Landslide Susceptibility

Landslide in Brooke County
Photo by WV DOT

West Virginia Landslide Risk Assessment

Region 11 – Brooke and Hancock counties

FEBRUARY 10, 2022

In support of FEMA HMGP Project

Executive Summary

The West Virginia Emergency Management Division (WVEMD), Department of Homeland Security (DHS), and Federal Emergency Management Agency (FEMA) have facilitated landslide susceptibility studies and community-based risk assessments in support of local and state hazard mitigation plans. Landslide susceptibility was modeled using a random forest machine learning method. The model used LiDAR-identified landslide locations, topography, soil type, and proximity to roads and streams among many input variables to produce landslide susceptibility grids. Overall, 261 landslide points were identified using LiDAR in Region 11. Risk assessment was performed at the sub-county scale and includes results on roads and structures/parcels. This report summarizes risk assessment results by West Virginia planning and development council regions. Results for Region 11 can be integrated into hazard mitigation plans to enhance resilience and protect communities from landslide hazards.

This landslide risk report provides non-regulatory landslide risk information to help local officials, planners, emergency managers, and others better understand their landslide risk, take steps to mitigate those risks, and communicate those risks to citizens and local businesses.

Road risk analysis – In Region 11, **Brooke County** has almost 23 miles of road that is susceptible to high/medium probability of landslides. **Hancock County** has about 21 miles of road prone to high/medium risk for slope failure. Counties were ranked for slope failure risk based on the number of miles that are at risk. Of all 55 counties, Brooke County ranks 49th and Hancock ranks 51st. In both counties, most of the at-risk roads are in unincorporated areas.

Structure/Parcel analysis - **Brooke County** has a total of 311 primary structures with a total appraisal value of $7,005,582 that are in high/medium susceptibility areas. **Hancock County** has 381 primary structures with a total appraisal value of $11,926,699 in high/medium susceptibility areas. Brooke County ranks 30th among all counties in the state for at-risk structure count and 39th for total asset value in high/medium risk areas. Hancock County ranks 23rd for at-risk structure count and 28th for total asset value in high/medium risk areas.

This report is for informational purposes related to general emergency services planning. It has not been prepared for, and may not be suitable for legal, design, engineering, or site-preparation purposes. This report cannot substitute for site-specific investigations by qualified practitioners. Landslide risk is complex and continually changing. Although other existing studies or reports may provide more precise and comprehensive information, detailed original site investigations are normally an essential best practice for public safety, sustainability, and financial viability. These other data sources may give results that differ from those in this report.

Introduction

West Virginia has been divided into 11 regional and planning development councils to more effectively utilize funding, plan development, and aid cooperation. Landslide risk assessment has been performed in Region 11 for roads and structures/parcels. Roads provide critical service to communities. FEMA recently developed the community lifelines to enhance their effectiveness in disaster operations and better position themselves to respond to catastrophic incidents. Community lifelines cover seven sectors: Safety and Security; Food, Water, Shelter; Health and Medical; Energy; Communications; Transportation; and Hazardous Material. Roads are classified under Transportation in FEMA community lifelines.
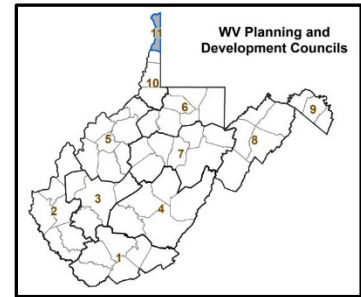

Figure 1. Planning and development regions in West Virginia

Landslide risk assessment has been performed to assess high and medium risk road segments and structures/parcels. **This study is suitable for planning-level analysis. The risk analysis for roads should be used in conjunction with site-specific risk analysis performed by WV Department of Transportation.** FEMA's goal is to ensure that communities address natural hazards. A comprehensive plan should acknowledge all hazards that pose a risk and identify steps to avoid these hazards altogether or incrementally reduce a community's exposure to them.

Community Engagement and Verification:
Review Landslide points identified using LiDAR data in the WV Landslide Tool. Add any missing major landslide points in the web application. A photo of the landslide incident can also be uploaded to the Landslide Tool. Review the susceptibility grid in WV Landslide or WV Flood Tool. Report any major discrepancies in high/medium landslide susceptible zones.

About Landslide Risk

Landslides are naturally occurring phenomena that can happen almost everywhere in West Virginia, especially on steep slopes. In its most basic form, a landslide is the movement of soil or rock down a slope. Landslides become hazardous to people and property when they happen in an area where development has occurred, causing losses. Many landslides have relatively little impact on people or property, such as minor road damage, tree throws, or tilting of fences and walls. However, severe landslide damage can topple buildings, destroy roads, disrupt utilities, and cause critical injuries or death.

Figure 2. Landslides present a risk to critical infrastructure and public safety (Photo by WVDOT)

Calculating Landslide Risk

It is not enough to simply identify where landslides may occur. Knowing approximately where a landslide may occur is not the same as understanding the **risk** posed by landslides. The most common method for determining landslide risk, also referred to as vulnerability (the exposure of a given population to harmful effects from a hazard), is to identify the susceptibility of landslide occurrence and then determine the subsequent consequences. In other words:

Landslide Risk = Susceptibility x Consequences

Where,

Susceptibility = the likelihood of occurrence
Consequences = the estimated impacts associated with the occurrence

An area's **landslide susceptibility** is the likelihood that a landslide will occur. The likelihood of a landslide occurring can change based on physical, environmental, or contributing human factors. Factors affecting the likelihood of landslide occurrence in an area include seasonality, weather, climate, slope, human disturbance, and the existence of mitigation structures. The ability to

*Figure 3. The **consequences** of a landslide are often higher in populated areas due to resulting property damage and injury to citizens (Photo by WVDOT)*

assess the likelihood of landslide occurrence and the level of accuracy for that assessment are enhanced by landslide modeling methodology advancements and more widespread reporting or mapping of landslide occurrence.

