Mudslide along Route-7 in Hardy County
Photo from WHSV

West Virginia Landslide Risk Assessment

Region 8 – Mineral, Hampshire, Hardy, Pendleton, & Grant counties

FEBRUARY 10, 2022

In support of FEMA HMGP Project

FEMA

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, 1,478 landslide points were identified using LiDAR in Region 8. 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 8 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 8, **Grant County** has about 38 miles of road that is susceptible to high/medium probability of landslides. **Hampshire County** has about 45 miles, **Hardy County** has almost 33 miles, **Mineral County** has 45 miles, and **Pendleton County** has almost 86 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, Grant ranks 45th, Hampshire 41st, Hardy 46th, Mineral 42nd, and Pendleton 24th. Most of the at-risk roads are in the unincorporated areas of each county.

Structure/Parcel analysis - **Grant County** has a total of 177 primary structures with a total appraisal value of $10,668,180 that are in high/medium susceptibility areas. **Hampshire County** has 402 primary structures with a total appraisal value of $30,402,706 in high/medium susceptibility areas. **Hardy County** has 399 primary structures with a total appraisal value of $19,721,868 in high/medium susceptibility areas. **Mineral County** has a total of 351 primary structures with a total appraisal value of $34,302,956 that are in high/medium susceptibility areas. **Pendleton County** has 268 primary structures with a total appraisal value of $16,676,265 in high/medium susceptibility areas. Counties were ranked by the total count of primary structures in high/medium landslide risk areas and by the total asset value in high/medium landslide risk areas. Two Region 8 counties (Hampshire and Hardy) rank in the Top 20 for highest structure count and three counties (Hampshire, Hardy, and Mineral) rank in the Top 20 for highest asset value at risk. For total count of at-risk structures, Grant ranks 48th, Hampshire 19th, Hardy 20th, Mineral 26th, and Pendleton 38th. For total asset value, Grant ranks 31st, Hampshire 14th, Hardy 20th, Mineral 11th, and Pendleton 24th.

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 8 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.

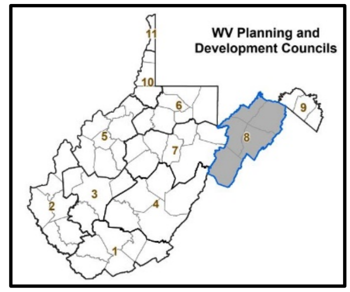

Figure 1. *Planning and development regions in West Virginia*

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

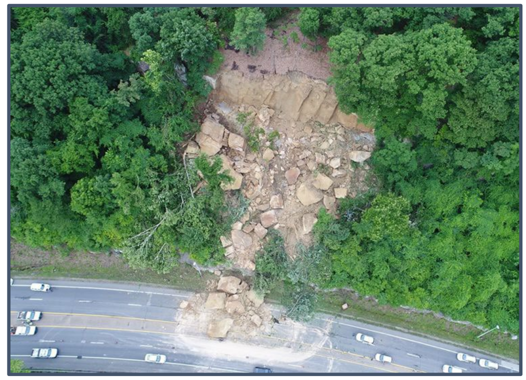

Figure 3. *The* ***consequences*** *of a landslide are often higher in populated areas due to resulting property damage and injury to citizens (Photo by WVDOT)*

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 no landslide polygons for Region 8.

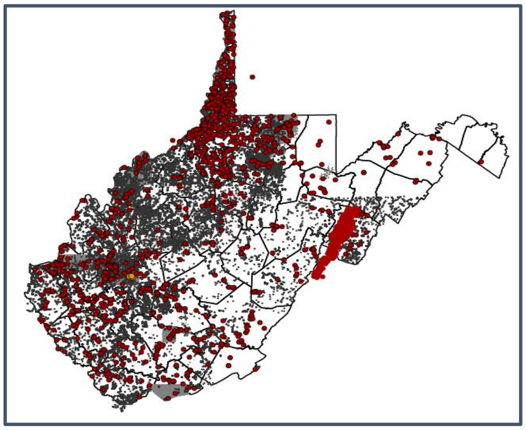

Figure 4. *Historical landslides were compiled from several studies to create a comprehensive landslide dataset (Image adapted from the West Virginia Landslide Tool)*

- **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 1,199 polygons from Region 8.

