Landslide along WV-82 in Nicholas County

West Virginia Landslide Risk Assessment

Region 4 – Webster, Pocahontas, Greenbrier, Fayette, & Nicholas counties

FEBRUARY 10, 2022

In support of FEMA HMGP Project

Executive Summary

The West Virginia Emergency Management Division (WVEMD), Department of Homeland Security (DHS), and Federal Emergency Management Agency (FEMA) have facilitated landslide susceptibility studies and community-based risk assessments in support of local and state hazard mitigation plans. Landslide susceptibility was modeled using a random forest machine learning method. The model used LiDAR-identified landslide locations, topography, soil type, and proximity to roads and streams among many input variables to produce landslide susceptibility grids. Overall, 9,172 landslide points were identified using LiDAR in Region 4. 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 4 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 4, **Fayette County** has approximately 96 miles of road that is susceptible to high/medium probability of landslides. **Greenbrier County** has almost 110 miles, **Nicholas County** has 46 miles, **Pocahontas County** has about 119 miles, and **Webster County** has nearly 105 miles of road prone to high/medium risk for slope failure. Several Region 4 counties rank in the Top 20 for highest number of road miles at risk from landslides in the state. Of all 55 counties, Fayette County ranks 19th, Greenbrier 12th, Nicholas 41st, Pocahontas 11th, and Webster 18th.

Structure/Parcel analysis - **Fayette County** has a total of 305 primary structures with a total appraisal value of $17,653,817 that are in high/medium susceptibility areas. **Greenbrier County** has 281 primary structures with a total appraisal value of $61,943,791 in high/medium susceptibility areas. **Nicholas County** has 282 primary structures with a total appraisal value of $5,033,059 in high/medium susceptibility areas. **Pocahontas County** has 219 primary structures with a total appraisal value of $18,129,847 in high/medium susceptibility areas. **Webster County** has 214 primary structures with a total appraisal value of $1,795,466 in high/medium susceptibility areas. Fayette County ranks 32nd, Greenbrier 35th, Nicholas 34th, Pocahontas 42nd, and Webster 43rd for total number of at-risk structures in WV counties. For the value of total assets at high or medium risk of landslides, Fayette County ranks 23rd, Greenbrier 6th, Nicholas 46th, Pocahontas 21st, and Webster 51st. Fayette, Greenbrier, and Pocahontas counties have higher rankings for total asset value at risk than for the total number of structures at risk. This may be due to higher property values in these counties.

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 4 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.

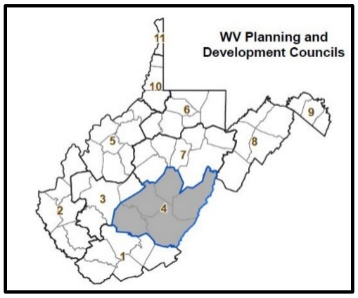

Figure 1. *Planning and development regions in West Virginia*

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

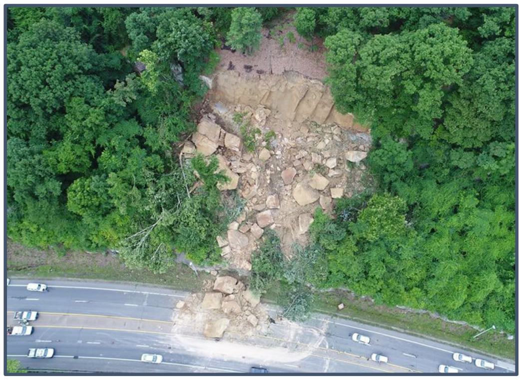

Figure 3. *The* ***consequences*** *of a landslide are often higher in populated areas due to resulting property damage and injury to citizens (Photo by WVDOT)*

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 published data from Region 4.

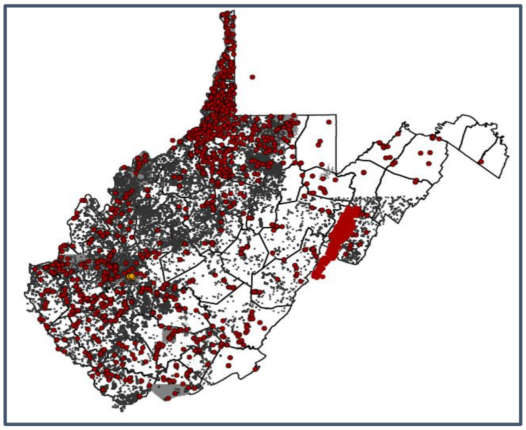

Figure 4. *Historical landslides were compiled from several studies to create a comprehensive landslide dataset (Image adapted from the West Virginia Landslide Tool)*

- **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 1,858 polygons from Region 4.