The **consequences of a landslide** are the estimated impacts related to the landslide occurrence. Consequences relate to human activities within an area and how a landslide impacts natural and manmade infrastructures.
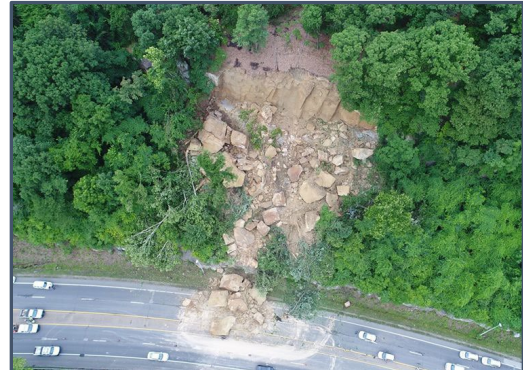
Sources of Data for Landslide Risk Assessments

To assess potential community losses or the consequences portion of the "risk equation", the following data is typically collected for analysis and inclusion in a landslide risk project:

- Locations of past landslide occurrence

- Areas susceptible to landslide occurrence

- Information about local assets or resources at risk from landslide occurrence

- Information about where the risk is most severe

The following sources of incidence information were compiled for the statewide Landslide Risk Project and can be viewed on the West Virginia Landslide Tool. A detailed table showing landslide points and polygons collected in the state can be reviewed here. However, **only high-resolution LiDAR-identified landslide incidence points were used for susceptibility modeling**.

- **WVGES Study** - A study by West Virginia Geological and Economic Survey in the 1970s led to a report by Lessing et al. (1976) published as WVGES Environmental Geology Bulletin no. 15. The study mapped 46,330 landslide polygons in 39 7.5-minute quadrangles throughout West Virginia. The study was largely based on air photos taken in the 1960s and 1970s. The West Virginia GIS Technical Center (WVGISTC) digitized many of these polygons in 2018. Failures were categorized into three broad categories based on original map symbology: older landslides, recent landslides, and rockfalls. Mapping efforts yielded 1,503 landslide polygons from Region 11.

Figure 4. Historical landslides were compiled from several studies to create a comprehensive landslide dataset (Image adapted from the West Virginia Landslide Tool)

- **USGS Study** - The United States Geological Survey completed a multiple-author study between 1975 and 1985 that mapped various failures over 382 7.5-minute quadrangles. The WVGISTC digitized 41,307 "active or recently active" slope failure polygons in 2018. Mapping efforts yielded 710 polygons from Region 11.

- **Landers and Smosna (1973)** evaluated the damage caused by flooding and slope failure during a 1973 storm event in Kanawha City. From this study, ten landslide points were mapped in the Charleston area.

- **Jacobson et al. (1993)** mapped 3,571 slope failures near the Wills Mountain anticline to evaluate the effects of the November 1985 flood in the upper Potomac and Cheat basins.

- **Kory Konsoer (2008) and Beau Downing (2008**), as part of their M.S. theses, performed a landslide study in the Horseshoe Run watershed in Tucker County, WV. This research mapped 149 landslide polygons within the watershed and included a statistical analysis to quantitatively assess risk. In 2014, **Yates and Kite** created a landslide inventory in the Bluestone National Scenic River and vicinity. Following this analysis, an inventory of 212 polygons was created for the New River Gorge National River area by the same authors (Yates and Kite, 2016).

- **West Virginia Department of Transportation (WVDOT) database of landslide locations** – The road landslide Inventory (2016) contains 1,406 points where landslides have occurred along roadways. Many of these incident points are no longer visible with LiDAR data, even at the 1-meter scale, either because they are small enough to escape visibility or because the WVDOT has repaired the damage. The database contains 53 landslide points in Region 11 counties.
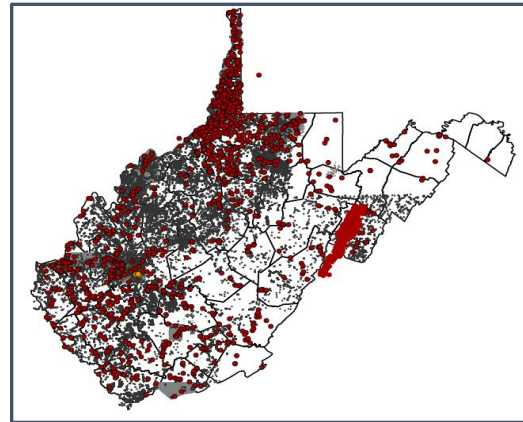
- **High-resolution LiDAR-identified landslide incidence points** - Landslide initiation points were identified and mapped specifically for this project on DEMs created from recent high resolution (1- or 2-m) LiDAR. Trained technicians placed points at the approximate center of the landslide headscarp and classified the failures into one of six general slope failure categories: slide, debris flow, lateral spread, multiple failures, fall, or undetermined. The details of classification can be found here. The nature of the West Virginia landscape and the LiDAR imagery limited mapping to landslides at least 33 feet wide. This approach undercounts small, shallow landslides and slope failures that human agents may have mitigated or removed. Rockfalls, a major landslide risk along roadways, are considerably undercounted in this approach. Overall, 261 landslide points were identified in Region 11. **Low landslide incidence numbers in the region reflect a lack of high-resolution LiDAR data at the time of mapping.**
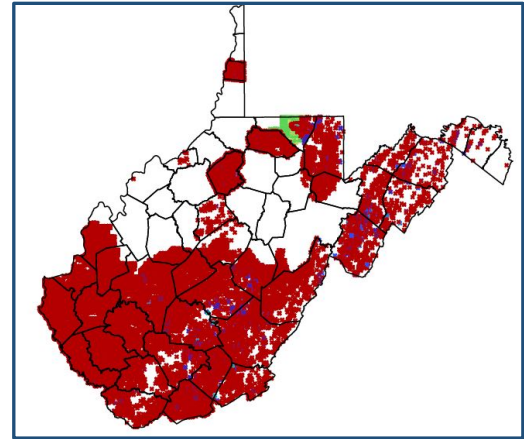

