference in normalized difference vegetation index (rdNDVI).

Field Inspection

The primary landslide documentation approach was visual field inspection from late September to early November 2022. Several teams of KGS researchers drove the impacted area, recorded landslide type, and took photos. We attempted to document all sizes and types of landslides and debris flows, ranging from approximately 10 to 700

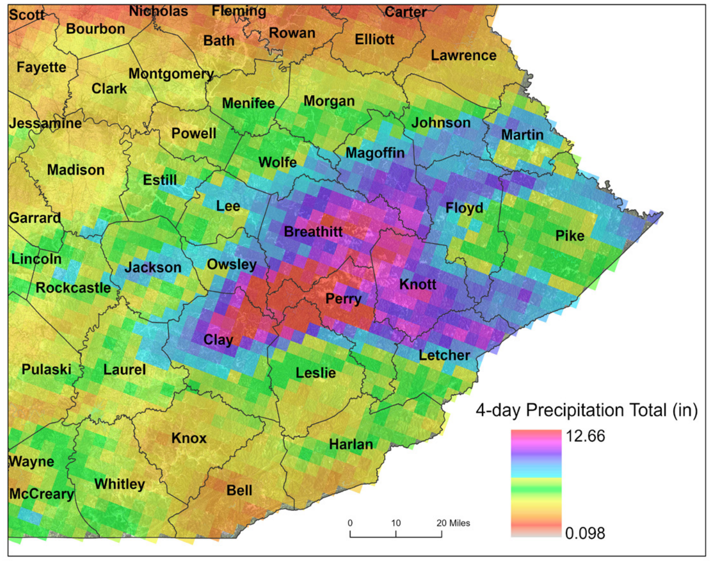

Figure 14. Four-day observed precipitation total from July 26 to July 29. Note the highest amount of precipitation in the purple, pink, and red areas. Precipitation data from the NOAA National Weather Service Advanced Hydrologic Precipitation Center (2022).

feet in length. Figure 15 shows the locations of more than 1,000 new landslides and debris flows identified during our field reconnaissance and were triggered by the July event. More landslides and debris flows are likely to have occurred away from modified or engineered slopes because our field observations were only in areas that have road access. We also covered a few specific stretches of road that went outside the heaviest rain band, attempting to document landslides, in order to reduce bias of occurrence (Figs 16-17). Filtering or weighing of landslide size thresholds and landslides that are insignificant, because they are too small and not threatening, will be done in the future.

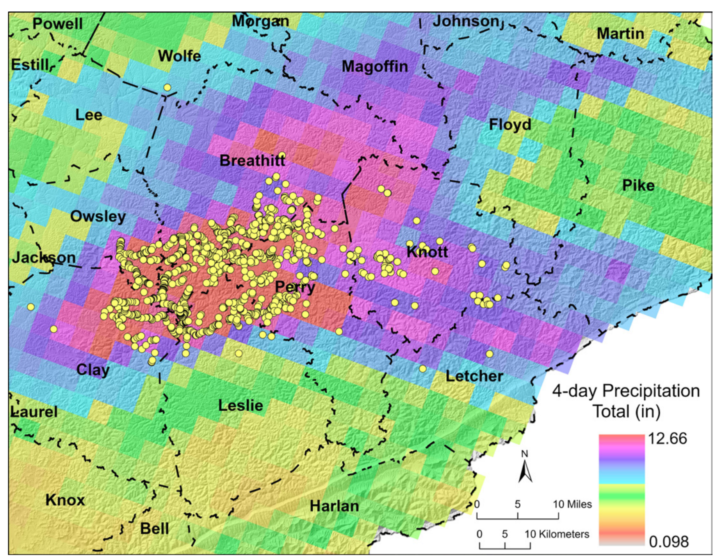

Figure 15. Newly documented landslides plotted on 4-day precipitation totals.