- **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. 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 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 125 landslide points in Region 4 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, 9,172 landslide points were identified in Region 4.

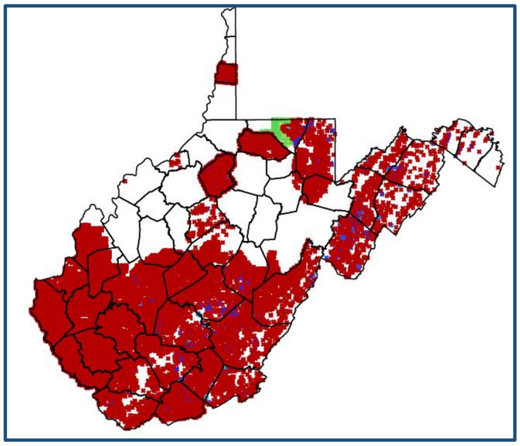

Figure 5. *LiDAR-mapped landslide points are dependent upon the presence of 1- or 2-meter LiDAR data (Image from the West Virginia Landslide Tool)*

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:

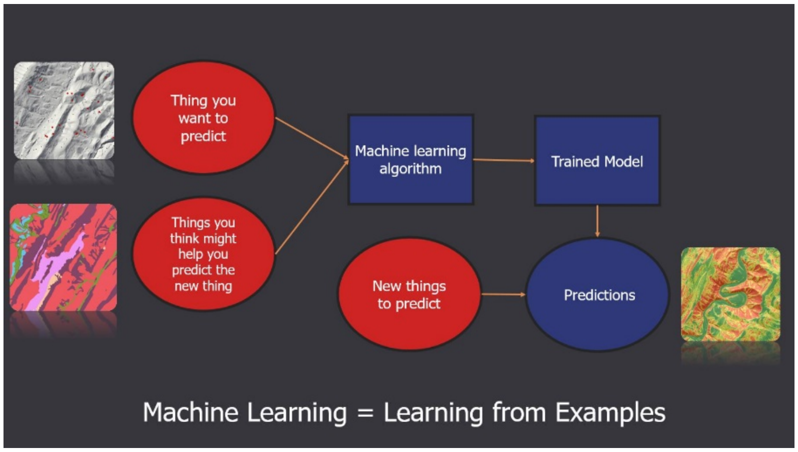

Figure 6. *Simplified diagram showing machine learning process for generating landslide susceptibility grid*

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

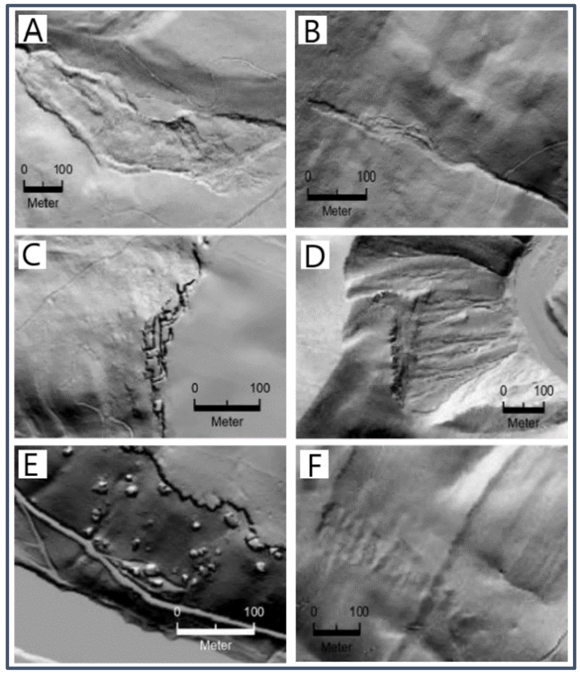

Figure 7. *A) Slide B) Debris Flow C) Lateral Spread D) Multiple Failures E) Fall F) Undetermined*

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. Three different MLRAs are present in Region 4 (see Figure 8): the **Eastern Allegheny Plateau and Mountains** (which is broken into Northern and Southern sections for this analysis) accounts for the largest portion of Region 4 and is present in western Pocahontas and Greenbrier counties and in eastern Webster, Nicholas, and Fayette counties; the **Cumberland Plateau and Mountains**, which is present in western Webster, Nicholas, and Fayette counties; and the **Northern Appalachian Ridges and Valleys**, which is present in eastern Pocahontas and Greenbrier counties.