Figure 5. LiDAR-mapped landslide points are dependent upon the presence of 1- or 2-meter LiDAR data (Image from the West Virginia Landslide Tool)

Landslide Susceptibility Methodology

Landslide susceptibility has been generated as a raster grid dataset for the state. Much like the pixels in a photo or graphic, a grid is made up of square cells, where each grid cell stores a value representing a landslide susceptibility value. Using Random Forest machine learning methods, landslide incidence was modelled and rendered as a raster grid dataset. In machine learning, a model is generated by learning from examples. Figure 6 shows a simplified diagram of the machine learning model. Modeling starts with two basic variables:

1) Response variable you want to predict (example: landslide susceptibility) and,

2) Predictor variables you think might help you predict the new response variable (for example: prior locations of landslide, geology, soil, slope, etc.). Then, these predictor variables are run through a machine learning algorithm to train a model. This
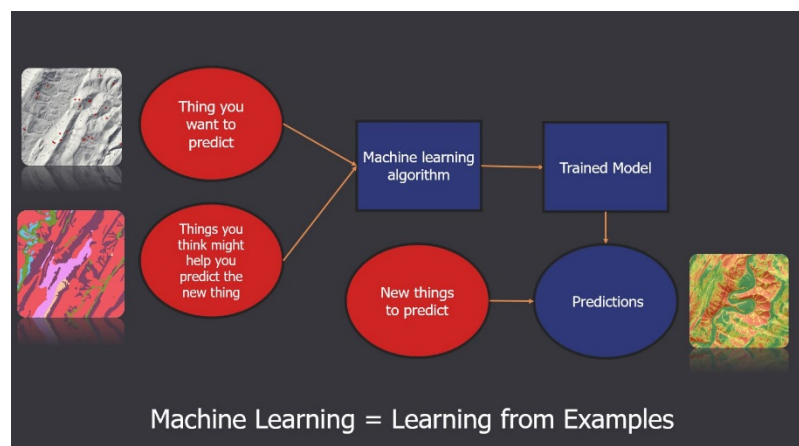

Figure 6. Simplified diagram showing machine learning process for generating landslide susceptibility grid

trained model is used for making predictions. In the end, a new prediction grid is generated (in this case, landslide susceptibility grid).

Following is the methodology for landslide susceptibility grids generated using the Random Forest machine learning model:

Landslide locations were mapped throughout West Virginia using light detection and ranging (LiDAR) elevation data products, including hillshades and slopeshades. Mapped failure types include slide, debris flow, lateral spread, multiple failures (when several failures were present in a small area, but were too small or close together to map separately), fall, and undetermined failure type (Figure 7). Site characteristics and terrain variables, such as slope, lithology, soil type, and distance to roads and streams, were extracted from the mapped landslide locations. Using a random forest machine learning algorithm, these variables were used as inputs to calculate a probabilistic landslide susceptibility grid. A majority of the mapped landslide locations were used to train the model, and the remaining locations were used to validate the model's accuracy. The resulting grid cells were classified into low, medium, and high susceptibility areas using professional judgement and model statistics. On an average, over 95% of known failure locations were found to occur within the modeled high susceptibility areas (Maxwell et al., 2020).
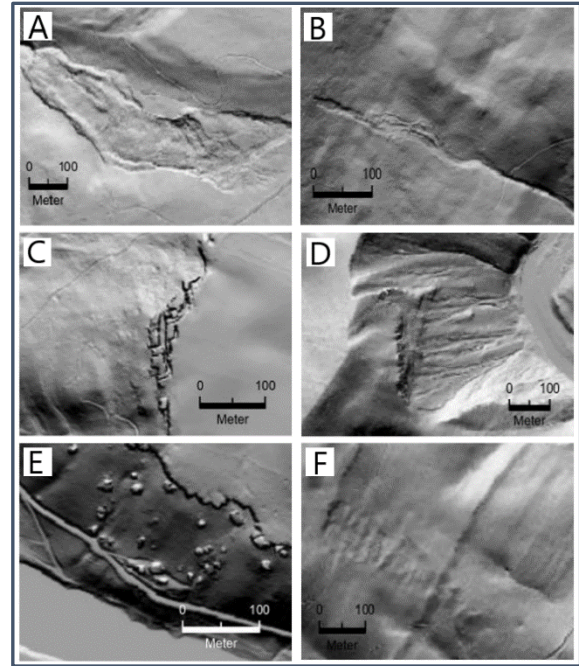

Figure 7. *A) Slide B) Debris Flow C) Lateral Spread D) Multiple Failures E) Fall F) Undetermined*

Landslide susceptibility modeling was performed at the Major Land Resource Area (MLRA) scale. MLRAs are geographic areas defined by the Natural Resources Conservation Service based upon shared characteristics, such as lithology, climate, soils, land uses, and water resources. There are four major MLRAs in West Virginia. Models were generated for each MLRA to take advantage of similarities in physiographic conditions that may influence landslide susceptibility. All of Region 11 lies within the **Central Allegheny Plateau MLRA** (Figure 8).

