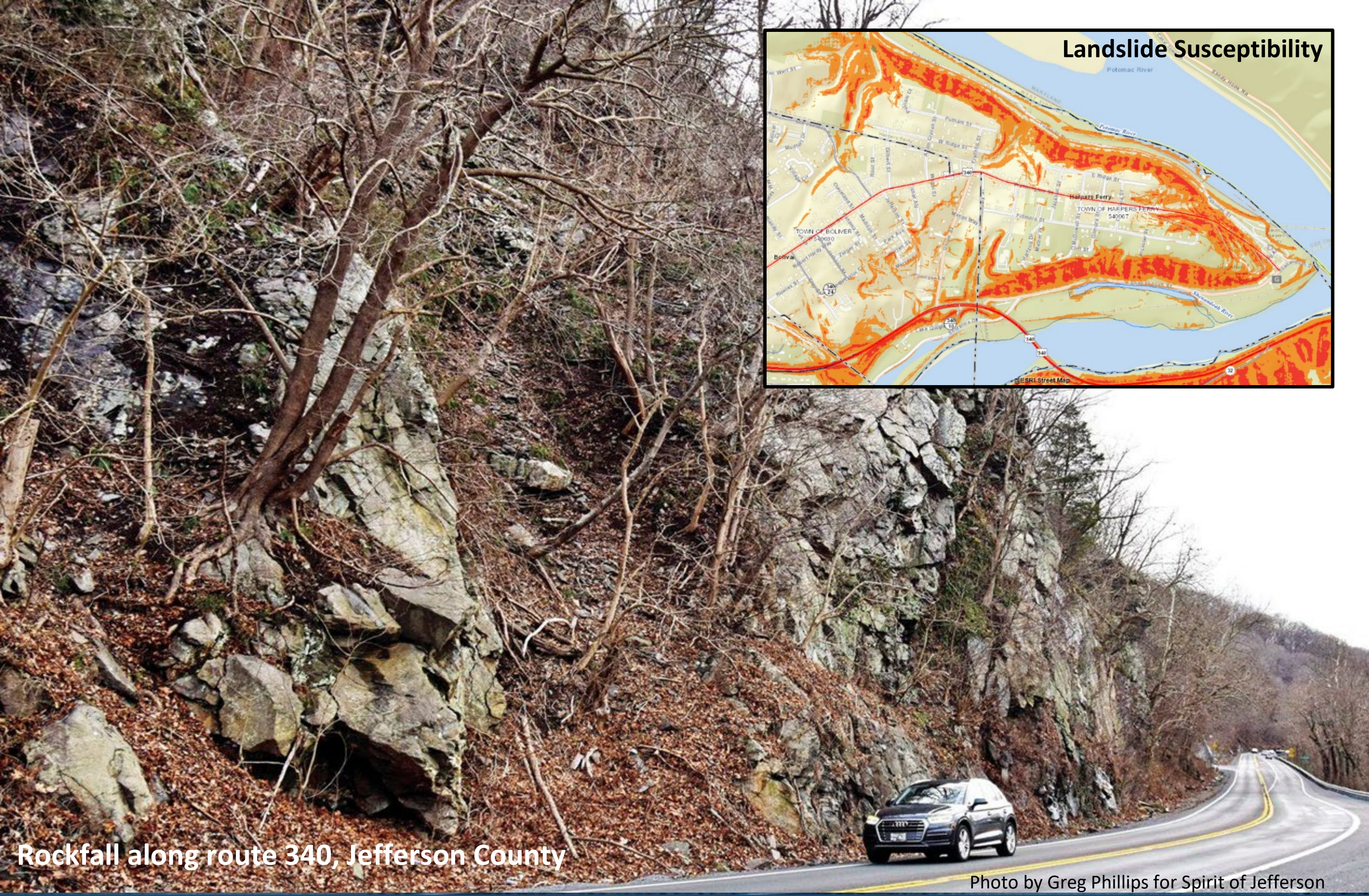

Rockfall along route 340, Jefferson County

Photo by Greg Phillips for Spirit of Jefferson

West Virginia Landslide Risk Assessment

Region 9 – Berkeley, Jefferson, Morgan county

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. 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 62 landslide points were identified using LiDAR. 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 of Region 9 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 9, **Morgan County** has about 21 miles of road that is susceptible to high/medium probability of landslide vulnerability. **Berkeley County** has about 16 miles, and **Jefferson County** has nearly 9 miles of road prone to high/medium risk for slope failure. Overall, Region 9 has relatively lower risk as compared to the rest of the state. Of all 55 counties, Morgan County ranks 51st, Berkeley 54th, and Jefferson 55th in high/medium landslide risk to roads.