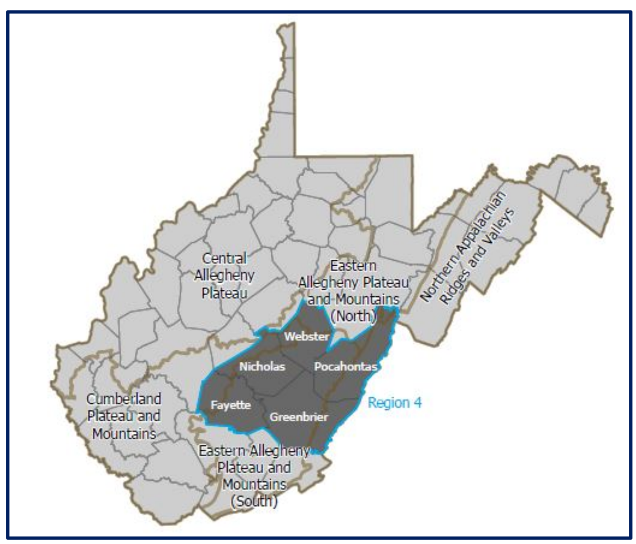

Figure 8. *Major land resource areas in West Virginia*

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 detailed MLRA characteristics for Region 4 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 4 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.

The Northern Appalachian Ridges and Valleys MLRA, present along the eastern border of Region 4, 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 Northern Appalachian Ridges and Valleys.*

Landslide Characteristics and Contributing Factors

Slides and **slumps** are the most common landslide types in Region 4 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 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 Region 4 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 4. 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 Northern Appalachian Ridges and Valleys MLRA, 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 4 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 Northern Appalachian Ridges and Valleys MLRA, 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”, “somewhat excessively drained”, and “excessively drained” cover the majority of Region 4 MLRAs and account for the majority of landslide initiation points. Excessively drained soils are common in mining regolith but uncommon in other soil parent material. All of these drainage classes commonly occur on steep slopes, so the over-representation of landslides in these three 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 4 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 Northern Appalachian Ridges and Valleys MLRA may also present localized rockfall susceptibility.

Forest products are part of the economy in many of the Region 4 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 have 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 Fayette, Greenbrier, Nicholas, Pocahontas, and Webster 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 4.

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 road feature class as most landslides initiate on the side slopes of roads. An intersection between the buffered road layer and 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 buffer layer to identify high and medium risk road segments for each community.

Results:

Roads were analyzed at two scales. 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. Railroad 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. **Fayette County** has about 96 miles of road that is susceptible to high/medium probability of landslides. **Greenbrier County** has almost 110 miles, **Nicholas County** has about 46 miles, **Pocahontas County** has 119 miles, and **Webster County** has nearly 105 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. Several Region 4 counties rank in the Top 20 for highest number of road miles at risk from landslides in the state. Of all 55 counties, Fayette County ranks 19th, Greenbrier 12th, Nicholas 41st, Pocahontas 11th, and Webster 18th. In each county, most of the at-risk roads are in unincorporated areas. Figure 9 shows an example of landslide risk along Route 20 in Webster 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]
Fayette County*	FAYETTE	917.8	88.7	22
Ansted	FAYETTE	10.5	1.5	28
Fayetteville	FAYETTE	23	1.3	33
Gauley Bridge	FAYETTE	9.7	0.3	100
Meadow Bridge	FAYETTE	2.6	0	189
Montgomery**	FAYETTE	6.8	0.3	100
Mount Hope	FAYETTE	11	0.3	100
Oak Hill	FAYETTE	50.4	2.4	17
Pax	FAYETTE	4.4	0.2	127
Smithers**	FAYETTE	8.8	0	189
Thurmond	FAYETTE	1.2	1	45
	FAYETTE	**1042.6**	**95.8**	**19**
Greenbrier County*	GREENBRIER	1077	107	12
Alderson**	GREENBRIER	4.5	0.1	155
Falling Springs	GREENBRIER	2.2	0.3	100
Lewisburg	GREENBRIER	24.6	0.2	127
Quinwood	GREENBRIER	3.9	0.1	155
Rainelle	GREENBRIER	7.2	0.3	100
Ronceverte	GREENBRIER	9.1	1.6	27
Rupert	GREENBRIER	3.5	0	189
White Sulphur Springs	GREENBRIER	15	0.4	85
	GREENBRIER	**1145.6**	**109.9**	**12**
Nicholas County*	NICHOLAS	707.6	44	42
Richwood	NICHOLAS	10.3	1.4	31
Summersville	NICHOLAS	26.9	0.9	45
	NICHOLAS	**744.8**	**46.3**	**41**
Pocahontas County*	POCAHONTAS	688.2	114.3	11
Durbin	POCAHONTAS	5.1	1	39
Hillsboro	POCAHONTAS	3.2	0	189
Marlinton	POCAHONTAS	31.2	3.7	9
	POCAHONTAS	**727.7**	**119**	**11**
Webster County*	WEBSTER	476.4	104.1	17
Addison	WEBSTER	4.8	0.4	85
Camden-On-Gauley	WEBSTER	2	0.1	155
Cowen	WEBSTER	4.7	0	189
	WEBSTER	**487.9**	**104.6**	**18**