- **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. During this study, 2,996 landslides were mapped in Region 8.

- **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 39 landslide points in Region 8 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, 1,478 landslide points were identified in Region 8.

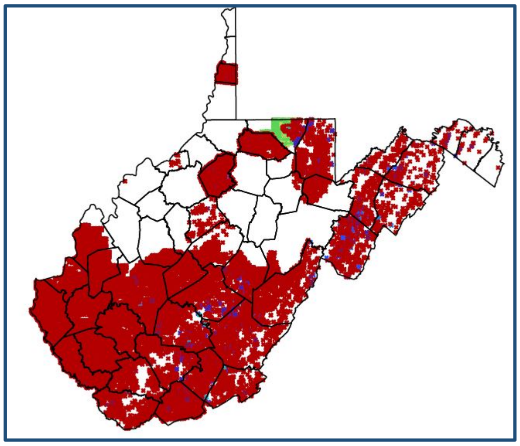

Figure 5. *LiDAR-mapped landslide points are dependent upon the presence of 1- or 2-meter LiDAR data (Image from the West Virginia Landslide Tool)*

Landslide Susceptibility Methodology

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

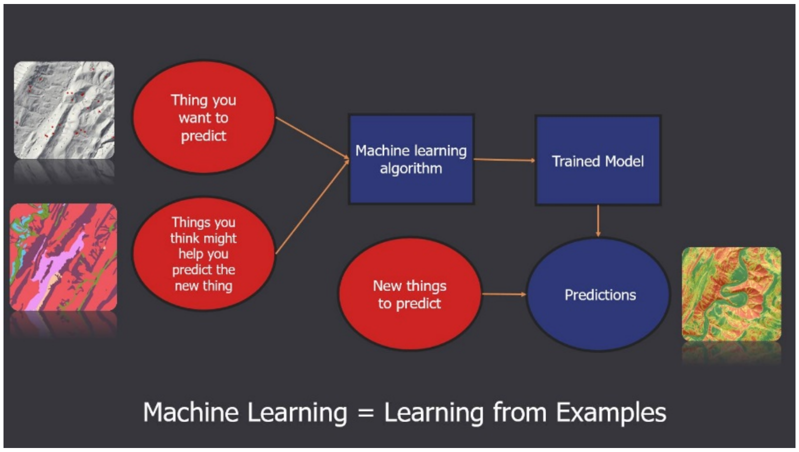

Figure 6. *Simplified diagram showing machine learning process for generating landslide susceptibility grid*

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).

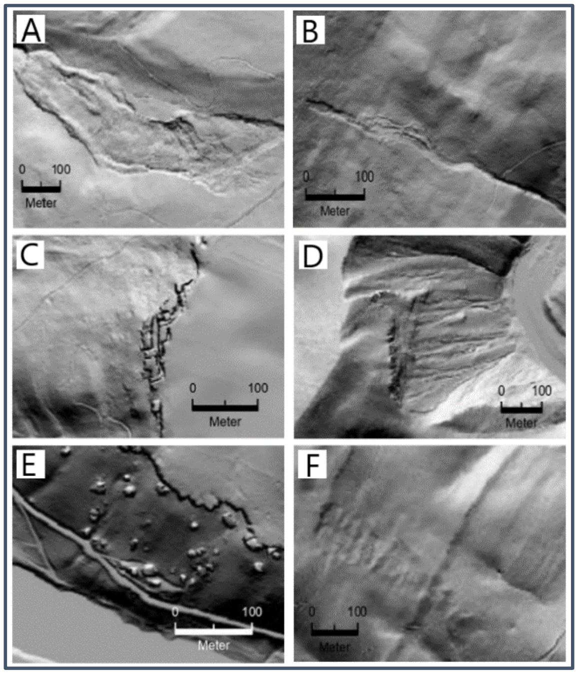

Figure 7. *A) Slide B) Debris Flow C) Lateral Spread D) Multiple Failures E) Fall F) Undetermined*

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. Two MLRAs are present in Region 8: the **Northern Appalachian Ridges and Valleys** and the northern portion of the **Eastern Allegheny Plateau and Mountains** (Figure 8). The Northern Appalachian Ridges and Valleys MLRA covers all of Hampshire and Hardy counties, and most of Pendleton, Grant, and Mineral counties. The Eastern Allegheny Plateau and Mountains MLRA covers the western edge of Pendleton, Grant, and Mineral counties.