Structure/Parcel risk analysis - **Morgan County** has a total of 356 primary structures with a total appraisal value of $31,940,422 that are in high/medium susceptibility areas. **Berkeley County** has 516 primary structures with total appraisal value of $57,360,557 in high/medium susceptibility areas. **Jefferson County** has 323 primary structures with a total appraisal value of $52,730,494 in high/medium susceptibility areas. Morgan County ranked 25th, Berkeley 15th, and Jefferson 29th for total number of at-risk structures in WV counties. However, Morgan ranks 13th, Berkeley 7th, and Jefferson 9th for total assets that are at risk for high/medium susceptibility of landslide. All Region 9 counties have a lower ranking for the number of at risk structures. This indicates that there are fewer landslide-vulnerable structures as compared to other counties in the state. Ranking changes when considering the ranking of Region 9 counties for total vulnerable assets. This jump in ranking for Region 9 counties can be due to the higher property value/parcel value in this region.

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 9 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.

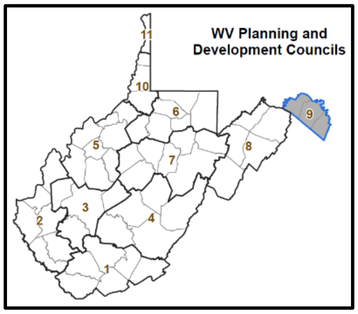

Figure 1. *Planning and development regions in West Virginia*

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

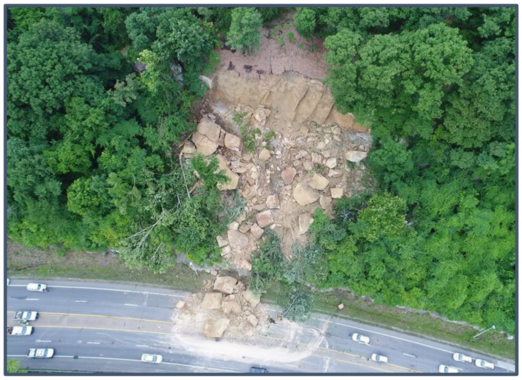

Figure 3. *The* ***consequences*** *of a landslide are often higher in populated areas due to resulting property damage and injury to citizens (Photo by WVDOT)*

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 9.

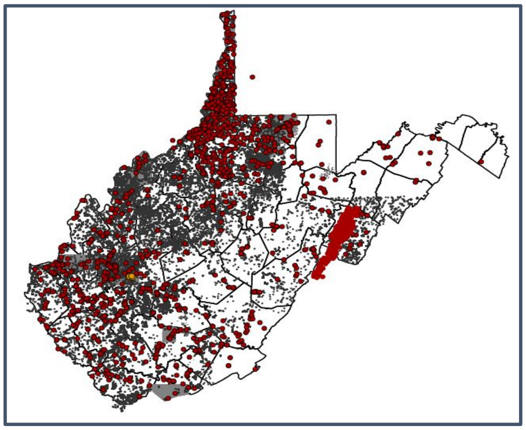

Figure 4. *Historical landslides were compiled from several studies to create a comprehensive landslide dataset (Image adapted from the West Virginia Landslide Tool)*

- **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. Unfortunately, mapping efforts yielded no published data from Region 9.

- **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 contained only one landslide in Jefferson County.

- **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. Rockfall, a major landslide risk in Jefferson County and Region 9 is considerably undercounted in this approach. Overall, 62 landslide points were identified in Region 9. Morgan County has 37 points, Berkeley has 24, and Jefferson has 1 landslide point.