The primary landslide types we identified include shallow translational slides, rotational slides (slumps), and debris flows, however, the majority of our observations were shallow translational landslides. Translational landslides occur when soil and rock move downslope along a relatively planar surface. These landslides commonly occur along the

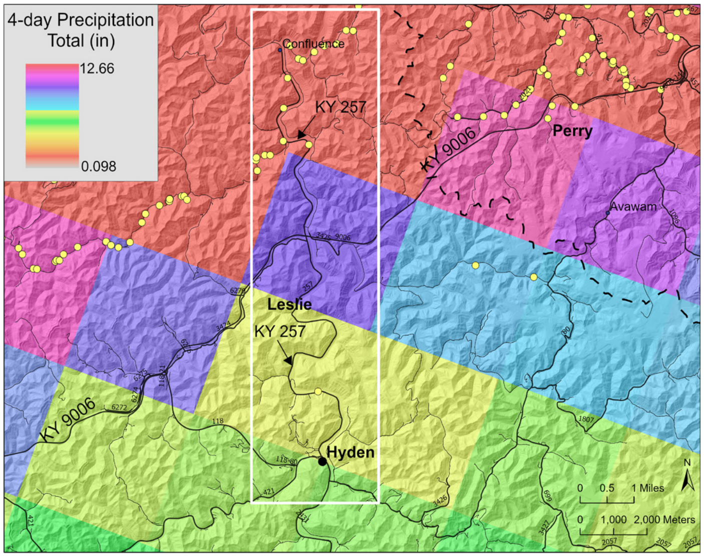

Figure 16. The white box encompasses a part of KY 257 driven to document landslides. An increase in landslide occurrence was evident within the heavy rain band (red pixels) and fewer landslides were observed outside heavy rainfall (yellow and green pixels). Total precipitation pixel resolution is 2.5 miles.

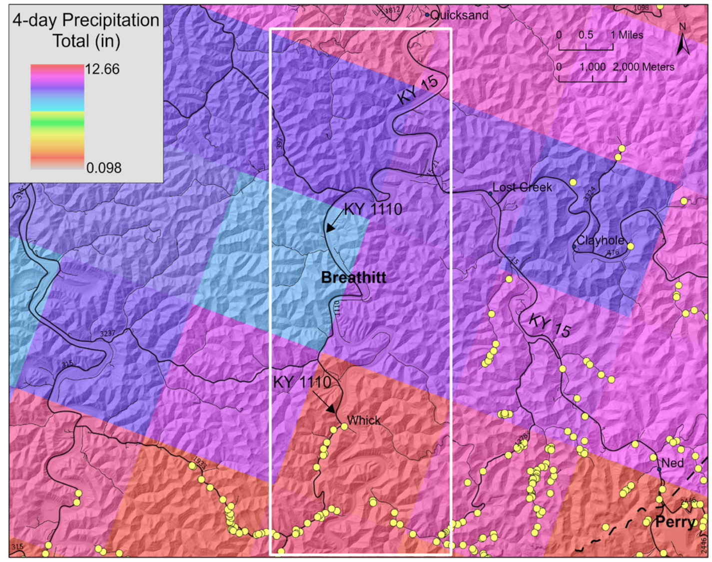

Figure 17. The white box encompasses a part of KY 1110 driven to document landslides. An increase in landslide occurrence was evident within the heavy rain band (red pixels) and fewer landslides were observed outside heavy rainfall (blue and purple pixels). Total precipitation pixel resolution is 2.5 miles.

soil and bedrock interface, where the surface of rupture is less than 10 feet below the original ground surface. The translational landslide length can vary from small (less than 30 feet) to very long (several hundred feet) (Hunger and others, 2014). The velocity of translational landslides can range from slow (less than 3 feet per year) to rapid (several meters per second) (Cruden and Varnes,1996; Hungr and others, 2014). Figures 18 through 21 show four translational landslides observed during the field reconnaissance. Specific measurements of landslide dimensions were not made during field reconnaissance.

Rotational slides, also called slumps, are distinguished by a curved surface of rupture (Fig. 5). The initial headscarp displacement is commonly vertically downward, but much of the displaced soil, rock, or trees further downslope can be tilted backward (upslope toward headscarp) creating a hummocky surface and thick deposit at the toe of the slide. Rotational slide velocity ranges from slow (less than 1 foot every 5 years) to moderately fast (5 feet per month) (Cruden and Varnes,1996; Hungr and others, 2014). Figures 22 - 23 show two slumps observed during field reconnaissance.

Flows are a type of landslide that commonly include debris flows, earth flows, and creep (Fig. 5). Debris flows are a widespread, rapid, and often dangerous occurrence in mountainous terrain. They are distinct from other landslides by the fact that they often occur in established channels, drainages, or ravines that have collected soil and rock over time. Debris flows are rapid movements with a velocity of up to 5 m/s and extents ranging from a few hundred meters to several kilometers (Hunger and others, 2014). Often, existing translational slides or slumps can be subsequently reactivated, morphing into more mobile flow-type movements. Many debris flow channels were left entirely scoured out, free of soil and rock debris (Figs. 24-25). We observed many debris fans associated with initiation in upslope catchments or channels (Figs. 26-29).