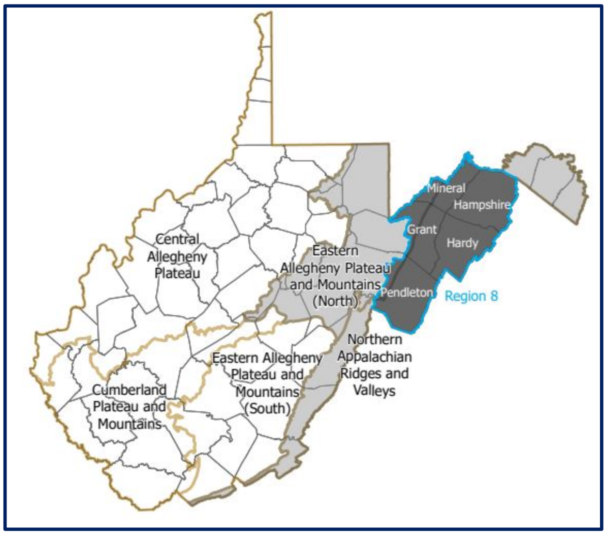

Figure 8. *Major land resource areas in West Virginia*

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 8 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 **Northern Appalachian Ridges and Valleys** MLRA has very diverse topography, geology, and soils. These factors contribute to higher variability in landslide distribution and a wider variety of landslide types than in any other MLRA in West Virginia. This MLRA encompasses most of the gentle topography in the state, and LiDAR-based mapping reveals the MLRA has fewer landslides. It is an erosional landscape underlain by folded and faulted bedrock with varied resistance to weathering and erosion. Hard, resistant bedrock units, primarily composed of quartz-rich sandstone, form parallel linear ridges, separated by valleys underlain by more erodible shale, siltstone, and limestone. Slope failures are most common on the steep flanks of ridges but less common on ridge crests; landslides rarely initiate on flat land, but large landslides may extend from steep slopes onto valley bottoms.

The **Eastern Allegheny Plateau and Mountains** MLRA is dominated by rugged topography, clastic sedimentary bedrock, and well-drained soils. Over two-thirds of the MLRA in West Virginia is underlain by substantially folded bedrock with gently to steeply dipping beds at many locations, including much of the Cheat and Tygart Valley river basins and the Allegheny Front along the eastern border of the MLRA. Two non-coal bearing bedrock units have the highest landslide susceptibility, but unconsolidated material produced by mining is locally significant and associated with landslides.

In both Region 8 MLRAs, 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. 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.

Landslide Characteristics and Contributing Factors

Slides and **slumps** are the most common landslide types in the region. 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.* 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 region, 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 Eastern Allegheny Plateau and Mountains 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 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 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. **In the Northern Appalachian Ridges and Valleys, almost ninety percent of mapped slides and slumps initiated on slopes greater than 20°, while about eighty percent of debris flows initiated on slopes between 25° to 45°. In the Eastern Allegheny Plateau and Mountains, about eighty percent of slides and slumps initiated on slopes between 21° to 40°, while about eighty percent of debris flows initiated on slopes of 17° to 46°.**

Geology: Geology is a universally cited factor in landslide distribution, and this is the case for Region 8. 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 Eastern Allegheny Plateau and Mountains MLRA, weaker bedrock units, like shale and siltstone, tend to be more deeply incised and more prone to failure than resistant sandstone units, even where the weaker units contain some significant sandstone beds. However, in the Northern Appalachian Ridges and Valleys, the highest mapped landslide density occurs in sandstone-dominated units.