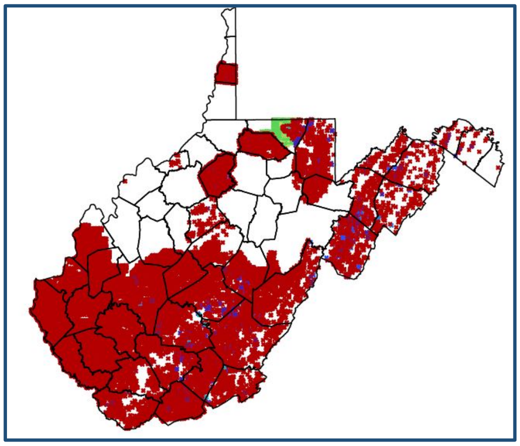

Figure 5. *LiDAR-mapped landslide points are dependent upon the presence of 1- or 2-meter LiDAR data (Image from the West Virginia Landslide Tool)*

Well-known incidences of rockfall and other landslides exist in Region 9, so the scarcity of landslides within the county database confirms the general nature of susceptibility maps. It also reinforces the importance of site-specific geotechnical investigations. Analyses in this report rely heavily upon relationships between high-resolution LiDAR-identified landslide incidence points and control factors in other West Virginia counties located in the Northern Appalachian Ridges and Valleys Major Land Resource Area. Fortunately, susceptibilities predicted by modeling are consistent with known landslide-risk areas in Region 9.

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).

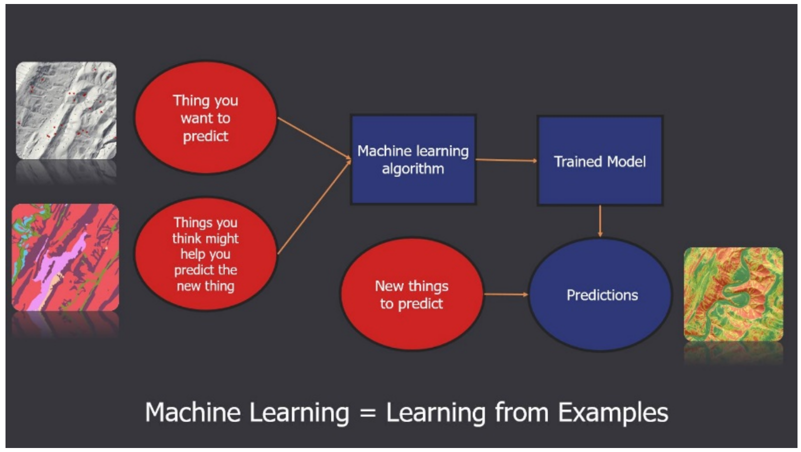

Figure 6. *Simplified diagram showing machine learning process for generating landslide susceptibility grid*

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).

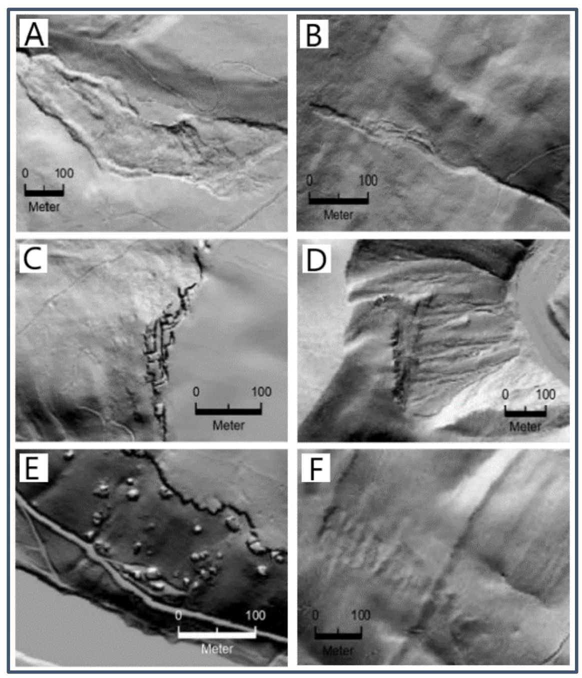

Figure 7. *A) Slide B) Debris Flow C) Lateral Spread D) Multiple Failures E) Fall F) Undetermined*

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. Region 9 counties (Berkeley, Morgan, and Jefferson) are in the **Northern Appalachian Ridge and Valley MLRA** (Figure 8).