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

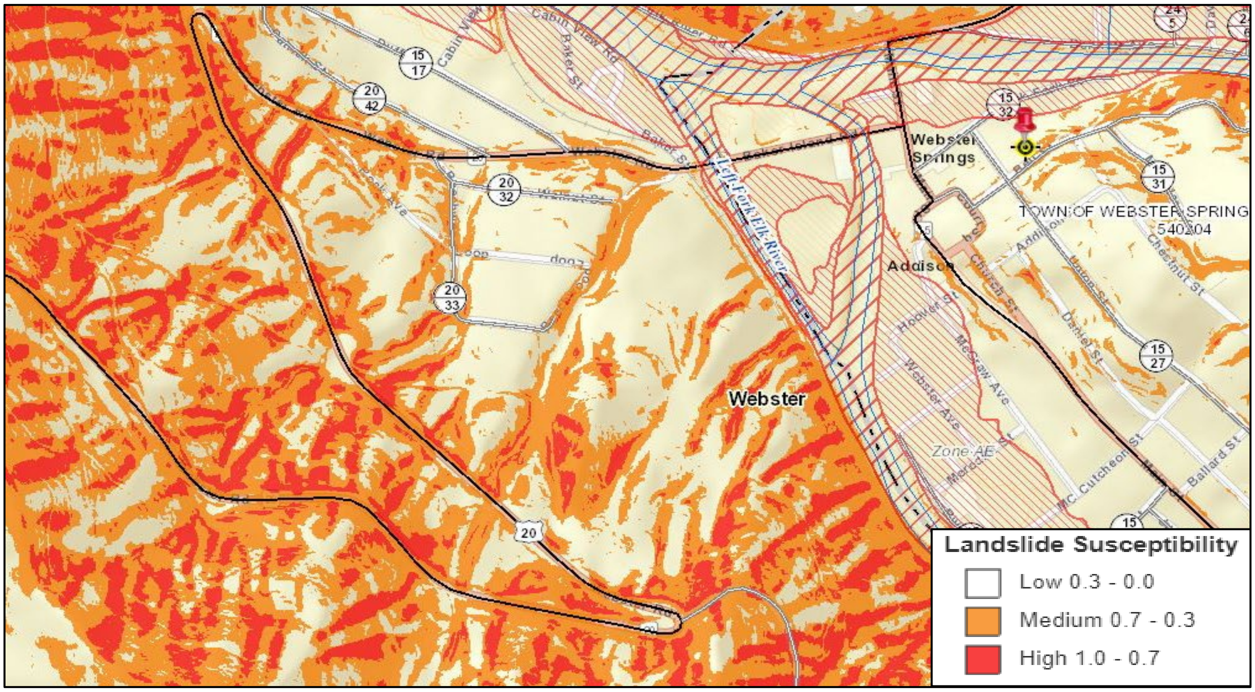

Figure 9. *Landslide Susceptibility in an unincorporated area near Addison, WV in Webster County. Notice high and medium susceptibility landslide areas along Route 20. Data can be accessed on* *WV Flood Tool*

