Landslide along Old US-19 in Mercer County

West Virginia Landslide Risk Assessment

Region 1 – Raleigh, Summers, Monroe, Mercer, McDowell, & Wyoming counties

FEBRUARY 9, 2022

In support of FEMA HMGP Project

FEMA

WV GIS TC

EMERGENCY MANAGEMENT DIVISION WVEMD WEST VIRGINIA

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, 7,935 landslide points were identified using LiDAR in Region 1. 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 1 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 1, **McDowell County** has almost 91 miles of road that is susceptible to high/medium probability of landslides. **Mercer County** has about 138 miles, **Monroe County** has about 52 miles, **Raleigh County** has about 78 miles, **Summers County** has around 150 miles, and **Wyoming County** has about 47 miles of road prone to high/medium risk for slope failure. Counties were ranked for slope failure risk based on the number of at-risk road miles. Two Region 1 counties rank in the Top 10 for highest number of road miles at risk from landslides in the state. Of all 55 counties, McDowell ranks 21st, Mercer 6th, Monroe 37th, Raleigh 27th, Summers 5th, and Wyoming 39th. In each county, most of the at-risk roads are in unincorporated areas

Structure/Parcel analysis - **McDowell County** has a total of 1205 primary structures with a total appraisal value of $7,645,862 that are in high/medium susceptibility areas. **Mercer County** has 992 primary structures with total appraisal value of $29,675,908 in high/medium susceptibility areas. **Monroe County** has 67 primary structures with a total appraisal value of $3,171,550 in high/medium susceptibility areas. **Raleigh County** has 689 primary structures with a total appraisal value of $21,287,089 in high/medium susceptibility areas. **Summers County** has 343 primary structures with a total appraisal value of $8,679,023 in high/medium susceptibility areas. **Wyoming County** has 193 primary structures with total appraisal value of $6,270,175 in high/medium susceptibility areas. Two Region 1 counties rank in the Top 10 for total number of at-risk structures in the state. McDowell County ranked 3rd, Mercer 5th, Monroe 54th, Raleigh 11th, Summers 27th, and Wyoming 44th for total count of at-risk structures. For the value of total assets at high or medium risk of landslides, McDowell County ranks 37th, Mercer 15th, Monroe 49th, Raleigh 18th, Summers 33rd, and Wyoming 41st.

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 1 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.

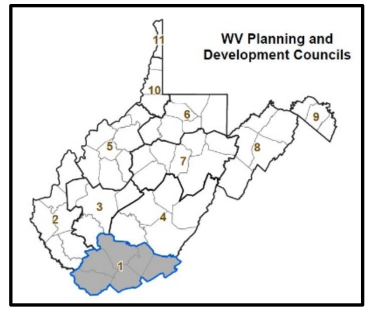

Figure 1. *Planning and development regions in West Virginia*

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

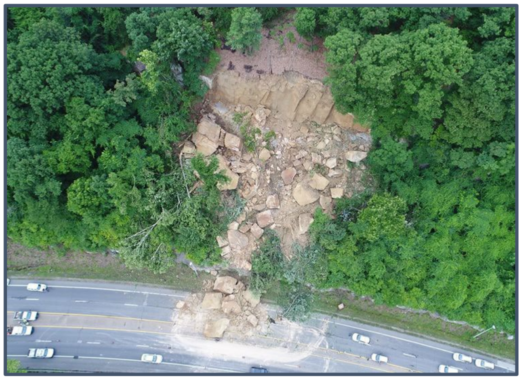

Figure 3. *The* ***consequences*** *of a landslide are often higher in populated areas due to resulting property damage and injury to citizens (Photo by [WVDOT])*

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 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 8,825 landslide polygons from Region 1.

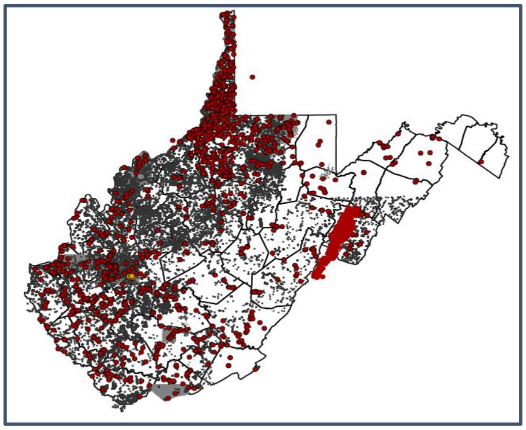

Figure 4. *Historical landslides were compiled from several studies to create a comprehensive landslide dataset (Image adapted from the West Virginia Landslide Tool)*

- **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 2,435 polygons from Region 1.

- **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. This inventory included 12 landslide polygons in Region 1. 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), including 72 polygons from Region 1.

- **West Virginia Department of Highways (WVDOH) 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 114 landslide points in Region 1 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 and debris flows, major landslide risks along roadways, are considerably undercounted in this approach. Overall, 7,935 landslide points were identified in Region 1.