Human-induced slope modification, including cut (excavating) and fill (loading) processes are common for road and building construction in steep terrains with narrow valleys in eastern Kentucky. Cuts include removal of slope material, commonly mid-slope or along the base of slopes. Fill includes soil and rock material that adds weight to different parts of a slope. These cuts and fills create changes in the balance of forces on a slope, which then can establish more favorable conditions for triggering landslides by heavy rainfall. We observed numerous structures including roads and homes damaged by landslides where cut-and-fill techniques were apparent. Figures 30 - 35 shows some examples of damage to roads and property related to cut-and-fill techniques.

Remote Sensing and NDVI

Our team also utilized a second approach to documenting landslides associated with the July flooding by using a remote sensing application called HazMapper. HazMapper is a global, open-source software mapping program that runs through Google Earth Engine (Scheip and Wegman, 2021). The mapping program allows users to derive rdNDVI (relative difference in normalized difference vegetation index) maps. These maps identify areas on the landscape where vegetation was removed following a storm event or other natural disaster. The differencing relies on NASA satellites Sentinel and Landsat datasets, constrained by the storm event date and pre-and-post event window for the satellite imagery. To overcome common obscuring atmospheric conditions (like clouds), HazMapper includes an algorithm that combines the greenest pixel images, reducing differencing artifacts, based on the event windows. The resulting rdNDVI shows a color-coded percent gain or loss in vegetation. HazMapper is an effective tool for post-event landslide mapping, particularly for identifying larger features that may be inaccessible by road or foot.

Figure 18. Photo of a translational landslide behind home, triggered by the July storms.

Figure 19. Photo of translational landslide along Hardshell Caney Road in Breathitt County, triggered by the July storms.

Figure 20. Photo of translational landslide along KY 2446 in Perry County, triggered by the July storms.

Figure 21. Photo of translational landslide along KY 28 in Perry County, triggered by the July storms

Figure 22. Slump observed off KY 28 in Perry County. Note tilted trees in the upper part of the slide.

Figure 23. Slump observed off 451 in Perry County. Note the thick soil and buldging toe along the road.

Figure 24. Narrow debris flow channel along KY 2446 in Perry County.

Figure 25. Narrow debris flow channel and fan deposit toward the mouth of channel along Middle Fork River Road in Perry County.

Figure 26. Debris fan along Middle Fork River Road in Breathitt County. These deposits initiate upslope and are not overbank flood deposits.

Figure 27. Debris fan along KY 3392 in Knott County. These deposits initiate upslope and are not overbank flood deposits.

Figure 28. Debris fan along KY 28 in Breathitt County. These deposits initiate upslope and are not overbank flood deposits. Note the lobe shape to the fan. .

Figure 29. Debris fan that inundated a home along KY 28 in Perry County. These deposits initiate upslope and are not overbank flood deposits.

Figure 30. Trucks hauling away landslide debris along KY 267 in Perry County. The road was closed for several weeks.

Figure 31. Landslide-damaged road along KY 2446 in Perry County.

Figure 32. Road stabilization work after a landslide damaged KY 28 in Perry County.

Figure 33. Translational landslide behind home near KY 28 in Breathitt County.

Figure 34. Translational landslide behind home near KY 451 in Perry County.

Figure 35. Landslide-damaged property in front of home off KY 484 in Perry County.

Here we show two examples of debris flows identified using HazMapper. Figure 36 shows the program interface, rdNDVI classification, and the event parameters window. The red arrow points to a thin, elongated area of pixels classified as a lost in vegetation. To establish that this feature may be a debris flow, we checked the pre-and post-event Sentinel images (Figs. 37-38). In the post event image, the elongated area of vegetation loss appears as tan-colored pixels and is free of cloud or other atmospheric artifacts. We interpreted the vegetation loss to be a debris flow and then field checked the interpretation, verifying a debris flow track approximately 700 feet long (Figs. 39-40). A second example shows a long, thin, curving area of vegetation loss along a narrow channel approximately 1,300 feet long. Similarly, we noticed pixels in the post-event Sentinel data that appeared to be free of vegetation, and we interpreted the feature to be a debris flow. Field checking the area confirmed this interpretation as we observed a large debris fan deposit at the mouth of the catchment (Figs. 41-42).