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 **Fayette County**, the unincorporated area has 88.7 miles of at-risk roads, constituting 93% of at-risk roads in the county; 11.1 miles of US roads; and 8.5 miles of State roads are at-risk. Ansted has 1.5 miles of at-risk roads, Fayetteville has 1.3 miles, Oak Hill has 2.4 miles, and Thurmond has 1 mile. All other communities in Fayette County have less than 1 mile of at-risk roads. **Greenbrier County** has 107 miles of at-risk roads in unincorporated areas, constituting 97% of at-risk roads in the county. Unincorporated areas have 4.2 miles of Interstate roads at-risk, 14.6 miles of US roads, and 4.5 miles of State roads at-risk. Ronceverte has 1.6 miles of at-risk roads and the remaining communities have less than 1 mile each. In **Nicholas County**, the unincorporated area has 44 miles of at-risk roads, constituting 95% of at-risk roads in the county. The unincorporated area has 0.3 miles of US roads and 8.4 miles of State roads at risk. Richwood has a total of 1.4 road miles at risk and Summersville has 0.9. There are no Interstate roads at risk in Nicholas County. **Pocahontas County** has 114.3 miles of at-risk roads in unincorporated areas, constituting 96% of at-risk roads in the county. The unincorporated area has 21.5 miles of US roads at-risk and 17.3 miles of State roads at risk. Durbin has 1 mile of road at risk, Marlinton has 3.7 miles, and Hillsboro has no at-risk roads. No Interstate roads are at risk in the county. **Webster County** has 104.1 miles of at-risk roads in unincorporated areas, constituting 99% of at-risk roads in the county. The unincorporated area has 21.2 miles of State roads at risk, but no Interstate or US roads. The remaining communities have less than 1 mile of at-risk roads each. There are no Interstate or US roads at risk in Webster County.

Table 2. *Different road type and length susceptible to High/Medium Risk 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
Fayette County*	FAYETTE	917.8	88.7	0.8	11.1	8.5	68.2
Ansted	FAYETTE	10.5	1.5	0	0.6	0	0.9
Fayetteville	FAYETTE	23	1.3	0	0.1	0.3	0.8
Gauley Bridge	FAYETTE	9.7	0.3	0	0	0	0.3
Meadow Bridge	FAYETTE	2.6	0	0	0	0	0
Montgomery**	FAYETTE	3.4	0.1	0	0	0.1	0
Mount Hope	FAYETTE	11	0.3	0	0.1	0.1	0.2
Oak Hill	FAYETTE	50.4	2.4	0	0.2	0.4	1.8
Pax	FAYETTE	4.4	0.2	0.1	0	0	0.1
Smithers**	FAYETTE	8.6	0	0	0	0	0
Thurmond	FAYETTE	1.2	1	0	0	0	1
	FAYETTE	**1042.6**	**95.8**	**0.9**	**12.6**	**9.5**	**79.3**
Greenbrier County*	GREENBRIER	1077	107	4.2	14.6	4.5	83.8
Alderson**	GREENBRIER	3.1	0	0	0	0	0
Falling Springs	GREENBRIER	2.2	0.3	0	0	0	0.3
Lewisburg	GREENBRIER	24.6	0.2	0	0.1	0	0.1
Quinwood	GREENBRIER	3.9	0.1	0	0	0	0.1
Rainelle	GREENBRIER	7.2	0.3	0	0	0	0.3
Ronceverte	GREENBRIER	9.1	1.6	0	0.8	0.3	0.5
Rupert	GREENBRIER	3.5	0	0	0	0	0
White Sulphur Springs	GREENBRIER	15	0.4	0.3	0.1	0	0.1
	GREENBRIER	**1145.6**	**109.9**	**4.6**	**15.7**	**4.8**	**87.3**
Nicholas County*	NICHOLAS	707.6	44	0	0.3	8.4	35.3
Richwood	NICHOLAS	10.3	1.4	0	0	0.5	1
Summersville	NICHOLAS	26.9	0.9	0	0.1	0.1	0.6
	NICHOLAS	**744.8**	**46.3**	**0**	**0.4**	**9.1**	**38.6**
Pocahontas County*	POCAHONTAS	688.2	114.3	0	21.5	17.3	75.5
Durbin	POCAHONTAS	5.1	1	0	0.1	0	0.8
Hillsboro	POCAHONTAS	3.2	0	0	0	0	0
Marlinton	POCAHONTAS	31.2	3.7	0	2.4	0.1	1.2
	POCAHONTAS	**727.7**	**119**	**0**	**24.4**	**18.4**	**79.6**
Webster County*	WEBSTER	476.4	104.1	0	0	21.2	82.9
Addison	WEBSTER	4.8	0.4	0	0	0.1	0.3
Camden-On-Gauley	WEBSTER	2	0.1	0	0	0	0
Cowen	WEBSTER	4.7	0	0	0	0	0
	WEBSTER	**487.9**	**104.6**	**0**	**0**	**22.2**	**91.2**