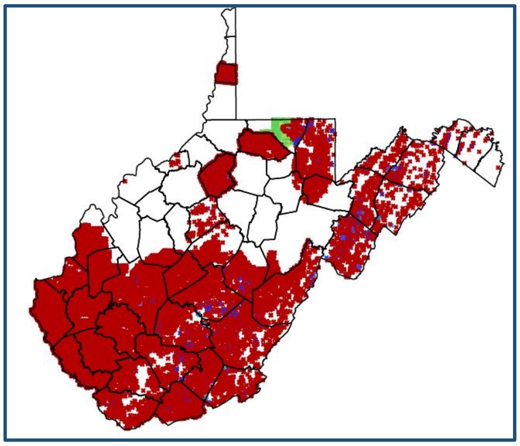

Figure 5. *LiDAR-mapped landslide points are dependent upon the presence of 1- or 2-meter LiDAR data (Image from the West Virginia Landslide Tool)*

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:

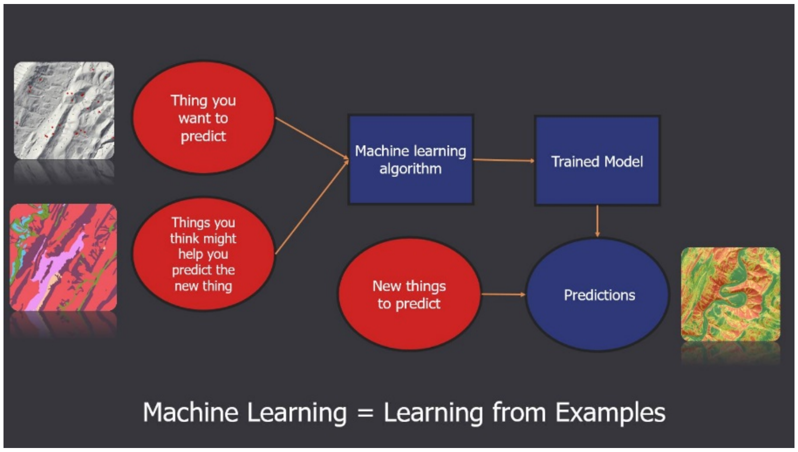

Figure 6. *Simplified diagram showing machine learning process for generating landslide susceptibility grid*

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 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 average, over 95% of known failure locations were found to occur within the modeled high susceptibility areas (Maxwell et al., 2020).

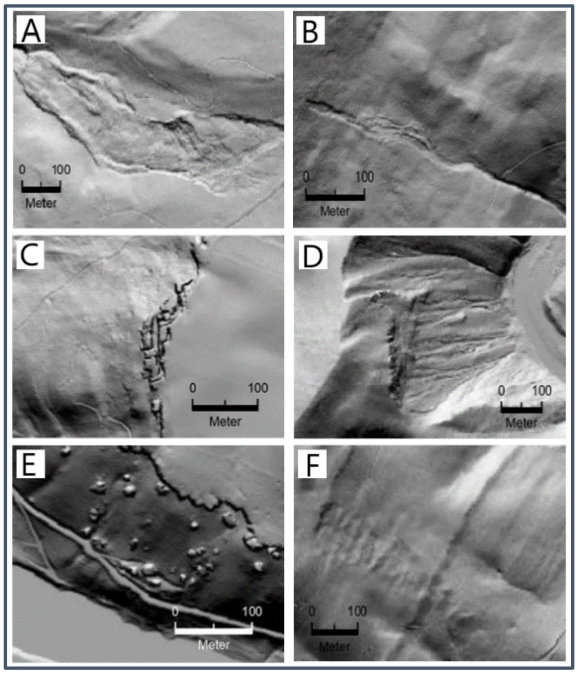

Figure 7. *A) Slide B) Debris Flow C) Lateral Spread D) Multiple Failures E) Fall F) Undetermined*

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. Two MLRAs account for most of Region 1 (see Figure 8): the **Cumberland Plateau and Mountains** and the Southern portion of the **Eastern Allegheny Plateau and Mountains.** The **Cumberland Plateau and Mountains MLRA** covers all of McDowell and Wyoming counties, and portions of western Raleigh and Mercer counties. The **Eastern Allegheny Plateau and Mountains MLRA** covers all of Summers County, large swaths of eastern Raleigh and Mercer counties, and western Monroe County. Eastern Monroe County hosts very small segments of the **Northern and Southern Appalachian Ridges and Valleys MLRAs**. The Southern Ridges and Valleys is also present along the southeastern border of Mercer County.

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 detailed MLRA characteristics for Region 1 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

Region 1 MLRAs are largely dominated by rugged topography, clastic sedimentary bedrock, and well-drained soils developed in residuum, colluvium, and mining regolith. 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 region. Residuum depth varies with rock type and degree of weathering; most rock types in the area produce thin residual soils, but limestone units throughout the area and sandstones on stable, low-relief upland surfaces typically develop thick 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 mining, is locally extensive within coal-bearing geologic units.