This 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. In Region 9, Northern Appalachian Ridges and Valleys encompass most of the gentle topography in the state, and LiDAR-based mapping reveals the MLRA has fewer landslides.

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).

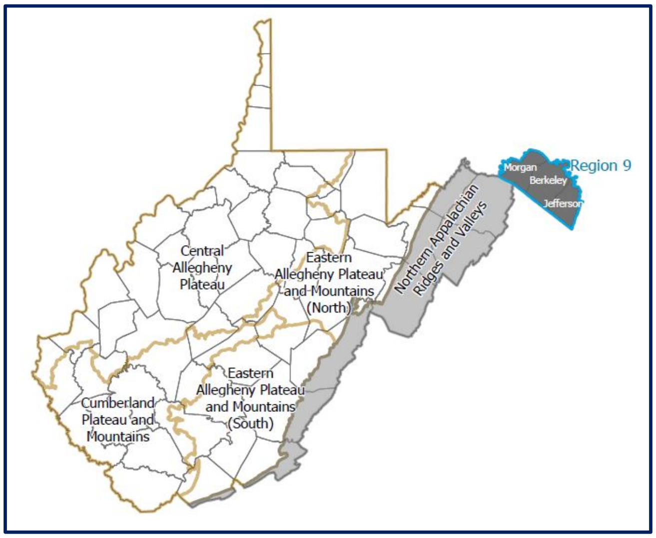

Figure 8. *Major land resource areas in Eastern West Virginia*

Following are detailed MLRA characteristics in Region 9 counties 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 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.

Residuum (material weathered in place or nearly in place) and colluvium (material transported some distance by gravitational processes) are the dominant earth materials in which soils develop in the MLRA. Residuum depth varies with rock type and degree of weathering; limestones and very old stable surfaces typically develop thick residual soils. Colluvium, which includes landslide deposits, is generally thin close to ridgetops, increasing in thickness further downslope.

Landslide Characteristics and Contributing Factors

Rockfall and **debris flow** are the most common types of landslides in Region 9. Debris flows initiate as slumps or slides in residuum or colluvium on upper slopes but may run downslope for a mile or more from their source. *The most frequent causes of debris flows are heavy rains associated with intense spring and early 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, in the Appalachians, debris flows are infrequent, with recurrence intervals at the most vulnerable sites estimated to be hundreds or thousands of years. Less common landslide types in the Appalachian Ridges and Valleys MLRA include multiple failures (tight clusters of small landslides and debris flows that tend to occur during debris flow events) and lateral spreads (clusters of large rock blocks that appear to move rarely).

Slope: Analysis of the LiDAR-based landslide data and model results from the MLRA reveals that slope steepness may be the most critical control over where landslides develop, especially in steep hillslope hollows that allow subsurface moisture, surface-water runoff, and unconsolidated material to accumulate. Almost 90 percent of mapped landslides occur on **slopes greater than 20 degrees.**

Geology: Geology is a universally cited factor in landslide distribution, and this is the case in the Ridges and Valleys of eastern West Virginia. Most of the role of geology on landslides is indirect. The distribution of resistant bedrock at the earth surface determines the location of ridge crests and steep adjacent side slopes. Weaker rock types on side slopes may be just as prone or even more prone to failure as a resistant rock type responsible for the ridge. Shale is the primary rock type in geological units covering over 45 percent of the Ridges and Valleys MLRA, providing initiation sites for 51 percent of landslides. Siltstone, sandstone, and limestone are the primary rock types in about 1/6th of the MLRA, but sandstone units are more strongly associated with landslides. Alluvium (unconsolidated floodplain and river terrace deposits) and dolomite cover smaller fractions of the MLRA, and are host to even smaller fractions of landslides.

Soil: USDA Natural Resource Conservation Service (NRCS) SSURGO data show that soil parent material and drainage class influence landslide susceptibility in the Ridges and Valleys MLRA area. Over 75 percent of the soils in the area are developed predominantly in the residuum parent material, and over 90 percent of landslides are initiated in these residual soils.