Many local factors contribute to landslides and their related losses. Contributing factors can be natural or human induced, but slope and local bedrock geology strongly influences county and community scale landslide incidence. Bedrock control on landslides is relatively consistent throughout individual MLRAs, which are geographically associated with Land Resource Units (LRUs).

The following paragraphs present MLRA characteristics for Region 11 and a summary of the critical underlying variables that affect landslide susceptibility in this region. A detailed report on these variables can be found here.

Landscape Characteristics

The Central Allegheny Plateau is an extensive MLRA situated in an area dominated by rugged topography, nearly flat-lying clastic sedimentary bedrock (siltstone, shale, and sandstone), and well-drained soils formed in residuum and colluvium. The Conemaugh Group, a bedrock unit with few mineable coal resources, has the highest landslide susceptibility, but unconsolidated material produced by mining in the Monongahela Group bedrock unit is locally linked to abundant landslides. Preliminary results of LiDAR-based mapping suggest landslide abundance is greater in the Central Allegheny Plateau than in any other MLRA within West Virginia.
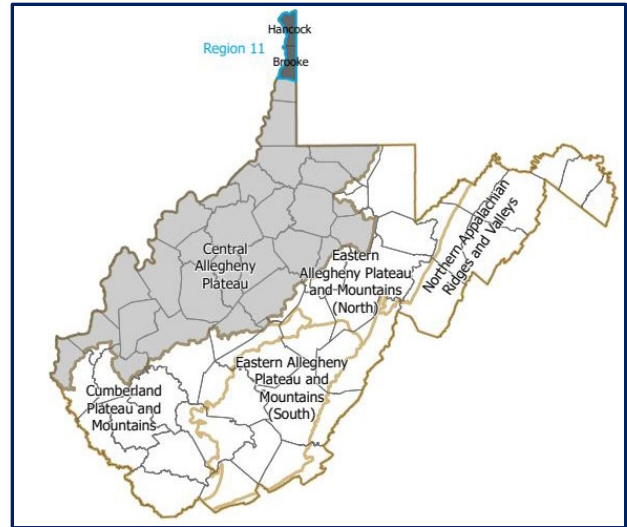

Figure 8. *Major land resource areas in West Virginia*

Central Allegheny Plateau geology is characterized by mostly horizontally bedded Pennsylvanian-age sandstone, siltstone, shale, coal, and some limestone. River valleys have significant alluvial deposits ranging from coarse gravel in steep upland river channels to fine silt and clay on broad low-gradient river bottoms. Residuum (material weathered in place or nearly in place) and colluvium (material transported some distance by gravitational processes) are the dominant earth materials in which soils develop in the MLRA. Residuum depth varies with rock type and degree of weathering; most rock types in the area produce thin residual soils, although sandstones on stable low-relief upland surfaces and thin calcareous sandstones dispersed throughout the area typically develop moderately deep residual soils. Colluvium, which includes landslide deposits, is generally thin close to mountain tops and ridge lines, increasing in thickness farther downslope. Lenses of thick colluvium may accumulate in hillslope hollows, directly upslope from the beginnings of ephemeral stream channels. Mining regolith, unconsolidated material produced as a result of coal extraction, is locally extensive within coal-bearing bedrock units and adjacent terrain.

Landslide Characteristics and Contributing Factors

Slides and **slumps** are the most common landslide types in the MLRA. They tend to develop when soil moisture and pore pressure are highest. *They are most problematic after prolonged wet seasons, particularly in late winter and early spring when soils are saturated and ground-water tables usually are high throughout the MLRA.* Debris flows initiate as slumps or slides in residuum or colluvium on upper slopes, but may run considerable distances downslope from their source. The most frequent cause of debris flows is heavy rain associated with intense spring and summer storms or late summer and early autumn remnants of tropical cyclones. The high-intensity rainfall events that trigger debris flows tend to produce numerous slope failures in local clusters. Fortunately, large debris flows are uncommon in the Central Allegheny Plateau, and they are infrequent even at the most vulnerable Appalachian sites, with recurrence intervals estimated to be hundreds or thousands of years. Rock fall failures are commonly reported in the MLRA, especially on disturbed slopes such as rock cuts along transportation corridors and mine highwalls, but the scope of rock fall susceptibility is not well shown by this landslide inventory. Less common landslide types in the MLRA include multiple failures (tight clusters of small landslides and

debris flows that tend to occur during debris flow events) and lateral spreads (clusters of large rock blocks that appear to move rarely).