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 West Virginia. Over 90 percent of landslides in Region 8 initiated in residuum or colluvium. In the Northern Appalachian Ridges and Valleys, the highest mapped landslide density occurs in acid clastic residuum. However, in the Eastern Allegheny Plateau and Mountains, the landslide density is highest in mining regolith and calcareous clastic residuum.

In the Northern Appalachian Ridges and Valleys, soil polygons assigned as “somewhat excessively drained” cover about 85 percent of the landscape and account for almost 95 percent of landslide initiation points. In the Eastern Allegheny Plateau and Mountains, soil polygons assigned as “well drained” cover about 67 percent of the MLRA, account for almost 82 percent of landslide initiation points, and have the second highest landslide susceptibility. “Excessively drained” soils cover 10 percent of the area, contain the second highest number of landslides, and have the highest landslide susceptibility of any class. **All of these drainage classes commonly occur on steep slopes, so their over-representation in landslides may reflect the important role of slope as a control of both soil drainage and landslide initiation.**

Other Landslide Factors: Anthropogenic disturbance can be significant, especially in landscapes underlain by coal-bearing bedrock. Unreclaimed coal mine high walls and limestone quarries have local rock-fall susceptibility, but falls elsewhere in the area are most commonly associated with over-steepened road and railroad cuts.

Forest products are part of the economy in some Region 8 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. 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 Mineral, Hampshire, Hardy, Pendleton, & Grant 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 8.

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**. Grant County** has about 38 miles of road that is susceptible to high/medium probability of landslides. **Hampshire County** has about 45 miles, **Hardy County** has almost 33 miles, **Mineral County** has 45 miles, and **Pendleton County** has almost 86 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, Grant ranks 45th, Hampshire 41st, Hardy 46th, Mineral 42nd, and Pendleton 24th. Most of the at-risk roads are in the unincorporated areas of each county. Figure 9 shows an example of landslide risk along US-33 near Franklin, WV in Pendleton 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]
Bayard	GRANT	1.3	0.1	155
Grant County*	GRANT	433.5	38.1	45
Petersburg	GRANT	7.1	0.1	155
	GRANT	**441.9**	**38.3**	**45**
Capon Bridge	HAMPSHIRE	3.8	0.6	63
Hampshire County*	HAMPSHIRE	734.8	44.7	39
Romney	HAMPSHIRE	4.2	0	189
	HAMPSHIRE	**742.8**	**45.3**	**41**
Hardy County*	HARDY	559.3	32.1	46
Moorefield	HARDY	17	0.5	68
Wardensville	HARDY	1.8	0.1	155
	HARDY	**578.1**	**32.7**	**46**
Carpendale	MINERAL	2.3	0.2	127
Elk Garden	MINERAL	1.2	0	189
Keyser	MINERAL	11.7	0.2	127
Mineral County*	MINERAL	412.9	44.2	40
Piedmont	MINERAL	1.6	0.4	85
Ridgeley	MINERAL	1.5	0	189
	MINERAL	**431.2**	**45**	**42**
Franklin	PENDLETON	6.6	0.1	155
Pendleton County*	PENDLETON	634.8	85.7	22
	PENDLETON	**641.4**	**85.8**	**24**