*Unincorporated Community
**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 and 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 floodplain in each community. Verified primary structures located inside 1% annual chance floodplain were used as a point to assess landslide risk within a parcel. For primary structures in the rest of the area outside of 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. **Fayette County** has a total of 305 primary structures with a total appraisal value of $17,653,817 that are in high/medium susceptibility areas. **Greenbrier County** has 281 primary structures with total appraisal value of $61,943,791 in high/medium susceptibility areas. **Nicholas County** has 282 primary structures with a total appraisal value of $5,033,059 in high/medium susceptibility areas. **Pocahontas County** has 219 primary structures with a total appraisal value of $18,129,847 in high/medium susceptibility areas. **Webster County** has 214 primary structures with a total appraisal value of $1,795,466 in high/medium susceptibility areas. Fayette County ranked 32nd, Greenbrier 35th, Nicholas 34th, Pocahontas 42nd, and Webster 43rd for total number of at-risk structures in WV counties. For the value of total assets at high or medium risk of landslides, Fayette County ranks 23rd, Greenbrier 6th, Nicholas 46th, Pocahontas 21st, and Webster 51st. Fayette, Greenbrier, and Pocahontas counties have significantly higher rankings for total asset value at risk than for the total number of structures at risk. This may be due to higher property values in these counties.

***Table 3**. Structures susceptible to High/Medium Risk Landslide*

Community Name	County	Total Count	Total Value	Ranking(Count)[1]	Ranking(Value)[1]
Fayette County*	FAYETTE	199	$14,529,677	36	21
Ansted	FAYETTE	9	$156,783	104	119
Fayetteville	FAYETTE	7	$378,400	118	86
Gauley Bridge	FAYETTE	21	$343,850	56	90
Meadow Bridge	FAYETTE	0	$0	195	191
Montgomery**	FAYETTE	2	$7500	164	189
Mount Hope	FAYETTE	7	$129,600	118	127
Oak Hill	FAYETTE	46	$1,886,606	36	35
Pax	FAYETTE	0	$0	195	191
Smithers**	FAYETTE	1	$500	178	190
Thurmond	FAYETTE	15	$228,400	75	102
	FAYETTE	**305**	**$17,653,817**	**32**	**23**
Greenbrier County*	GREENBRIER	228	$60,296,899	32	3
Alderson**	GREENBRIER	3	$62,700	151	155
Falling Springs	GREENBRIER	0	$0	195	191
Lewisburg	GREENBRIER	10	$553,130	94	71
Quinwood	GREENBRIER	0	$0	195	191
Rainelle	GREENBRIER	3	$11,700	151	187
Ronceverte	GREENBRIER	24	$458,740	53	79
Rupert	GREENBRIER	0	$0	195	191
White Sulphur Springs	GREENBRIER	15	$595,121	75	67
	GREENBRIER	**281**	**$61,943,791**	**35**	**6**
Nicholas County*	NICHOLAS	180	$3,498,959	40	44
Richwood	NICHOLAS	85	$755,000	23	60
Summersville	NICHOLAS	17	$779,100	69	58
	NICHOLAS	**282**	**$5,033,059**	**34**	**46**
Pocahontas County*	POCAHONTAS	213	$17,920,547	34	18
Durbin	POCAHONTAS	1	$26,500	178	180
Hillsboro	POCAHONTAS	0	$0	195	191
Marlinton	POCAHONTAS	5	$182,800	129	111
	POCAHONTAS	**219**	**$18,129,847**	**42**	**21**
Webster County*	WEBSTER	188	$1,608,440	38	50
Addison	WEBSTER	14	$75,227	78	149
Camden-On-Gauley	WEBSTER	8	$73,700	111	150
Cowen	WEBSTER	4	$38,100	139	171
	WEBSTER	**214**	**$1,795,466**	**43**	**51**

*Unincorporated Community
**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 4 counties, the **Residential** occupancy class has the highest total replacement cost in high/medium landslide susceptibility areas. **Commercial** occupancy class is mostly second, followed by **Other** occupancy class structures. 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.

Fayette County is the only county in Region 4 where Commercial replacement costs exceed Residential replacement costs. There are 33 Commercial structures with a total replacement cost of $10,257,782 and 210 Residential structures with replacement costs of $6,969,372. There are also 62 Other occupancy class structures at high/medium risk of landslides. The unincorporated areas of Fayette County have the highest structure counts and corresponding replacement values in all occupancy classes. Meadow Bridge, Montgomery, and Pax have no at-risk structures.