Slope: Analysis of the LiDAR-based landslide data from West Virginia reveals that slope steepness may be the most important control over where landslides develop, especially in steep hillslope hollows that allow subsurface moisture, surface-water runoff, and unconsolidated material to accumulate. The slopes on upland surfaces where slides (including slumps) and debris flows initiate are significantly steeper than most of the nearby landscape. **Eighty percent of slides and slumps initiated on slopes between 17° to 39° and eighty percent of debris flows initiated on slopes between 14° to 40°.**

Geology: Geology is a universally cited factor in landslide distribution, and this is the case in the Central Allegheny Plateau of West Virginia. The role of geology on landslides may be complex and indirect. Bedrock units heavily dominated by sandstone, the hardest and most resistant rock type in the region, generally are responsible for the highest-elevation topography in the MLRA. The inherent strength of thick sandstones makes them more stable than other rocks at any given slope angle. Across the Central Allegheny Plateau, weaker bedrock units containing significant amounts of shale and siltstone tend to be more deeply incised and more prone to failure than resistant units, even if the weaker units contain some sandstone beds.

Soil: Analysis of mapped landslides and the digital NRCS Soil Survey Geographic database (SSURGO) indicate soil parent material and drainage class correlate with landslide susceptibility in the Central Allegheny Plateau. Almost 98 percent of slides were mapped in residuum developed from clastic sedimentary bedrock or in colluvium, parent materials that cover almost 87 percent of the MLRA. Acid clastic residuum, in particular, has a mapped landslide density that is significantly greater than the average for the entire MLRA. However, mining regolith is the most slide-prone parent material. Most of the mining regolith slides mapped in this MLRA lie within the Conemaugh and Monongahela group bedrock units, most likely associated with materials produced by extensive mining of the Pittsburgh Coal, which lies immediately above the contact boundary between the two groups.

Soil polygons assigned as "well drained" cover over 90 percent of mapped portions of the Central Allegheny Plateau MLRA, account for almost 97 percent of slide initiation points, and have the highest slide susceptibility. This drainage class commonly occurs on steep slopes, so its over-representation in number of slides may reflect a key role of slope as a control of both soil drainage and landslide initiation.

Other Landslide Factors: Although many factors influencing slope stability are universal, some aspects of slope stability in the Central Allegheny Plateau differ from other areas in West Virginia. Anthropogenic disturbance is significant in the Plateau, especially in urban areas and landscapes underlain by or adjacent to coal-bearing bedrock. Urban and rural development has long been known to enhance landslide susceptibility in West Virginia. Hillslopes underlain by weak bedrock or soil may obtain a significant fraction of their shear strength from tree roots, so intensive clearing for timber harvesting or real estate development may lessen slope strength. Ill-designed or poorly constructed roadways, commercial sites, and housing developments may lead to surface drainage disruptions that cause unprecedented soil saturation and abnormal slope destabilization. The importance of good engineering design, based on slope-stability site analysis by professional geologists and certified civil engineers, cannot be over-emphasized. Neither can the importance of long-term monitoring and maintenance of constructed drainage and retaining structures.

Landslide Susceptibility E-size maps for Brooke and Hancock counties can be viewed here.

Risk Assessment

The following datasets have been used in risk assessment study for roads and structures/parcels

- Landslide susceptibility analyses using random forest machine learning algorithms and landslide occurrence locations (Maxwell et al., 2020)

- E-911 site address points inside the floodplain

- Parcel centroids for areas outside the floodplain

- Roads (accessed from WV DOH website)

Risk Analysis

Roads

Road risk analysis provides an assessment of landslide risk along roads in West Virginia. **This analysis is suitable only for planning level analysis and should be used in conjunction with site-specific risk analysis performed by WV Department of Transportation.** This "big picture" perspective will benefit the planning of route improvements and lead to more effective landslide risk mitigation for West Virginia roads. The analysis classifies roads into high, medium, and low risk areas. The following methodology was used to assess landslide risk to roads in Region 11.

The statewide landslide susceptibility grid was classified as High (1-0.7), Medium (< 0.7-0.3), and Low (0.3-0) susceptibility. This raster grid was then converted to a vector feature class. Road data from WV Department of Transportation was used for analysis. For analysis, roads were analyzed for Interstate, US Roads, State, and Other roads (county roads, N/A, state parks, and forests road, FANS, HARP, and Others). Municipal non-state roads, railroads, and trail features were not included in the analysis. Since the road feature class is a line layer, a buffer of four meters was created for the road feature class. A buffer was created to adequately capture the risk for the road feature class as most landslides initiate on the side slopes of roads. An intersection between the buffered road layer and the susceptibility feature class was performed to capture risk information for road segments that overlapped with high and medium susceptibility areas. Finally, the road layer was clipped using the buffer layer to identify high and medium risk road segments for each community.

Results:

Roads were analyzed at two scales. An overview level analysis was performed on all of the roads without any distinction to get the total risk to the roads in each community. This result was used to rank communities based on the length of susceptible roads. The second set of analyses contains susceptibility details relating to Interstates, US Roads, State Roads, and Others. Railroads and trails were not part of the analysis.

Table 1 shows the total miles of road that are prone to high/medium slope failure risk. The table also shows the rank of landslide susceptibility within the state. **Brooke County** has almost 23 miles of road

that is susceptible to high/medium probability of landslides. **Hancock County** has about 21 miles of road prone to high/medium risk for slope failure. Counties were ranked for slope failure risk based on the number of miles that are at risk. Of all 55 counties, Brooke County ranks 49th and Hancock ranks 51st. In both counties, most of the at-risk roads are in unincorporated areas. Figure 9 shows an example of landslide risk along US-22 near Weirton, WV in Brooke and Hancock counties. The road segments susceptible to landslide can be viewed on the Landslide Tool.