* Unincorporated

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

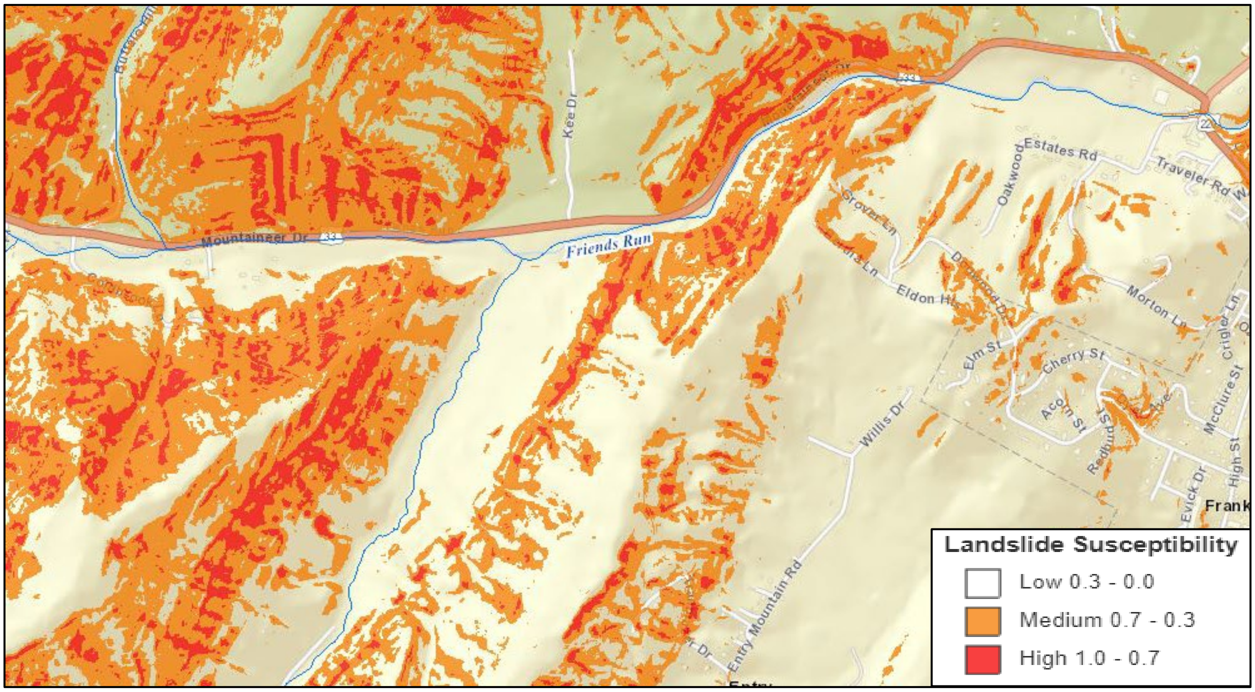

Figure 9. *Landslide Susceptibility near Franklin, WV in Pendleton County. Notice high and medium landslide susceptibility areas along US-33 (Mountaineer Drive). Data can be accessed on* *WV Flood Tool*

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 **Grant County**, the unincorporated area has 38.1 miles of at-risk roads, constituting over 99% of at-risk roads in the county; 10 miles of US roads and 6.5 miles of State roads are at risk. Bayard and Petersburg each have 0.1 miles of road at risk. There are no Interstate roads at risk in Grant County. **Hampshire County** has 44.7 miles of at-risk roads in unincorporated areas, constituting almost 99% of at-risk roads in the county. Unincorporated areas have 5.7 miles of US roads at risk and 4.5 miles of State roads at risk. Capon Bridge has 0.6 miles of road at risk and Romney has none. There are no Interstate roads at risk in Hampshire County. **Hardy County** has 32.1 miles of at-risk roads in unincorporated areas, accounting for 98% of at-risk roads in the county. Unincorporated areas have 4.1 miles of US roads and 2 miles of State roads at risk. Moorefield has 0.5 miles of road at risk and Wardensville has 0.1 miles. There are no Interstate roads at risk in Hardy County. **Mineral County** has 44.2 miles of at-risk roads in unincorporated areas, constituting 98% of at-risk roads in the county. The unincorporated area has 7.2 miles of US roads and 14.6 miles of State roads at risk. The incorporated communities each have less than 1 mile of road at risk. There are no at-risk roads in Elk Garden or Ridgeley. There are no Interstate roads at risk in Mineral County. **Pendleton County** has 85.7 miles of at-risk roads in unincorporated areas, constituting over 99% of at-risk roads in the county. The unincorporated area has 32.2 miles of US roads and 2.5 miles of State roads at risk. Franklin has 0.1 miles of road at risk. There are no Interstate roads at risk in Pendleton 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
Bayard	GRANT	1.3	0.1	0	0	0.1	0
Grant County*	GRANT	433.5	38.1	0	10	6.5	21.5
Petersburg	GRANT	7.1	0.1	0	0	0.1	0
	GRANT	**441.9**	**38.3**	**0**	**10**	**6.7**	**21.5**
Capon Bridge	HAMPSHIRE	3.8	0.6	0	0.3	0	0.3
Hampshire County*	HAMPSHIRE	734.8	44.7	0	5.7	4.5	34.5
Romney	HAMPSHIRE	4.2	0	0	0	0	0
	HAMPSHIRE	**742.8**	**45.3**	**0**	**6**	**4.5**	**34.8**
Hardy County*	HARDY	559.3	32.1	0	4.1	2	26.1
Moorefield	HARDY	17	0.5	0	0.3	0.1	0.1
Wardensville	HARDY	1.8	0.1	0	0	0.1	0
	HARDY	**578.1**	**32.7**	**0**	**4.4**	**2.2**	**26.2**
Carpendale	MINERAL	2.3	0.2	0	0	0	0.2
Elk Garden	MINERAL	1.2	0	0	0	0	0
Keyser	MINERAL	11.7	0.2	0	0	0.1	0.1
Mineral County*	MINERAL	412.9	44.2	0	7.2	14.6	22.3
Piedmont	MINERAL	1.6	0.4	0	0	0.2	0.2
Ridgeley	MINERAL	1.5	0	0	0	0	0
	MINERAL	**431.2**	**45**	**0**	**7.2**	**14.9**	**22.8**
Franklin	PENDLETON	6.6	0.1	0	0.1	0	0.1
Pendleton County*	PENDLETON	634.8	85.7	0	32.2	2.5	51
	PENDLETON	**641.4**	**85.8**	**0**	**32.3**	**2.5**	**51.1**