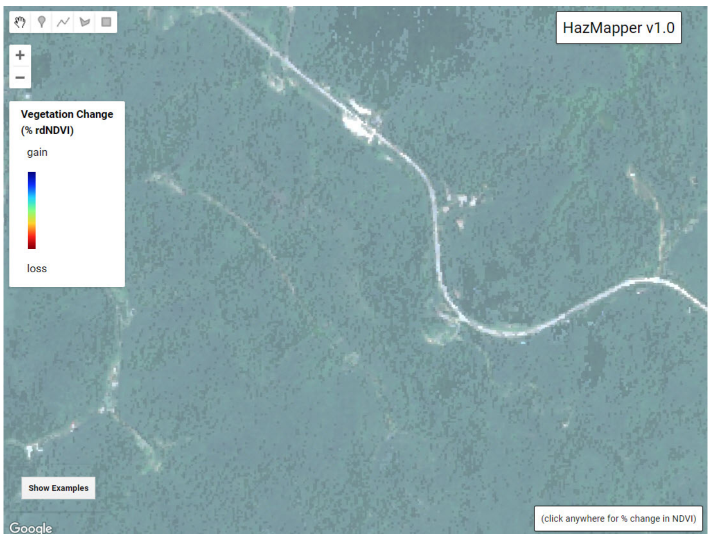

Figure 37. A pre-July storm event Sentinel image from HazMapper near Little Leatherwood Road in Breathitt County.

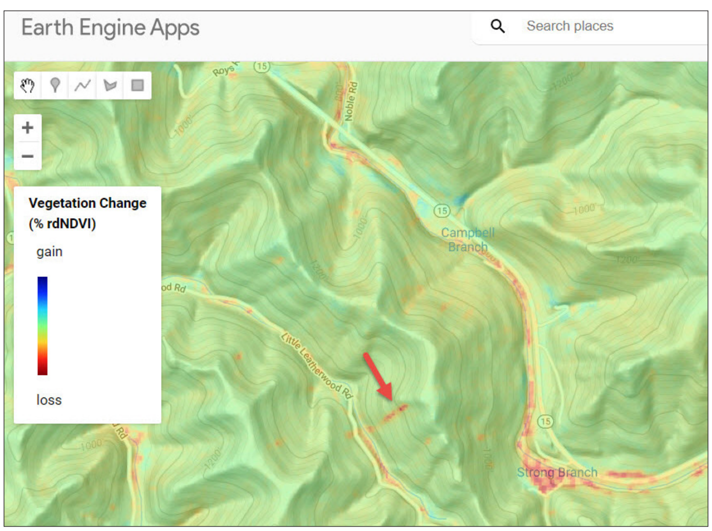

Figure 39. The HazMapper rdNDVI index showing the zoomed-in area from Figures 36, 37, and 38. Warm colors are areas of vegetation loss and greens to blues are vegetation gain. The red arrow points to the interpreted debris flow. This debris flow is approximately 700 feet long near Little Leatherwood Road in Breathitt County.

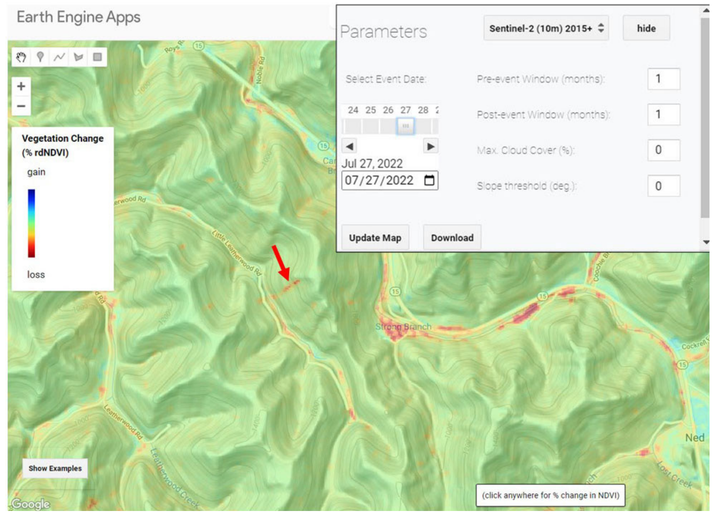

Figure 36. HazMapper interface showing normalized difference vegetation index (rdNDVI) and storm parameter settings. Warm colors are areas of vegetation loss and greens to blues are vegetation gain. The red arrow points to a long, thin area of vegetation loss that we interpreted to be a debris flow.