Table 1. *Road length susceptible to High/Medium Risk of Landslide*

Community Name	County	Roads Total (miles)	Roads Total (miles)- High/Medium Risk	Rank[1]
Beech Bottom	BROOKE	4.4	0.3	100
Bethany	BROOKE	4.3	0.3	100
Brooke County*	BROOKE	201.9	20.3	50
Follansbee	BROOKE	5.5	0.4	85
Weirton**	BROOKE	19.1	1.3	8**
Wellsburg	BROOKE	9.2	0.3	100
Windsor Heights	BROOKE	0.5	0	189
	BROOKE	**244.9**	**22.9**	**49**
Chester	HANCOCK	6.3	0.3	100
Hancock County*	HANCOCK	198.2	17.3	51
New Cumberland	HANCOCK	5.7	1.2	34
Weirton**	HANCOCK	24.3	2.5	8**
	HANCOCK	**234.5**	**21.3**	**51**

8**: Parts of Weirton in each county represented separately, ranking is based on the sum of values in the city:

Community Name	County	Roads Total (miles)	Roads Total (miles)- High/Medium Risk	Rank[1]
Weirton**	BROOKE & HANCOCK	43.4	3.8	8

* Unincorporated
** Split Community
[1] Group Rank on Community Type: County, Unincorporated, Incorporated

Figure 9. Landslide Susceptibility near Weirton, WV in Brooke and Hancock counties. Notice high and medium landslide susceptibility areas along US-22. Data can be accessed on <u>WV Flood Tool</u>

The second set of risk analyses was performed to evaluate the total length of different types of roads in high/medium susceptible areas in each community. Table 2 shows details of different types of roads in high/medium susceptibility zones in each community. In each county, most of the at-risk roads are in the unincorporated areas. In **Brooke County**, the unincorporated area has 20.3 miles of at-risk roads, constituting 89% of at-risk roads in the county; 0.6 miles of US roads and 5.5 miles of State roads are at risk. The portion of Weirton falling inside Brooke County has 1.3 miles of at-risk roads and the remaining communities each have less than 1 mile of roads at risk. There are no at-risk roads in Windsor Heights. There are no Interstate roads at risk in Brooke County. **Hancock County** has 17.3 miles of at-risk roads in unincorporated areas, constituting over 81% of at-risk roads in the county. Unincorporated areas have 0.1 miles of US roads at risk and 3.8 miles of State roads at-risk. Chester has 0.3 miles of at-risk roads, New Cumberland has 1.2 miles, and the portion of Weirton in Hancock County has 2.5 miles of at-risk roads. There are no Interstate roads at risk in the county.

Table 2. *Different road type and length susceptible to High/Medium Risk of Landslide*

Community Name	County	Roads Total (miles)	Roads Total (miles)- High/Medium Risk	Interstate Roads High/Medium Risk	US Roads High/Medium Risk	State Roads High/Medium Risk	Other Roads
Beech Bottom	BROOKE	4.4	0.3	0	0	0.3	0
Bethany	BROOKE	4.3	0.3	0	0	0.3	0
Brooke County*	BROOKE	201.9	20.3	0	0.6	5.5	14.2
Follansbee	BROOKE	5.5	0.4	0	0	0.1	0.3
Weirton**	BROOKE	19.1	1.3	0	0.7	0	0.5
Wellsburg	BROOKE	9.2	0.3	0	0	0	0.3
Windsor Heights	BROOKE	0.5	0	0	0	0	0
	BROOKE	**244.9**	**22.9**	**0**	**1.3**	**6.2**	**15.3**
Chester	HANCOCK	6.3	0.3	0	0.1	0	0.2
Hancock County*	HANCOCK	198.2	17.3	0	0.1	3.8	13.3
New Cumberland	HANCOCK	5.7	1.2	0	0	0.9	0.3
Weirton**	HANCOCK	24.3	2.5	0	0	0.7	1.8
	HANCOCK	**234.5**	**21.3**	**0**	**0.2**	**5.4**	**15.6**
Weirton**	BROOKE & HANCOCK	43.4	3.8	0	0.7	0.7	2.3

* Unincorporated
** Split Community

Land Use Landslide Risk

Land use risk analysis provides an assessment of landslide risk to structures/parcels in West Virginia. **This study is not intended for site-specific analysis or remediation measures and is only suitable for planning-level analysis.** This "big picture" perspective will benefit planning and lead to more effective landslide risk mitigation for West Virginia. The following methodology was used to assess landslide risk to structures/parcels.

Primary structures were extracted for each parcel both inside and outside of the 1% annual chance floodplain in each community. Verified primary structures located inside the 1% annual chance floodplain were used as a point to assess landslide risk within a parcel. For primary structures outside of the floodplain, the following methodology was applied to extract primary structures. This method was used to avoid overestimating the values for each parcel. A spatial join was performed between the site address point and property tax assessment record. To avoid overestimating the appraisal value, the average was calculated by dividing the building appraisal value of the tax assessment record by the number of points located in the parcel. A spatial join was performed between the site addresses and parcels with the average building appraisal value. The output resulted in a site address point feature class representing primary structures attributed to the building appraisal value. These processing steps avoided adding the same building appraisal value multiple times to more than one site address point within a tax parcel.

One notable limitation of this method was that parcels containing no addressing points are assigned a building value of zero ($0). In addition, the building values for some structures are less than the values recorded in the community-wide building dollar exposure report because for specific parcels the appraisal values may be in neighboring parcels instead of the parcel where the structure is located. This results in building values not being assigned to site address points. Also, some government and other property values do not get pulled in from the statewide assessment database, resulting in lower value of at-risk structures.

Results:

Structures were analyzed at two scales for each community. An initial overview-level analysis was performed for all of the structures without any distinction to occupancy type. A second analysis was performed for different types of occupancy for high/medium risk of landslide.