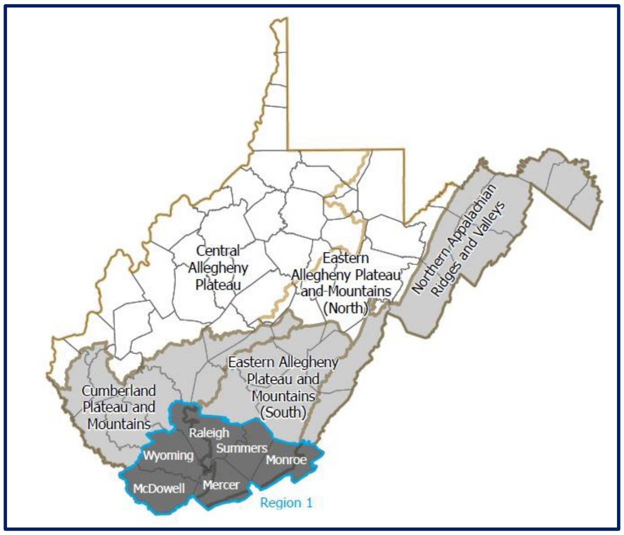

Figure 8. *Major land resource areas in West Virginia*

The Appalachian Ridges and Valleys, present only along the southeastern border of Region 1, has more diverse topography than other MLRAs and encompasses most of the gentle topography in the state. Mining regolith is not a significant source of unconsolidated earth material in this MLRA. *LiDAR-based mapping reveals that landslides are over five times more abundant in the Cumberland Plateau and Mountains and the Southern section of the Eastern Allegheny Plateau and Mountains MLRAs than in the Appalachian Ridges and Valleys.*

Landslide Characteristics and Contributing Factors

Slides and **slumps** are the most common landslide types in Region 1 counties. 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 region*. Debris flows can initiate as slumps or slides in residuum or colluvium on upper slopes, but may run long distances downslope from their source. The most frequent cause of Appalachian debris flows is heavy rain associated with intense spring and early summer storms or late summer and early autumn remnants of tropical cyclones. Fortunately, Appalachian debris flows are infrequent, with recurrence intervals at the most vulnerable sites estimated to be hundreds or thousands of years. Rock fall failures are commonly reported in the region, especially on disturbed slopes such as road 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 region 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 Region 1 MLRAs 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. Close to 90 percent of mapped landslides initiated on **slopes greater than 20 degrees.**

Geology: Geology is a universally cited factor in landslide distribution, and this is the case for MLRAs in Region 1. 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 area and numerous cliffs along major river valleys. The inherent strength of thick sandstone layers generally makes them more stable than other rock types at any given slope angle. Weaker bedrock units on side slopes, like shale, siltstone, and claystone, tend to be more deeply incised and more prone to failure than resistant sandstone units, even if the weak units contain some significant sandstone beds. A notable exception is the Appalachian Ridges and Valleys, where LiDAR-mapped landslide density in sandstone-dominated units is 36 percent higher than the average for the entire MLRA.

Soil: Analysis of mapped landslides and the NRCS Soil Survey Geographic database (SSURGO) indicate soil parent material and drainage class influence landslide susceptibility in Region 1 MLRAs. Generally, soils formed from acid clastic residuum, colluvium, and calcareous clastic residuum parent materials are highly prone to landslides. Collectively, these parent materials cover around 85-90 percent of the MLRAs, so they contribute significantly to the regional landslide density. However, mining regolith is the parent material with the highest mapped landslide density in most of the MLRAs. Again, the exception is the Appalachian Ridges and Valleys, where no landslides were mapped in mining regolith and landslide density in colluvium is significantly lower than other MLRAs in the region.

Soil polygons assigned as “well drained” and “somewhat excessively drained” cover the majority of Region 1 MLRAs and account for the majority of landslide initiation points. Both of these drainage classes commonly occur on steep slopes, so the over-representation of landslides in these two classes is correlated to the important 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 Region 1 MLRAs may differ from other areas in West Virginia. Anthropogenic disturbance is significant throughout the region, especially in landscapes underlain by coal-bearing bedrock. Unreclaimed mine high walls have local rock-fall susceptibility, but falls elsewhere in the area are most commonly associated with over-steepened road and railroad cuts. Limestone quarries in the Appalachian Ridges and Valleys may also present localized rockfall susceptibility.

Forest products are part of the economy in many of the Region 1 counties. Hillslopes underlain by weak bedrock or soil may obtain a significant fraction of their shear strength from tree roots, so intensive timber clearing may lessen slope strength for decades until new root systems develop. Ill-designed or poorly constructed haul roads and skidder trails may lead to surface drainage disruptions that causes unprecedented soil saturation and abnormal slope destabilization.

Urban, suburban, and rural development share many of the landslide issues characteristic of timber operations. Foundation excavations and inadequate retaining walls are additional contributors to slope failure on developed land, sometimes including farm land. New property development in rapidly-growing areas of West Virginia has the potential to impact slope stability, so the importance of good engineering design, based on slope-stability site analysis by professional geologists and certified civil engineers, cannot be over-emphasized.