The NRCS recognizes four residuum categories in the study area, differentiated by the underlying bedrock from which the soil was derived. Acid clastic residuum forms on sedimentary bedrock (shale, siltstone, or sandstone) lacking significant amounts of carbonate minerals, whereas calcareous clastic residuum develops from sedimentary bedrock either admixed with calcareous layers or bound together by calcium carbonate cement. Limestone residuum in the Ridges and Valleys forms from either limestone or dolomite. Metamorphic rock residuum in West Virginia is limited to phyllite, quartzite, and greenstone bedrock in the Blue Ridge Mountains of eastern Jefferson County.

Landslide initiation is heavily influenced by soil parent material. Acid clastic residuum, the most widespread category, has significantly more landslides than would be expected based on the extent of this parent material.

Soil polygons assigned as “somewhat excessively drained” cover about 85 percent of the Ridges and Valleys landscape and account for almost 95 percent of landslide initiation points; this over-representation reflects the importance of slope to soil drainage class landslide initiation.

Other Landslide Factors: Although many factors influencing slope stability are universal, some aspects of slope stability in the Ridges and Valleys area differ from elsewhere in West Virginia. Anthropogenic disturbance is locally significant but generally not as problematic as in more densely populated areas or coalfields farther west.

Limestone quarries present local rockfall susceptibility, but elsewhere in the area, falls are most commonly associated with over-steepened road cuts, particularly where dipping bedrock layers have been undercut. The scope of rockfall susceptibility along roads in the Ridges and Valleys is not well illuminated by the landslide inventory, and fallen rock is unlikely to be caught on occasional LiDAR surveys because it is usually removed promptly and commonly too small to be resolved.

Landslide Susceptibility E-size maps for Morgan, Berkeley and Jefferson 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 9.

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 roads that are prone to high/medium slope failure risk. The table also shows the rank of landslide susceptibility within the state**. Morgan County** has about 21 miles of road that is susceptible to high/medium probability of vulnerability. **Berkeley County** has about 16 miles, and **Jefferson County** has nearly 9 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. Overall, Region 9 has relatively lower risk as compared to the rest of the state. Of all 55 counties, Morgan County ranks 51st, Berkeley 54th, and Jefferson 55th. In each county, most of the at-risk roads are in unincorporated areas. Figure 9 shows an example of landslide risk along Route 9 in Berkeley County. The road segments susceptible to landslide can be viewed on the Landslide Tool.

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

Community Name	County	Roads Total (miles)	Roads Total (miles) - High/Medium Risk	Rank[1]
Morgan County*	MORGAN	423.9	21.1	49
Bath	MORGAN	4.5	0	182
Paw Paw	MORGAN	2.7	0.3	96
	MORGAN	**431.1**	**21.5**	**51**
Berkeley County *	BERKELEY	701.6	15.9	53
Hedgesville	BERKELEY	0.9	0	182
Martinsburg	BERKELEY	30.6	0.3	96
	BERKELEY	**733.1**	**16.4**	**54**
Jefferson County *	JEFFERSON	434.8	7.5	55
Bolivar	JEFFERSON	3	0.3	96
Charles Town	JEFFERSON	23.1	0.4	81
Harpers Ferry	JEFFERSON	1.7	0.4	81
Ranson	JEFFERSON	29.2	0.7	52
Shepherdstown	JEFFERSON	2.2	0	182
	JEFFERSON	**494**	**9.6**	**55**