* Unincorporated

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. **Grant County** has a total of 177 primary structures with a total appraisal value of $10,668,180 that are in high/medium susceptibility areas. **Hampshire County** has 402 primary structures with a total appraisal value of $30,402,706 in high/medium susceptibility areas. **Hardy County** has 399 primary structures with a total appraisal value of $19,721,868 in high/medium susceptibility areas. **Mineral County** has a total of 351 primary structures with a total appraisal value of $34,302,956 that are in high/medium susceptibility areas. **Pendleton County** has 268 primary structures with a total appraisal value of $16,676,265 in high/medium susceptibility areas. Counties were ranked by the total count of primary structures in high/medium landslide risk areas and by the total asset value in high/medium landslide risk areas. Two Region 8 counties (Hampshire and Hardy) rank in the Top 20 for highest structure count and three counties (Hampshire, Hardy, and Mineral) rank in the Top 20 for highest asset value at risk. For total count of at-risk structures, Grant ranks 48th, Hampshire 19th, Hardy 20th, Mineral 26th, and Pendleton 38th. For total asset value, Grant ranks 31st, Hampshire 14th, Hardy 20th, Mineral 11th, and Pendleton 24th.

***Table 3**. Structures with High/Medium Risk Landslide Susceptibility*

Community Name	County	Total Count	Total Value	Ranking(Count)[1]	Ranking(Value)[1]
Bayard	GRANT	2	$0	164	191
Grant County*	GRANT	165	$6,616,738	42	34
Petersburg	GRANT	10	$4,051,442	94	19
	GRANT	**177**	**$10,668,180**	**48**	**31**
Capon Bridge	HAMPSHIRE	7	$248,900	118	99
Hampshire County*	HAMPSHIRE	385	$29,629,609	15	12
Romney	HAMPSHIRE	10	$524,197	94	74
	HAMPSHIRE	**402**	**$30,402,706**	**19**	**14**
Hardy County*	HARDY	395	$19,388,118	13	16
Moorefield	HARDY	2	$98,850	164	142
Wardensville	HARDY	2	$234,900	164	101
	HARDY	**399**	**$19,721,868**	**20**	**20**
Carpendale	MINERAL	5	$115,600	129	133
Elk Garden	MINERAL	0	$0	195	191
Keyser	MINERAL	30	$3,010,100	47	25
Mineral County*	MINERAL	250	$29,948,056	28	11
Piedmont	MINERAL	38	$422,150	41	82
Ridgeley	MINERAL	28	$807,050	50	57
	MINERAL	**351**	**$34,302,956**	**26**	**11**
Franklin	PENDLETON	11	$516,589	89	75
Pendleton County*	PENDLETON	257	$16,159,676	26	19
	PENDLETON	**268**	**$16,676,265**	**38**	**24**

* Unincorporated

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

Table 4 shows detailed risk of slope failure based on different occupancy classes. For all Region 8 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.

