Statewide Hazard Assessment

Landslide Risk Assessment

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Landslide Risk Assessment

Goals

- Develop landslide inventory
- Create valid landslide models for specific WV regions
- Generate county-level resolution landslide maps
- Create an interactive web map application for displaying landslide models and variables
- Use the new landslide models and information to update the State Hazard Mitigation Plan

Did you know?

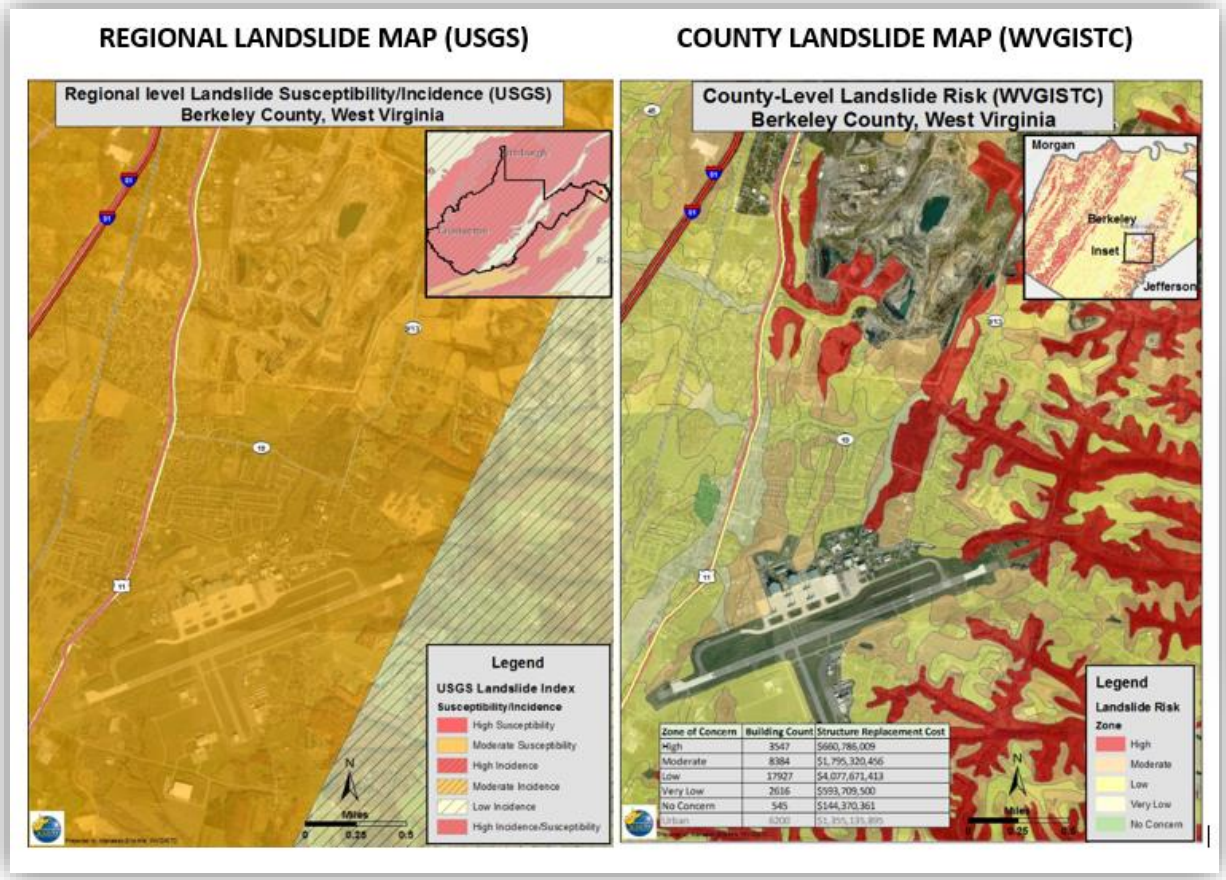
Landslides are the **#2 Hazard** in West Virginia