Table 3 shows the total count of primary structures in high/medium landslide susceptibility areas. Total asset values were then derived from the 2021 tax assessment database. Each county was ranked for the number of primary structures and the total asset values in high/medium susceptibility areas. **Brooke County** has a total of 311 primary structures with a total appraisal value of $7,005,582 that are in high/medium susceptibility areas. **Hancock County** has 381 primary structures with a total appraisal value of $11,926,699 in high/medium susceptibility areas. Brooke County ranks 30th among all counties in the state for at-risk structure count and 39th for total asset value in high/medium risk areas. Hancock County ranks 23rd for at-risk structure count and 28th for total asset value in high/medium risk areas.

Table 3. Structures with High/Medium Risk Landslide Susceptibility

Community Name	County	Total Count	Total Value	Ranking(Count)[1]	Ranking(Value)[1]
Beech Bottom	BROOKE	15	$346,700	75	89
Bethany	BROOKE	0	$0	195	191
Brooke County*	BROOKE	91	$1,818,050	49	49
Follansbee	BROOKE	116	$2,948,950	17	26
Weirton**	BROOKE	57	$1,155,882	9**	14**
Wellsburg	BROOKE	32	$736,000	45	61
Windsor Heights	BROOKE	0	$0	195	191
	BROOKE	**311**	**$7,005,582**	**30**	**39**
Chester	HANCOCK	36	$708,050	42	63
Hancock County*	HANCOCK	79	$1,907,310	51	48
New Cumberland	HANCOCK	53	$1,486,767	31	44
Weirton**	HANCOCK	213	$7,824,573	9**	14**
	HANCOCK	**381**	**$11,926,699**	**23**	**28**
9** & 14**: Parts of Weirton in each county represented separately, ranking is based on the sum of values in the city:					
Weirton**	BROOKE & HANCOCK	270	$8,980,453	9	14

* Unincorporated

** Split Community

[1] Group Rank on Community Type: County, Unincorporated, Incorporated

Table 4 shows detailed risk of slope failure based on different occupancy classes. For both Region 11 counties, the **Residential** occupancy class has the highest structure counts and total replacement costs in high/medium landslide susceptibility areas. Replacement costs for the Other occupancy class should

be ignored as some government and other property values do not get incorporated in the statewide assessment database, resulting in lower value of at-risk structures.

Brooke County has 261 structures in the Residential occupancy class with replacement costs of $6,373,650, followed by 40 Other structures, and 10 Commercial structures with a total replacement cost of $209,782. Follansbee has the highest structure count and corresponding replacement costs in the Residential class, while Weirton has the highest structure count and replacement costs in the Commercial class. There are no at-risk structures in Bethany or Windsor Heights.

Hancock County has a total of 325 structures in the Residential occupancy class with replacement costs of $9,915,983, followed by 47 Other structures, and 9 Commercial structures with replacement costs of $2,003,267. Weirton has the highest structure counts and replacement costs in both the Residential and Commercial classes.

Table 4. *Types of Structures with High/Medium Risk Landslide Susceptibility*

Community Name	County	RESIDENTIAL OCCUPANCY CLASS		COMMERCIAL OCCUPANCY CLASS		OTHER OCCUPANCY CLASS	
		High/Medium Susceptibility		High/Medium Susceptibility		High/Medium Susceptibility	
		Residential count	Residential-value	Commercial count	Commercial value	Other count	Other value***
Beech Bottom	BROOKE	11	$285,900	2	$59,500	2	$1,300
Bethany	BROOKE	0	$0	0	$0	0	$0
Brooke County*	BROOKE	68	$1,397,300	1	$0	22	$420,750
Follansbee	BROOKE	107	$2,948,850	0	$0	9	$100
Weirton**	BROOKE	46	$1,005,600	7	$150,282	4	$0
Wellsburg	BROOKE	29	$736,000	0	$0	3	$0
Windsor Heights	BROOKE	0	$0	0	$0	0	$0
	BROOKE	**261**	**$6,373,650**	**10**	**$209,782**	**40**	**$422,150**
Chester	HANCOCK	30	$708,050	0	$0	6	$0
Hancock County*	HANCOCK	67	$1,900,760	1	$0	11	$6,550
New Cumberland	HANCOCK	47	$818,200	1	$668,567	5	$0
Weirton**	HANCOCK	181	$6,488,973	7	$1,334,700	25	$900
	HANCOCK	**325**	**$9,915,983**	**9**	**$2,003,267**	**47**	**$7,450**

Weirton**	BROOKE & HANCOCK	227	$7,494,571	14	$1,484,981	29	$900

* Uncorporated
** Split Community
***Other occupancy class value is underreported as assessment value may be absent in assessment database.

Limitations and Expert Consultation

Landslide susceptibility classifications are based on physical characteristics associated with landslide locations mapped using LiDAR data. The nature of the West Virginia landscape and the LiDAR imagery limited mapping to landslides at least 33 feet wide. This approach undercounts small, shallow landslides and slope failures that may have been mitigated or removed by human agents. LiDAR-mapped landslide locations and landslide susceptibility maps derived from this data are inherently biased against these areas. Additionally, it is not feasible to thoroughly verify the accuracy of each dataset used for mapping and modeling. However, every effort has been made to ensure the integrity of this data.

Landslide risk is complex and continually changing. Future mitigation projects or alterations to topography, land use, and climate may render these results inaccurate. Other models, maps, reports, and future site-specific analyses may provide results that differ from those included here.