Grant County has 116 structures in the Residential occupancy class with replacement costs of $5,774,942, followed by 48 Other structures, and 13 Commercial structures with a total replacement cost of $3,907,115. The unincorporated area has the highest structure counts in all occupancy classes and the highest replacement costs in the Residential class, while Petersburg has the highest replacement costs in the Commercial class.

Hampshire County has a total of 316 structures in the Residential occupancy class with replacement costs of $23,612,212, followed by 78 Other structures, and 8 Commercial structures with replacement costs of $274,476. The unincorporated area has the highest structure counts and replacements costs in the Residential and Other occupancy classes, but Capon Bridge has the highest counts and replacement costs in the Commercial class.

Hardy County has a total of 219 structures in the Residential occupancy class with replacement costs of $13,574,004 and 180 structures in the Other occupancy class. There are no Commercial structures at risk in Hardy County. The unincorporated area has the highest structure counts and corresponding replacement costs in the Residential and Other occupancy classes.

Mineral County has a total of 270 structures in the Residential occupancy class with replacement costs of $20,074,852, followed by 65 Other structures, and 16 Commercial structures with replacement costs of $12,813,638. The unincorporated area has the highest replacement costs in the Residential and Commercial occupancy classes and the highest structure counts in the Residential and Other classes. Keyser has the highest structure count in the Commercial class, but only represents about 2% of total Commercial replacement costs. There are no at-risk structures in Elk Garden.

Pendleton County has a total of 173 structures in the Residential occupancy class with replacement costs of $10,943,665, followed by 85 Other structures, and 10 Commercial structures with replacement costs of $553,500. The unincorporated area has the highest structure counts and corresponding replacement costs in all occupancy 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**
Bayard	GRANT	1	$0	0	$0	1	$0
Grant County*	GRANT	109	$5,341,633	9	$288,982	47	$986,123
Petersburg	GRANT	6	$433,309	4	$3,618,133	0	$0
	GRANT	**116**	**$5,774,942**	**13**	**$3,907,115**	**48**	**$986,123**
Capon Bridge	HAMPSHIRE	2	$56,000	5	$192,900	0	$0
Hampshire County*	HAMPSHIRE	309	$23,213,315	3	$81,576	73	$6,334,718
Romney	HAMPSHIRE	5	$342,897	0	$0	5	$181,300
	HAMPSHIRE	**316**	**$23,612,212**	**8**	**$274,476**	**78**	**$6,516,018**
Hardy County*	HARDY	216	$13,292,604	0	$0	179	$6,095,514
Moorefield	HARDY	1	$46,500	0	$0	1	$52,350
Wardensville	HARDY	2	$234,900	0	$0	0	$0
	HARDY	**219**	**$13,574,004**	**0**	**$0**	**180**	**$6,147,864**
Carpendale	MINERAL	3	$115,600	0	$0	2	$0
Elk Garden	MINERAL	0	$0	0	$0	0	$0
Keyser	MINERAL	20	$1,917,250	7	$297,300	3	$795,550
Mineral County*	MINERAL	200	$16,901,202	5	$12,470,738	45	$576,117
Piedmont	MINERAL	25	$367,150	2	$37,300	11	$17,700
Ridgeley	MINERAL	22	$773,650	2	$8,300	4	$25,100
	MINERAL	**270**	**$20,074,852**	**16**	**$12,813,638**	**65**	**$1,414,467**
Franklin	PENDLETON	5	$377,489	2	$31,000	4	$108,100
Pendleton County*	PENDLETON	168	$10,566,176	8	$522,500	81	$5,071,000
	PENDLETON	**173**	**$10,943,665**	**10**	**$553,500**	**85**	**$5,179,100**

* Unincorporated
**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.