Landslide Susceptibility E-size maps for Raleigh, Summers, Monroe, Mercer, McDowell, and Wyoming 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 1.

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**. McDowell County** has almost 91 miles of road that is susceptible to high/medium probability of landslides. **Mercer County** has about 138 miles, **Monroe County** has about 52 miles, **Raleigh County** has about 78 miles, **Summers County** has around 150 miles, and **Wyoming County** has about 47 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. Two Region 1 counties rank in the Top 10 for highest number of road miles at risk from landslides in the state. Of all 55 counties, McDowell County ranks 21st, Mercer 6th, Monroe 37th, Raleigh 27th, Summers 5th, and Wyoming 39th. In each county, most of the at-risk roads are in unincorporated areas. Figure 9 shows an example of landslide risk near Hinton, WV in Summers County. 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]
Anawalt	MCDOWELL	5.9	0.5	68
Bradshaw	MCDOWELL	6.4	0.2	127
Davy	MCDOWELL	4	0.2	127
Gary	MCDOWELL	11.7	0.5	68
Iaeger	MCDOWELL	7.6	0.5	68
Keystone	MCDOWELL	3	0.1	155
Kimball	MCDOWELL	5.2	0.2	127
McDowell County*	MCDOWELL	682	79.2	25
Northfork	MCDOWELL	9.8	1.2	34
War	MCDOWELL	6.5	0.5	68
Welch	MCDOWELL	50.8	7.8	3
	MCDOWELL	**792.9**	**90.9**	**21**
Athens	MERCER	1.8	0	189
Bluefield	MERCER	56.7	3.5	11
Bramwell	MERCER	8.7	0.4	85
Mercer County*	MERCER	1035.4	133.3	6
Oakvale	MERCER	3.2	0.6	63
Princeton	MERCER	21.9	0.3	100
	MERCER	**1127.7**	**138.1**	**6**
Alderson**	MONROE	1.4	0.1	155**
Monroe County*	MONROE	633.2	51.7	37
Peterstown	MONROE	4.1	0.1	155
Union	MONROE	5.1	0	189
	MONROE	**643.8**	**51.9**	**37**
Beckley	RALEIGH	64	1	39
Lester	RALEIGH	7.8	0	189
Mabscott	RALEIGH	5.7	0.1	155
Raleigh County*	RALEIGH	1075.6	76.7	27
Rhodell	RALEIGH	1.9	0	189
Sophia	RALEIGH	13.6	0.3	100
	RALEIGH	**1168.6**	**78.1**	**27**
Hinton	SUMMERS	11.2	2.3	19
Summers County*	SUMMERS	622.2	147.8	4
	SUMMERS	**633.4**	**150.1**	**5**
Mullens	WYOMING	7.8	0.2	127
Oceana	WYOMING	5.7	0	189
Pineville	WYOMING	8.9	0.1	155
Wyoming County*	WYOMING	586.8	47	38
	WYOMING	**609.2**	**47.3**	**39**