This study is NOT intended for regulatory use and is NOT the final authoritative source of all landslide risk data in the community. It should be used in conjunction with other data sources to provide a comprehensive picture of general landslide risk. This report is for informational and planning purposes regarding landslide susceptibility and risk at the county scale. It may not be used to identify susceptibility at site-specific locations.

To address landslide susceptibility at a sub-county scale, geotechnical evaluations should be performed by professional engineers or geologists. For site-specific investigations, local officials, developers, and property owners should consult slope-stability experts, such as certified professional engineers and qualified geologists. Site-specific evaluations for landslide susceptibility can only be provided by performing detailed site-specific geotechnical studies, including bedrock and soil analyses, core description, physical testing, and slope-stability analyses.

Outreach Materials

- **The West Virginia Landslide Tool** (http://mapwv.gov/landslide) is a landslide web mapping application showing landslide incidence data and modeling results. The West Virginia GIS Technical Center created an ArcGIS online map that provides information about landslide susceptibility and landslides mapped throughout West Virginia. The map allows users to display landslide locations mapped by the West Virginia Department of Transportation (WV DOT), West Virginia Geological and Economic Survey (WVGES), United States Geological Survey (USGS), several independent research projects, and landslides mapped using high-resolution elevation data. The public can also add landslide locations to the West Virginia Landslide Tool (http://www.mapwv.gov/landslide) by taking a photo of the landslide and uploading it to the application.
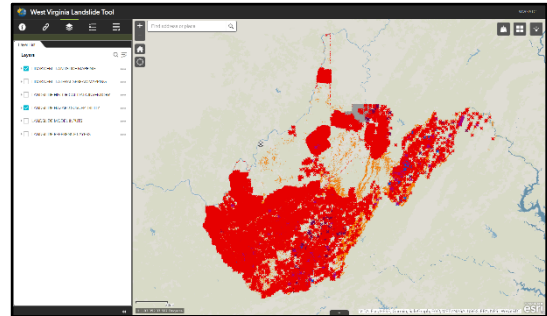
Figure 10. *West Virginia Landslide Tool*

- **Story Maps**

  - *Causes of Landslides in Mountain State, West Virginia* https://arcg.is/1SW0Sn discusses different causes of landslides in the state.

Figure 11. *Story Map showing causes of landslide*

  - *West Virginia Landslides and Slide Prone Areas, WVGES 1976* https://arcg.is/1KDnvq discusses landslide risk assessment published in 1976 by the WV Geological and Economic Survey that was funded by the Appalachian Regional Commission.
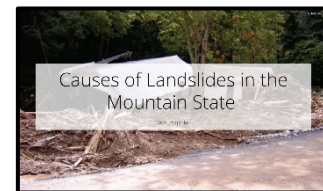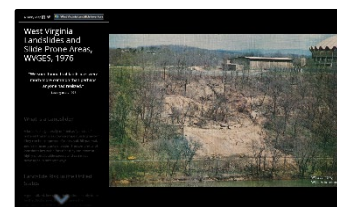

Figure 12. *WVGES 1976 Study details in Story Map*

- **Educational brochures** were developed to provide general information about identifying signs of slope instability and mitigation measures that may help reduce landslide risk at the [community](#) and [individual](#) property levels.

Figure 13. *Mitigation brochure for community and property owners*

- **Landslide susceptibility modelling publications**- Two peer reviewed modelling papers have been published in refereed journals

  - [Slope Failure Prediction Using Random Forest Machine Learning and LiDAR in an Eroded Folded Mountain Belt](#) – Published in journal Remote Sensing

  - [Assessing the Generalization of Machine Learning-Based Slope Failure Prediction to New Geographic Extents](#) – Published in journal International Journal of Geo-Information

- **County Landslide Susceptibility Maps** – Landslide susceptibility maps for Brooke and Hancock counties can be viewed and downloaded [here](#).
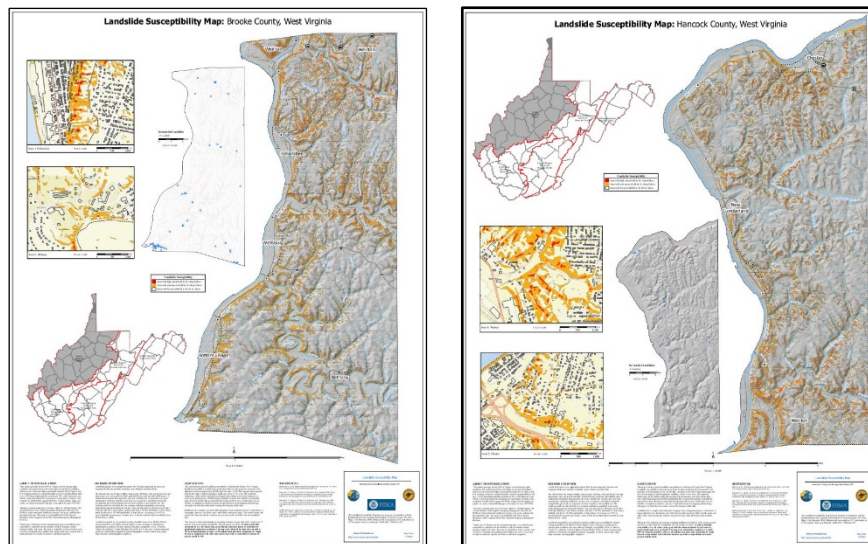

Figure 14. *Landslide Susceptibility maps of Brooke and Hancock counties*

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