* Unincorporated

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

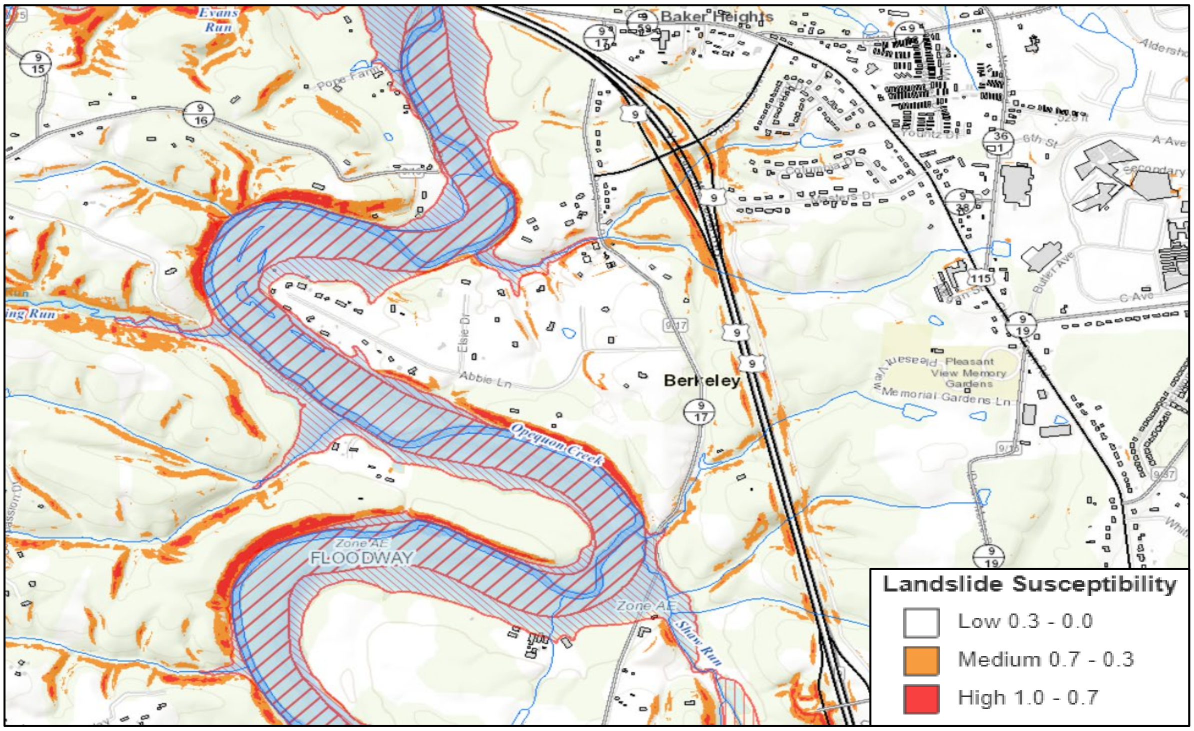

Figure 9. *Landslide Susceptibility in unincorporated area of Berkeley County. Notice high and medium susceptibility landslide area along Route 9. Data can be assessed on WV Flood Tool*

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 community, most of the at-risk roads are in the unincorporated area of each county. In **Morgan County**, the unincorporated area has 21 miles of at-risk roads, constituting 98% of at-risk roads in the county; 2.4 miles of US roads and 2.9 miles of State roads are at-risk. Paw Paw has only 0.3 miles, and Bath has no at-risk roads. **Berkeley County** has 16 miles of at-risk roads in unincorporated areas, constituting 97% of at-risk roads. Interstate has 1.9 miles, US roads has 0.4 miles, and State roads have 2.2 miles of at-risk roads. Martinsburg has 0.1 miles of at-risk US roads. In **Jefferson County**, the unincorporated area has 7.5 miles of at-risk roads, constituting 78% of at-risk roads in the county. The unincorporated area also has 1.6 miles of US roads and 1.9 miles of State roads at risk. US roads are majority percent of at-risk roads in Bolivar and Charlestown. Harpers Ferry has a majority percentage of at-risk US roads while Shepherdstown has no at-risk roads.