Figure 38. A post-July storm event Sentinel image from HazMapper near Little Leatherwood Road in Breathitt County. The red arrow points to a tan-colored, thin, elongated pixel area that was interpreted to be a debris flow triggered by the July storms.

Figure 40. Field-checked debris flow from Figure 39 identified in HazMapper. The debris flow is approximately 700 feet long near Little Leatherwood Road in Breathitt County.

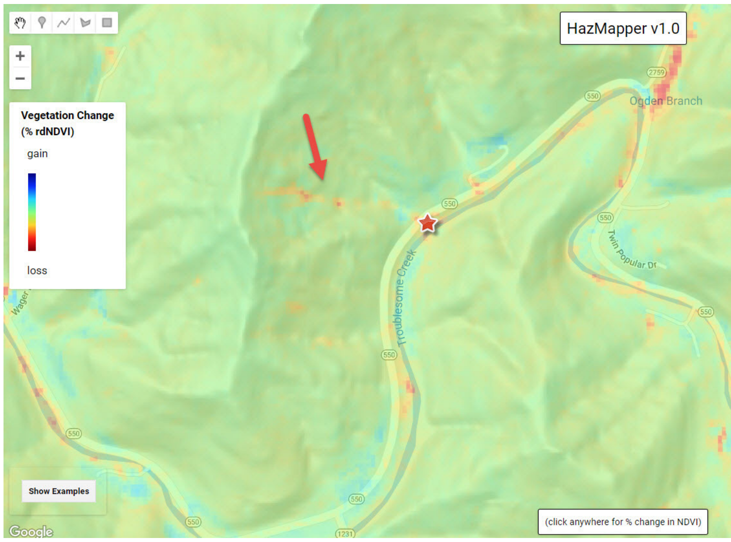

Figure 41. HazMapper interface showing normalized difference vegetation index (rdNDVI). Warm colors are areas of vegetation loss and greens to blues are vegetation gain. The red arrow points to a long, thin area of vegetation loss that we interpreted to be a debris flow along KY 550 in Knott County.

Figure 42. Field-checked debris flow from Figure 41 identified in HazMapper. The debris fan at the mouth of the catchment (marked by the star on the rdNDVI map) threatened the home and was deposited along KY 550 in Knott County.

Summary

Between July 25 and July 30, 2022, a series of convective storms generated approximately 14–16 inches of rainfall across parts of eastern Kentucky, including Clay, Leslie, Perry, Breathitt, Knott, and Letcher Counties. The historic rainfall led to catastrophic flooding along many rivers and streams, including the Kentucky River and associated North, Middle, and South forks. Rural communities located along forks of the Kentucky River and many tributary catchments and narrow hollows experienced devastating flood damage. Entire homes were destroyed, swept off their foundation, or flooded ruining the contents of the home. Miles of roads, bridges, and culverts were destroyed or washed away.

The historic rainfall triggered widespread landslides and debris flows and caused damages to roads, homes, and infrastructure in the area. In response to the flooding, KGS geologists conducted field reconnaissance, along with utilizing remote sensing techniques, to build a preliminary landslide inventory. Both field reconnaissance and remote sensing techniques are critical components to inventorying time-sensitive landslide data associated with storm-events. Several teams drove the impacted area and documented landslide locations, recorded landslide type, and took photos from late September to early November 2022. More than 1,000 landslides and debris flows were identified and documented during our field reconnaissance. More landslides and debris flows are likely to have occurred because our field observations were only in areas that have road access. HazMapper is a powerful remote sensing tool to assist with identification and assessment of landslide activity, particularly documenting larger slides or debris flows not able to be seen along roads.

Human-induced slope modification, including cut (excavating) and fill (loading) processes are common for road and building construction in steep terrains with narrow valleys in eastern Kentucky. These cuts and fills create changes in the balance of forces on a slope, which then can establish more favorable conditions for triggering landslides by heavy rainfall. We observed numerous structures including roads and homes damaged by landslides where cut and fill techniques were apparent.

Landslide inventories are also particularly important for identifying areas of future sliding. This inventory of landslides and debris flows provides an invaluable dataset for landslide hazard mapping and research. The data is intended for use by both scientists and non-scientists, such as emergency managers and public safety decision-makers, as well as be a foundation for future landslide hazard assessment or forecasting studies.

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