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

Total in Alderson	GREENBRIER & MONROE	4.5	0.1	155

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

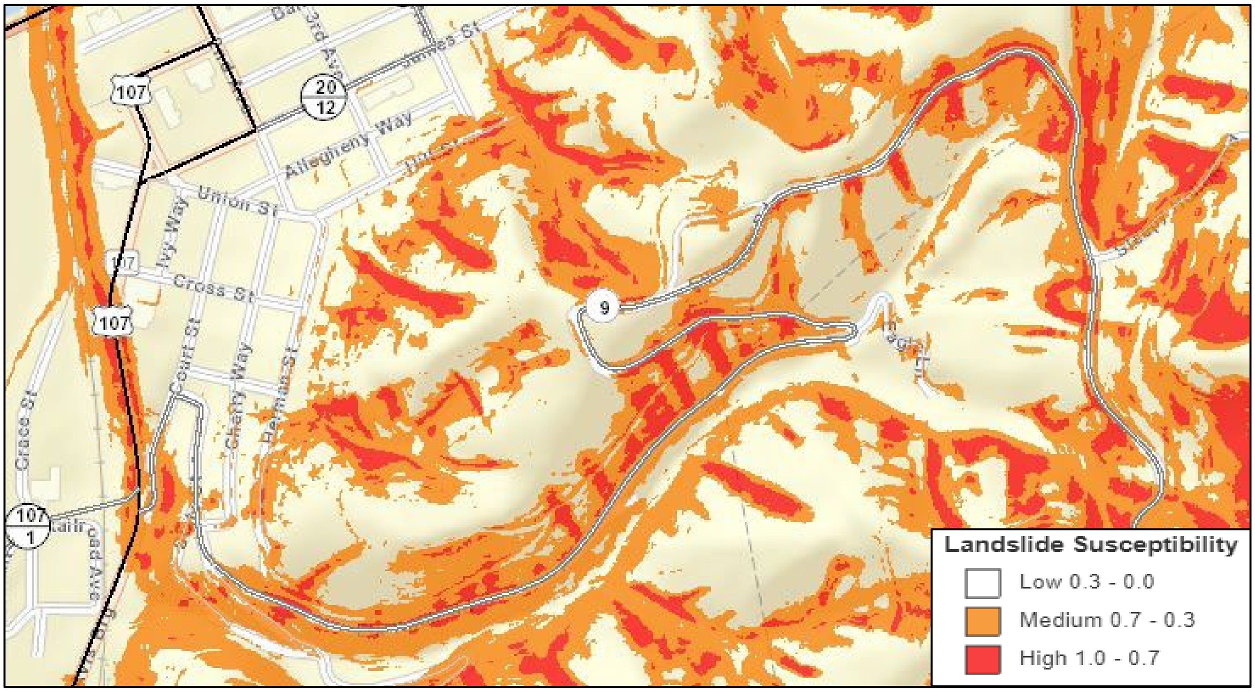

Figure 9. *Landslide Susceptibility near Hinton, WV in Summers County. Notice high and medium susceptibility landslide areas along roads leading into the city. Data can be accessed on WV Flood Tool*

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 **McDowell County**, the unincorporated area has 79.2 miles of at-risk roads, constituting 87% of at-risk roads in the county; 9.4 miles of US roads and 19.8 miles of State roads are at-risk. Northfork has 1.2 miles of at-risk roads and Welch has 7.8 miles. All other communities in McDowell County have less than 1 mile of at-risk roads each. There are no Interstate roads at risk in the county. **Mercer County** has 133.3 miles of at-risk roads in unincorporated areas, constituting 96% of at-risk roads in the county. Unincorporated areas have 2.5 miles of Interstate roads at-risk, 19.2 miles of US roads, and 9.8 miles of State roads at-risk. Bluefield has 3.5 miles of at-risk roads and the remaining communities have less than 1 mile each. There are no at-risk roads in Athens. In **Monroe County**, the unincorporated area has 51.7 miles of at-risk roads, constituting over 99% of at-risk roads in the county. The unincorporated area has 2.1 miles of US roads and 5 miles of State roads at risk. The incorporated communities have less than 1 mile of at-risk roads each. Union has no at-risk roads. There are no Interstate roads at risk in Monroe County. **Raleigh County** has 76.7 miles of at-risk roads in unincorporated areas, constituting 98% of at-risk roads in the county. The unincorporated area has 2.8 miles of Interstate roads at risk, 1.3 miles of US roads at risk, and 12 miles of State roads at risk. Beckley has 1 mile of road at risk and the remaining communities each have less than 1 mile of road at risk. There are no at-risk roads in Lester or Rhodell. **Summers County** has 147.8 miles of at-risk roads in the unincorporated area, constituting 98% of at-risk roads in the county. The unincorporated area has 0.8 miles of Interstate roads and 23 miles of State roads at risk. Hinton has 2.3 miles of road at risk. There are no US roads at risk in Summers County. **Wyoming County** has 47 miles of at-risk roads in unincorporated areas, constituting 99% of at-risk roads in the county. The unincorporated area has 6.3

miles of US roads and 14.8 miles of State roads at risk. The incorporated communities have less than 1 mile of at-risk roads each. Oceana has no at-risk roads. There are no Interstate roads at risk in Wyoming 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
Anawalt	MCDOWELL	5.9	0.5	0	0	0	0.5
Bradshaw	MCDOWELL	6.4	0.2	0	0	0.1	0.1
Davy	MCDOWELL	4	0.2	0	0	0	0.2
Gary	MCDOWELL	11.7	0.5	0	0	0.3	0.2
Iaeger	MCDOWELL	7.6	0.5	0	0.3	0.1	0.2
Keystone	MCDOWELL	3	0.1	0	0	0	0.1
Kimball	MCDOWELL	5.2	0.2	0	0	0	0.2
McDowell County*	MCDOWELL	682	79.2	0	9.4	19.8	50
Northfork	MCDOWELL	9.8	1.2	0	0.1	0	1.1
War	MCDOWELL	6.5	0.5	0	0	0.3	0.1
Welch	MCDOWELL	50.8	7.8	0	2.5	0.9	4.3
	MCDOWELL	**792.9**	**90.9**	**0**	**12.3**	**21.5**	**57**
Athens	MERCER	1.8	0	0	0	0	0
Bluefield	MERCER	56.7	3.5	0	0.7	1.5	1.3
Bramwell	MERCER	8.7	0.4	0	0.1	0	0.3
Mercer County*	MERCER	1035.4	133.3	2.5	19.2	9.8	101.9
Oakvale	MERCER	3.2	0.6	0	0	0	0.6
Princeton	MERCER	21.9	0.3	0	0.2	0	0
	MERCER	**1127.7**	**138.1**	**2.5**	**20.2**	**11.3**	**104.1**
Alderson**	MONROE	1.4	0.1	0	0	0	0.1
Monroe County*	MONROE	633.2	51.7	0	2.1	5	44.7
Peterstown	MONROE	4.1	0.1	0	0	0	0.1
Union	MONROE	5.1	0	0	0	0	0
	MONROE	**643.8**	**51.9**	**0**	**2.1**	**5**	**44.9**
Beckley	RALEIGH	64	1	0	0.5	0.1	0.4
Lester	RALEIGH	7.8	0	0	0	0	0
Mabscott	RALEIGH	5.7	0.1	0.1	0	0	0.1
Raleigh County*	RALEIGH	1075.6	76.7	2.8	1.3	12	60.6
Rhodell	RALEIGH	1.9	0	0	0	0	0
Sophia	RALEIGH	13.6	0.3	0	0	0	0.3
	RALEIGH	**1168.6**	**78.1**	**2.9**	**1.8**	**12.1**	**61.4**
Hinton	SUMMERS	11.2	2.3	0	0	1.4	0.9
Summers County*	SUMMERS	622.2	147.8	0.8	0	23	124
	SUMMERS	**633.4**	**150.1**	**0.8**	**0**	**24.4**	**124.9**
Mullens	WYOMING	7.8	0.2	0	0	0.2	0
Oceana	WYOMING	5.7	0	0	0	0	0
Pineville	WYOMING	8.9	0.1	0	0	0	0.1
Wyoming County*	WYOMING	586.8	47	0	6.3	14.8	26
	WYOMING	**609.2**	**47.3**	**0**	**6.3**	**15**	**26.1**