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
Morgan County*	MORGAN	423.9	21.1	0	2.4	2.9	15.8
Bath	MORGAN	4.5	0	0	0	0	0
Paw Paw	MORGAN	2.7	0.3	0	0	0.3	0
	MORGAN	**431.1**	**21.5**	**0**	**2.4**	**3.2**	**15.8**
Berkeley County*	BERKELEY	701.6	15.9	1.9	0.4	2.2	11.4
Hedgesville	BERKELEY	0.9	0	0	0	0	0
Martinsburg	BERKELEY	30.6	0.3	0	0.1	0	0.2
	BERKELEY	**733.1**	**16.4**	**1.9**	**0.5**	**2.2**	**11.6**
Jefferson County*	JEFFERSON	434.8	7.5	0	1.6	1.9	4
Bolivar	JEFFERSON	3	0.4	0	0.3	0	0.1
Charles Town	JEFFERSON	23.1	0.4	0	0.3	0.1	0
Harpers Ferry	JEFFERSON	1.7	0.4	0	0.2	0	0.2
Ranson	JEFFERSON	29.2	0.7	0	0	0.6	0.1
Shepherdstown	JEFFERSON	2.2	0	0	0	0	0
	JEFFERSON	**494**	**9.6**	**0**	**2.4**	**2.6**	**4.4**

* 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 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. **Morgan County** has a total of 356 primary structures with a total appraisal value of $31,940,422 that are in high/medium susceptibility areas. **Berkeley County** has 516 primary structures with total appraisal value of $57,360,557 in high/medium susceptibility areas. **Jefferson County** has 323 primary structures with a total appraisal value of $52,730,494 in high/medium susceptibility areas. Morgan county ranked 25th, Berkeley 15th, and Jefferson 29th for total number of at-risk structures in WV counties. However, Morgan ranks 13th, Berkeley 7th, and Jefferson 9th for total assets that are at risk for high/medium susceptibility of landslide. Notice that all of Region 9 counties have a lower ranking for the number of at risk structures. This indicates that there are fewer landslide-vulnerable structures as compared to other counties in the state. Ranking changes when we compare the ranking of Region 9 counties for total vulnerable assessment cost. This jump in ranking for Region 9 counties can be due to the higher property value/parcel in this region.

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

Community Name	County	Total Count	Total Value	Ranking(Count)[1]	Ranking(Value)[1]
Morgan County*		337	$30,207,387	18	10
Bath		19	$1,733,036	57	34
Paw Paw		0	$0	187	183
	MORGAN	**356**	**$31,940,422**	**25**	**13**
Berkeley County*		496	54441856.98	9	5
Martinsburg		18	2804600	62	23
Hedgesville		2	114100	158	130
	BERKELEY	**516**	**$57,360,557**	**15**	**7**
Jefferson County*		237	35200114.97	30	6
Bolivar		10	1033800	90	46
Charles Town		6	1699250	119	35
Harpers Ferry		60	10486112.66	25	10
Ranson		1	146700	171	117
Shepherdstown		9	4164516.668	100	15
	JEFFERSON	**323**	**$52,730,494**	**29**	**9**

* Unincorporated

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

Table 4 shows detailed risk of slope failure based on different occupancy classes. In general, the **residential** occupancy class has structures with the highest replacement cost in high/medium landslide susceptibility areas. **Commercial** occupancy class is mostly second, followed by **Other** occupancy class structures. This trend is similar in all three counties in Region 9. Property values of Other occupancy class should be ignored as some government and other property values do not get incorporated in from the statewide assessment database, resulting in lower value of at-risk structures.

Morgan County has a total of 298 structures in Residential occupancy class with replacement costs of $30,903,625 followed by 49 Other occupancy class structures and 9 Commercial structures with replacement costs of $712,158. The unincorporated areas of Morgan County have the highest structure count and corresponding replacement values, whereas Paw Paw has no structure or related replacement costs in high and medium-risk susceptibility areas.

Berkeley County has a total of 456 structures in the Residential occupancy class with replacement costs of $53,183,807 followed by 52 Other structures and finally 8 commercial structures with replacement costs of $2,575,300. The unincorporated areas of Berkeley County have the highest structure count and corresponding replacement values whereas Hedgesville has the lowest structure count and related replacement costs in high and medium risk susceptibility areas.

Jefferson County has a total of 271 structures in the Residential occupancy class with replacement costs of $39,628,571, followed by 33 Commercial structures with replacement costs of $8,628,019 and 19 Other structures. The unincorporated areas of Jefferson County have the highest structure count and corresponding replacement values, whereas Ranson has the lowest structure count and related replacement costs for high and medium risk structures.