Greenbrier County has a total of 207 structures in the Residential occupancy class with replacement costs of $59,810,011, followed by 62 Other structures, and 12 Commercial structures with replacement costs of $1,622,746. The unincorporated areas of Greenbrier County have the highest structure counts and corresponding replacement values in all occupancy classes. Falling Springs, Quinwood, and Rupert have no at-risk structures.

Nicholas County has a total of 183 structures in the Residential occupancy class with replacement costs of $3,273,458, followed by 86 Other structures, and 13 Commercial structures with replacement costs of $1,357,154. The unincorporated areas of Nicholas County have the highest structure counts and corresponding replacement costs in all occupancy classes. Richwood has the second highest Residential structure count, but Summersville has the second highest Residential replacement costs in the county.

Pocahontas County has a total of 169 structures in the Residential occupancy class with replacement costs of $17,007,600, followed by 49 Other structures, and 1 Commercial structure with a replacement cost of $212,894. The unincorporated area of Pocahontas County has the highest structure counts and corresponding replacement values and is the only community with at-risk structures in the Commercial or Other occupancy classes. There are no at-risk structures in Hillsboro.

Webster County has a total of 139 structures in the Residential occupancy class with replacement costs of $1,498,622, followed by 70 Other structures, and 5 Commercial structures with replacement costs of $181,683. The unincorporated areas of Webster County have the highest structure counts and corresponding replacement values in all occupancy classes. Camden-On-Gauley is the only community with no Commercial structures at risk, although Addison and Cowen have only 1 each.

Table 4. *Types of Structures susceptible to High/Medium Risk Landslide*

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***
Fayette County*	FAYETTE	135	$4,418,189	21	$9,874,027	43	$237,462
Ansted	FAYETTE	5	$120,633	3	$36,150	1	$0
Fayetteville	FAYETTE	5	$330,100	1	$48,300	1	$0
Gauley Bridge	FAYETTE	19	$343,650	0	$0	2	$200
Meadow Bridge	FAYETTE	0	$0	0	$0	0	$0
Montgomery**	FAYETTE	0	$0	0	$0	0	$0
Mount Hope	FAYETTE	4	$98,100	1	$31,500	2	$0
Oak Hill	FAYETTE	33	$1,537,000	7	$267,806	6	$81,800
Pax	FAYETTE	0	$0	0	$0	0	$0
Smithers**	FAYETTE	1	$500	0	$0	0	$0
Thurmond	FAYETTE	8	$121,200	0	$0	7	$107,200
	FAYETTE	**210**	**$6,969,372**	**33**	**$10,257,782**	**62**	**$426,662**
Greenbrier County*	GREENBRIER	167	$58,333,720	7	$1,477,146	54	$486,033
Alderson**	GREENBRIER	1	$28,200	0	$0	0	$0
Falling Springs	GREENBRIER	0	$0	0	$0	0	$0
Lewisburg	GREENBRIER	5	$448,730	3	$104,400	2	$0
Quinwood	GREENBRIER	0	$0	0	$0	0	$0
Rainelle	GREENBRIER	3	$11,700	0	$0	0	$0
Ronceverte	GREENBRIER	17	$400,640	2	$41,200	5	$16,900
Rupert	GREENBRIER	0	$0	0	$0	0	$0
White Sulphur Springs	GREENBRIER	14	$587,021	0	$0	1	$8,100
	GREENBRIER	**207**	**$59,810,011**	**12**	**$1,622,746**	**62**	**$511,033**
Nicholas County*	NICHOLAS	100	$1,780,408	10	$1,331,404	70	$387,147
Richwood	NICHOLAS	69	$723,950	3	$25,750	13	$5,300
Summersville	NICHOLAS	14	$769,100	0	$0	3	$10,000
	NICHOLAS	**183**	**$3,273,458**	**13**	**$1,357,154**	**86**	**$402,447**
Pocahontas County*	POCAHONTAS	163	$16,798,300	1	$212,894	49	$909,353
Durbin	POCAHONTAS	1	$26,500	0	$0	0	$0
Hillsboro	POCAHONTAS	0	$0	0	$0	0	$0
Marlinton	POCAHONTAS	5	$182,800	0	$0	0	$0
	POCAHONTAS	**169**	**$17,007,600**	**1**	**$212,894**	**49**	**$909,353**
Webster County*	WEBSTER	122	$1,336,628	3	$156,650	63	$115,161
Addison	WEBSTER	10	$74,493	1	$733	3	$0
Camden-On-Gauley	WEBSTER	5	$73,700	0	$0	3	$0
Cowen	WEBSTER	2	$13,800	1	$24,300	1	$0
	WEBSTER	**139**	**$1,498,622**	**5**	**$181,683**	**70**	**$115,161**

*Unincorporated Community
**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.