Total in Alderson	GREENBRIER & MONROE	4.5	0.1	0	0	0	0.1

* 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 1% annual chance floodplains in each community. Verified primary structures located inside 1% annual chance floodplains were used as a point to assess landslide risk within a parcel. For primary structures in the area 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 a 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. **McDowell County** has a total of 1,205 primary structures with a total appraisal value of $7,645,862 that are in high/medium susceptibility areas. **Mercer County** has 992 primary structures with total appraisal value of $29,675,908 in high/medium susceptibility areas. **Monroe County** has 67 primary structures with a total appraisal value of $3,171,550 in high/medium susceptibility areas. **Raleigh County** has 689 primary structures with a total appraisal value of $21,287,089 in high/medium susceptibility areas. **Summers County** has 343 primary structures with a total appraisal value of $8,679,023 in high/medium susceptibility areas. **Wyoming County** has 193 primary structures with total appraisal value of $6,270,175 in high/medium susceptibility areas. Two Region 1 counties rank in the Top 10 for total number of at-risk structures in the state. McDowell County ranked 3rd, Mercer 5th, Monroe 54th, Raleigh 11th, Summers 27th, and Wyoming 44th for total count of at-risk structures. For the value of total assets at high or medium risk of landslides, McDowell County ranks 37th, Mercer 15th, Monroe 49th, Raleigh 18th, Summers 33rd, and Wyoming 41st.

Table 3. Structures with High/Medium Risk Landslide Susceptibility

Community Name	County	Total Count	Total Value	Ranking(Count)[1]	Ranking(Value)[1]
Anawalt	MCDOWELL	13	$52,800	81	159
Bradshaw	MCDOWELL	12	$91,300	85	147
Davy	MCDOWELL	13	$93,100	81	146
Gary	MCDOWELL	9	$35,400	104	174
Iaeger	MCDOWELL	48	$259,350	33	96
Keystone	MCDOWELL	39	$336,750	39	91
Kimball	MCDOWELL	19	$161,100	61	117
McDowell County*	MCDOWELL	766	$3,031,269	3	46
Northfork	MCDOWELL	47	$252,700	35	97
War	MCDOWELL	32	$147,150	45	120
Welch	MCDOWELL	207	$3,184,943	12	21
	MCDOWELL	**1205**	**$7,645,862**	**3**	**37**
Athens	MERCER	3	$105,600	151	138
Bluefield	MERCER	458	$18,406,698	5	10
Bramwell	MERCER	9	$66,200	104	153
Mercer County*	MERCER	515	$10,881,459	8	26
Oakvale	MERCER	4	$18,200	139	185
Princeton	MERCER	3	$197,750	151	109
	MERCER	**992**	**$29,675,908**	**5**	**15**
Alderson**	MONROE	2	$34,500	151**	155**
Monroe County*	MONROE	64	$3,107,150	53	45
Peterstown	MONROE	0	$0	195	191
Union	MONROE	1	$29,900	178	177
	MONROE	**67**	**$3,171,550**	**54**	**49**
Beckley	RALEIGH	184	$8,991,823	13	13
Lester	RALEIGH	0	$0	195	191
Mabscott	RALEIGH	13	$757,700	81	59
Raleigh County*	RALEIGH	485	$11,423,665	10	25
Rhodell	RALEIGH	0	$0	195	191
Sophia	RALEIGH	7	$113,900	118	136
	RALEIGH	**689**	**$21,287,089**	**11**	**18**
Hinton	SUMMERS	81	$1,561,983	24	42
Summers County*	SUMMERS	262	$7,117,040	25	31
	SUMMERS	**343**	**$8,679,023**	**27**	**33**
Mullens	WYOMING	0	$0	195	191
Oceana	WYOMING	0	$0	195	191
Pineville	WYOMING	11	$1,407,667	89	46
Wyoming County*	WYOMING	182	$4,862,509	39	41
	WYOMING	**193**	**$6,270,175**	**44**	**41**

151** & 155**: Parts of Alderson in each county represented separately, ranking is based on the sum of values in the city:

Total in Alderson	GREENBRIER & MONROE	3	$62,700	151	155

* 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 most Region 1 counties, the **Residential** occupancy class has the highest total replacement cost in high/medium landslide susceptibility areas. In Wyoming County, structures in the Other occupancy class outvalue the Residential structures. However, 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 a lower value of at-risk structures.