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**
Morgan County*		279	$29,170,589	9	$712,158	49	$324,639
Bath		19	$1,733,036	0	$0	0	$0
Paw Paw		0	$0	0	$0	0	$0
	MORGAN	**298**	**$30,903,625**	**9**	**$712,158**	**49**	**$324,639**
Berkeley County*		441	$52,069,407	7	$771,500	48	$1,600,950
Martinsburg		13	$1,000,300	1	$1,803,800	4	$500
Hedgesville		2	$114,100	0	$0	0	$0
	BERKELEY	**456**	**$53,183,807**	**8**	**$2,575,300**	**52**	**$1,601,450**
Jefferson County*		205	$28,991,810	23	$5,576,545	9	$631,760
Bolivar		10	$1,033,800	0	$0	0	$0
Charles Town		5	$451,950	1	$1,247,300	0	$0
Harpers Ferry		43	$6,179,511	8	$1,764,457	9	$2,542,144
Ranson		1	$146,700	0	$0	0	$0
Shepherdstown		7	$2,824,800	1	$39,717	1	$1,300,000
	JEFFERSON	**271**	**$39,628,571**	**33**	**$8,628,019**	**19**	**$4,473,904**

* 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.

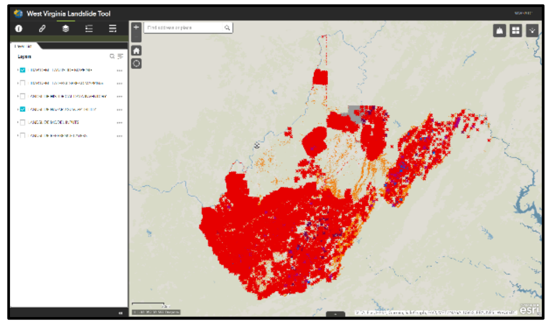

Figure 10. *West Virginia Landslide Tool*

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

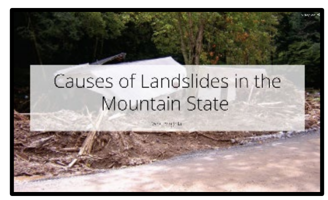

Figure 11. *Story Map showing causes of landslide*

    - ***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.

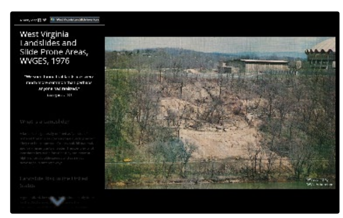

Figure 12. *WVGES 1976 Study details in Story Map*

- **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 Berkeley, Jefferson and Morgan counties can be viewed and downloaded here.

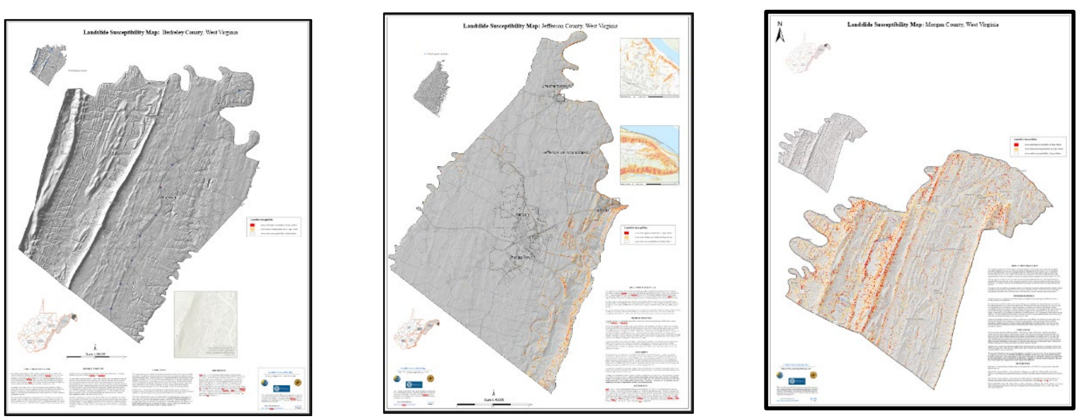

Figure 14. *Landslide Susceptibility maps of Berkeley, Jefferson and Morgan counties.*

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