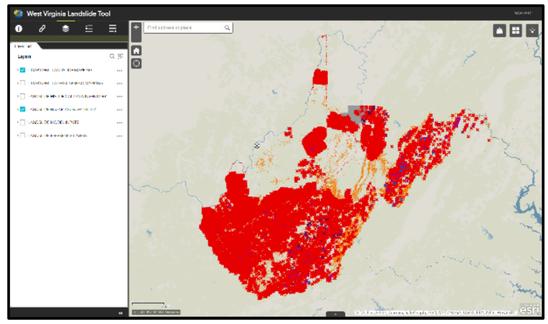

Figure 10. *West Virginia Landslide Tool*

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

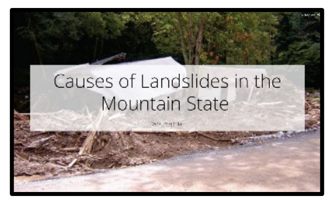

Figure 11. *Story Map showing causes of landslide*

  - ***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.

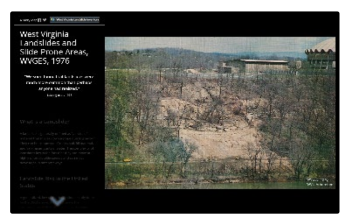

Figure 12. *WVGES 1976 Study details in Story Map*

- **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 Fayette, Greenbrier, Nicholas, Pocahontas, and Webster counties can be viewed and downloaded here.

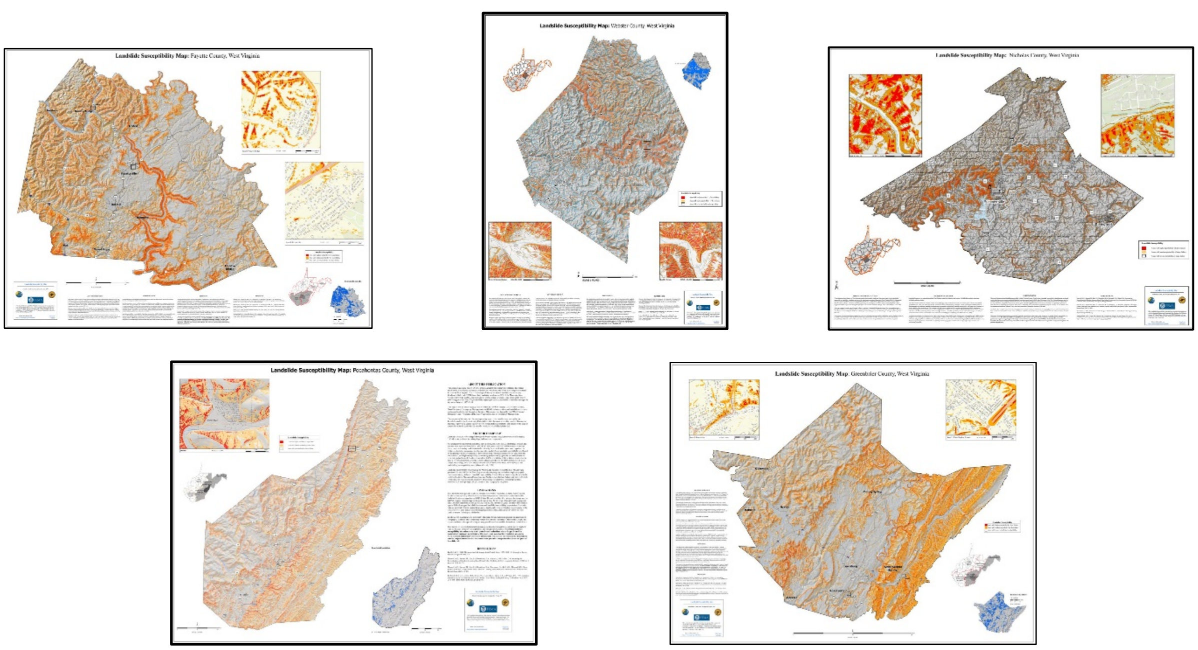

Figure 14. *Landslide Susceptibility maps of Fayette, Greenbrier, Nicholas, Pocahontas, and Webster counties.*

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