McDowell County has 866 structures in the Residential occupancy class with replacement costs of $5,766,401, followed by 306 Other structures, and 33 Commercial structures with a total replacement cost of $425,743. The unincorporated areas of McDowell County have the highest structure counts in all occupancy classes and the highest replacement costs for the Residential occupancy class. Welch has the highest Commercial replacement costs.

Mercer County has a total of 767 structures in the Residential occupancy class with replacement costs of $23,011,817, followed by 188 Other structures, and 37 Commercial structures with replacement costs of $1,591,120. The unincorporated areas of Mercer County have the highest structure counts for Residential and Other occupancy classes, but Bluefield has the highest Residential replacement costs. Bluefield also has the highest structure count and replacement costs for Commercial buildings.

Monroe County has a total of 42 structures in the Residential occupancy class with replacement costs of $1,905,783, followed by 23 Other structures, and 2 Commercial structures with replacement costs of $174,100. The unincorporated areas of Monroe County have the highest structure counts and corresponding replacement costs in all occupancy classes. There are no at-risk structures in Peterstown.

Raleigh County has a total of 457 structures in the Residential occupancy class with replacement costs of $17,298,148, followed by 186 Other structures, and 46 Commercial structure with a replacement cost of $3,199,777. The unincorporated area of Raleigh County has the highest structure counts for all occupancy classes and the highest Residential replacement costs. Beckley has the highest Commercial replacement costs. There are no at-risk structures in Lester or Rhodell.

Summers County has a total of 241 structures in the Residential occupancy class with replacement costs of $6,090,614, followed by 87 Other structures, and 15 Commercial structures with replacement costs of $2,487,198. The unincorporated areas of Summers County have the highest structure counts and corresponding replacement values in all occupancy classes.

Wyoming County has a total of 132 structures in the Residential occupancy class with replacement costs of $1,430,969, followed by 58 Other structures, and 3 Commercial structures with replacement costs of $87,875. The unincorporated areas of Wyoming County have the highest structure counts for all occupancy classes and the highest Residential replacement costs. Pineville has the highest Commercial replacement costs. There are no at-risk structures in Mullens or Oceana.

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***
Anawalt	MCDOWELL	9	$52,800	0	$0	4	$0
Bradshaw	MCDOWELL	8	$73,600	0	$0	4	$17,700
Davy	MCDOWELL	12	$93,100	0	$0	1	$0
Gary	MCDOWELL	6	$35,400	0	$0	3	$0
Iaeger	MCDOWELL	28	$125,650	3	$7,100	17	$126,600
Keystone	MCDOWELL	32	$309,500	0	$0	7	$27,250
Kimball	MCDOWELL	17	$161,100	0	$0	2	$0
McDowell County*	MCDOWELL	539	$2,465,681	19	$128,787	208	$436,801
Northfork	MCDOWELL	37	$231,500	0	$0	10	$21,200
War	MCDOWELL	20	$127,700	1	$8,250	11	$11,200
Welch	MCDOWELL	158	$2,090,370	10	$281,607	39	$812,967
	MCDOWELL	**866**	**$5,766,401**	**33**	**$425,743**	**306**	**$1,453,718**
Athens	MERCER	1	$37,100	2	$68,500	0	$0
Bluefield	MERCER	368	$12,499,652	20	$1,226,287	70	$4,680,759
Bramwell	MERCER	7	$66,200	0	$0	2	$0
Mercer County*	MERCER	385	$10,192,915	15	$296,333	115	$392,211
Oakvale	MERCER	3	$18,200	0	$0	1	$0
Princeton	MERCER	3	$197,750	0	$0	0	$0
	MERCER	**767**	**$23,011,817**	**37**	**$1,591,120**	**188**	**$5,072,970**
Alderson**	MONROE	2	$34,500	0	$0	0	$0
Monroe County*	MONROE	39	$1,841,383	2	$174,100	23	$1,091,667
Peterstown	MONROE	0	$0	0	$0	0	$0
Union	MONROE	1	$29,900	0	$0	0	$0
	MONROE	**42**	**$1,905,783**	**2**	**$174,100**	**23**	**$1,091,667**
Beckley	RALEIGH	159	$7,373,407	15	$1,552,417	10	$66,000
Lester	RALEIGH	0	$0	0	$0	0	$0
Mabscott	RALEIGH	10	$517,450	1	$240,100	2	$150
Raleigh County*	RALEIGH	282	$9,293,391	30	$1,407,260	173	$723,014
Rhodell	RALEIGH	0	$0	0	$0	0	$0
Sophia	RALEIGH	6	$113,900	0	$0	1	$0
	RALEIGH	**457**	**$17,298,148**	**46**	**$3,199,777**	**186**	**$789,164**
Hinton	SUMMERS	69	$1,535,383	0	$0	12	$26,600
Summers County*	SUMMERS	172	$4,555,230	15	$2,487,198	75	$74,612
	SUMMERS	**241**	**$6,090,614**	**15**	**$2,487,198**	**87**	**$101,212**
Mullens	WYOMING	0	$0	0	$0	0	$0
Oceana	WYOMING	0	$0	0	$0	0	$0
Pineville	WYOMING	7	$164,600	1	$87,100	3	$1,155,967
Wyoming County*	WYOMING	125	$1,266,369	2	$775	55	$3,595,364
	WYOMING	**132**	**$1,430,969**	**3**	**$87,875**	**58**	**$4,751,331**