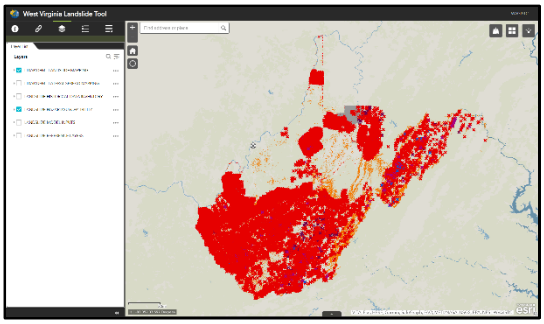

Figure 10. *West Virginia Landslide Tool*

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

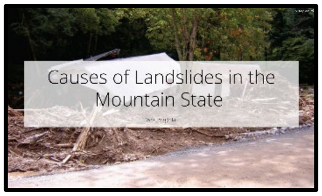

Figure 11. *Story Map showing causes of landslide*

  - ***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.

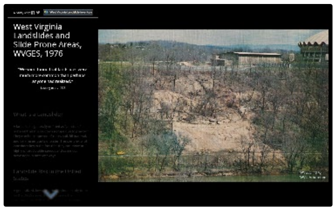

Figure 12. *WVGES 1976 Study details in Story Map*

- **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 Mineral, Hampshire, Hardy, Pendleton, & Grant counties can be viewed and downloaded here.

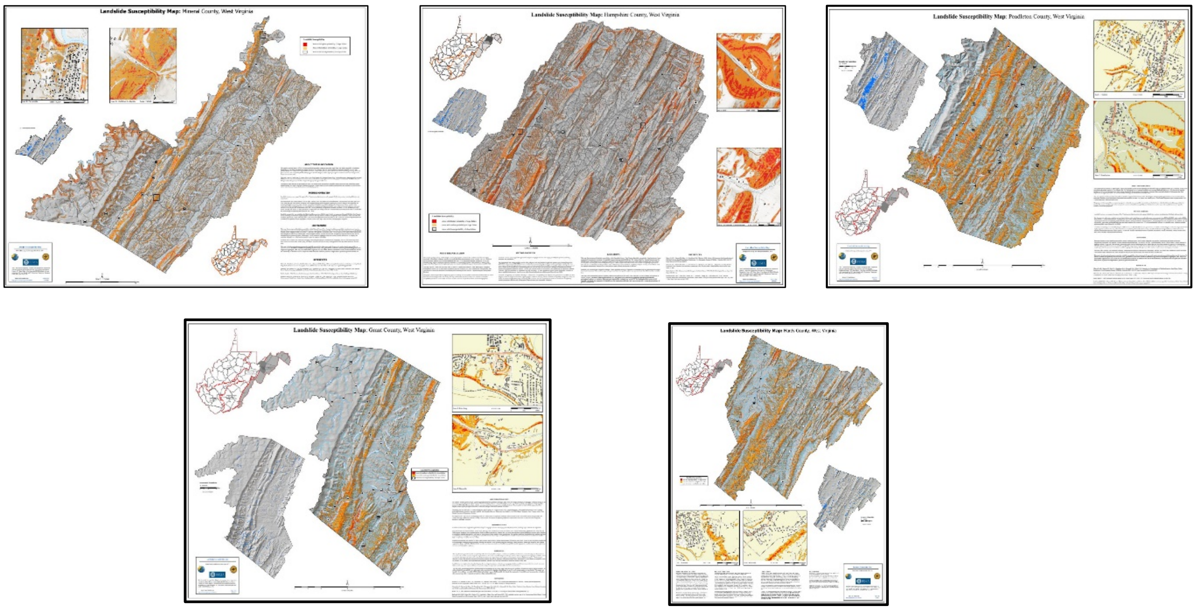

Figure 14. *Landslide Susceptibility maps of Mineral, Hampshire, Hardy, Pendleton, & Grant counties*

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