Total in Alderson	GREENBRIER & MONROE	3	$62,700	0	$0	0	$0

* Unincorporated
** 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.

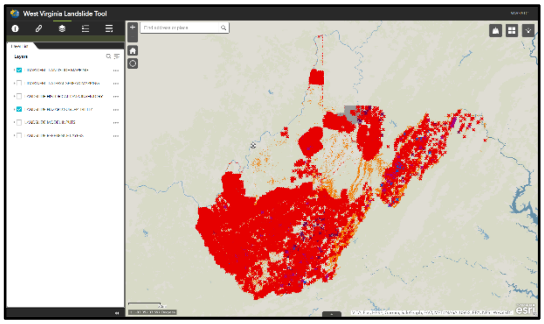

Figure 10. *West Virginia Landslide Tool*

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

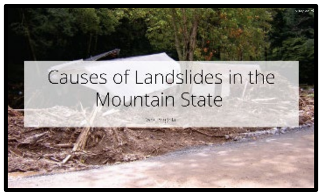

Figure 11. *Story Map showing causes of landslide*

  - ***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.

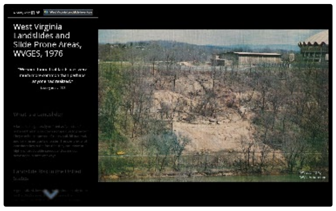

Figure 12. *WVGES 1976 Study details in Story Map*

- **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 Raleigh, Summers, Monroe, Mercer, McDowell, and Wyoming counties can be viewed and downloaded here.

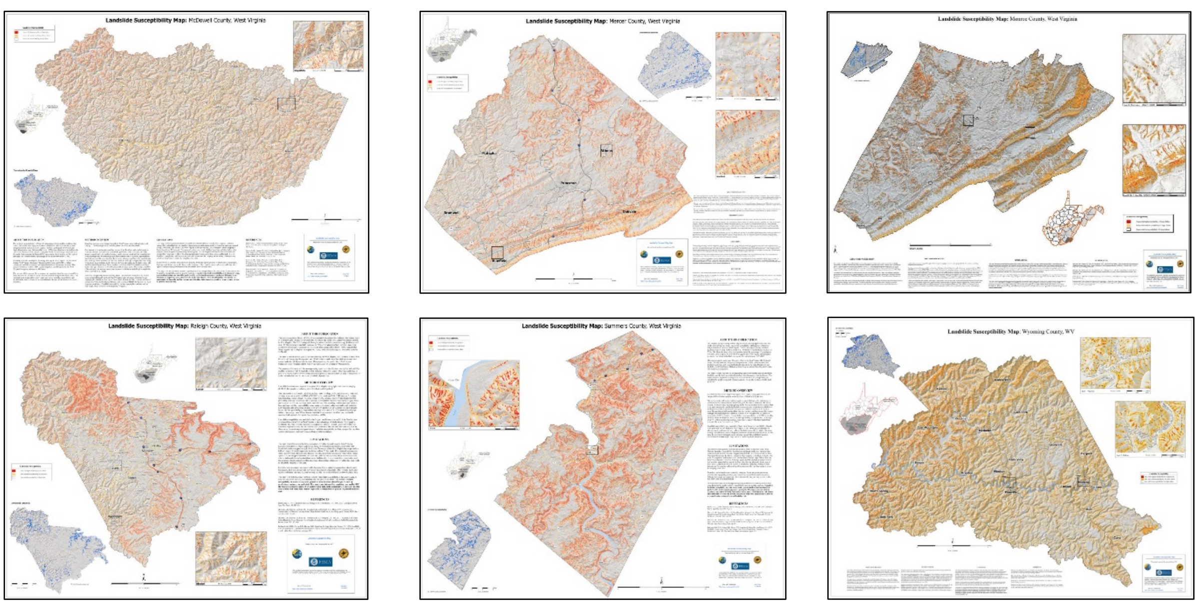

Figure 14. *Landslide Susceptibility maps of Raleigh, Summers, Monroe, Mercer, McDowell, and Wyoming counties.*

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