2015 Yeager Airport Slide

Landslide Maps – Old versus New

Old Way - Very Generalized

New Way – More Detailed



Landslide susceptibility map showing generalized USGS map and more detailed prototype map

Landslide Risks

Buildings Exposed to Landslide Risks

Zone of Concern	Building Count	Structure Replacement Cost
High	3547	$660,786,009
Moderate	8384	$1,795,320,456
Low	17927	$4,077,671,413
Very Low	2616	$593,709,500
No Concern	545	$144,370,361
*Urban (No relevant attributes)	6200	$1,355,135,895

Risk Assessment table showing building counts along with estimated replacement costs in landslide zones of concern

Landslide Study Limitations

Limitations

1. This study is suitable for overview planning-level and general emergency services planning
2. The risk analysis for roads should be used in conjunction with site-specific risk analysis performed by WV Department of Transportation
3. This study has **NOT** been done for, and may not be suitable for legal, design, engineering, or site-preparation purposes.
4. This study can **NOT** substitute for site-specific investigations by qualified practitioners. Landslide risk is complex and continually changing. Although other existing studies may provide more precise and comprehensive information, *detailed original site investigations are normally an essential best practice for public safety, sustainability, and financial viability.*

Landslide Incident Inventory

Key Takeaways

1. 159,247 landslide features inventoried
   I. 66,151 landslide initiation points mapped using high resolution (1- or 2-m) LiDAR.
   II. 46,330 landslide polygons digitized based on WV Geological and Economic Survey 1976 study.
   III. 41,307 landslide polygons digitized based on a USGS 1975-1985 study.
2. Most common landslide - Slides and slumps
3. Future work - Landslide mapping in areas where LiDAR coverage was incomplete; LiDAR for these areas delivered by FEMA in December 2021.

Landslide Incident Inventory

#	Agency	Year	Author or Source Agency	Title/Description	General Location	Purpose	Total Incidence Data
1	WVGES	**1973**	Landers and Smosna	Final Report on Landslides of July 9, 1973 in Kanawha City Area of Charleston, West Virginia	Charleston, West Virginia	Landslide mapping	10
2	WVGES	**1976-80**	Lessing et al.	WV Landslides and Slide-Prone Areas; funded by Appalachian Regional Commission	Statewide (39 topo quads)	Landslide mapping	46,330
3	USGS	**1978-85**	USGS (various)	Landslide Quad Maps: Open File Maps	Statewide (382 topo quads)	Landslide mapping	41,307
4	USGS	**1993**	Jacobson et al	U.S. Geological Survey Bulletin 1981: Geomorphic studies of the storm and flood of November 3-5, 1985, in the upper Potomac and Cheat River basins in West Virginia and Virginia	Cheat and Potomac River basins; Wills Mountain Anticline; Eastern WV	Research study (1985)	3,571
5	WVU	**1983-97**	WVU	Landslide incidences with Images	Statewide	Instruction & landslide inventory	46
6	WVU	**1996**	Kite and Grubb	Update of 1976 Landslide Maps, Morgantown North and South Quadrangles	Morgantown, West Virginia	Landslide inventory	41
7	WVU	**2008**	Konsoer et al	LiDAR, GIS, and multivariate statistical analysis to assess landslide risk, Horseshoe Run watershed, West Virginia	Horseshoe Run Watershed, Tucker County	Surficial Geology Mapping	149
8	NPS/WVGES	**2014**	Yates and Kite	Unpublished Digital Surficial Geologic Map of Bluestone National Scenic River and Vicinity, West Virginia (NPS, GRD, GRI, BLUE, BLUS digital map) adapted from a West Virginia University and West Virginia Geological and Economic Survey Open File Map by Yates and Kite (2014)	Bluestone National Scenic River and Vicinity	Surficial Geology Mapping	12
9	NPS/WVGES	**2015**	Yates and Kite	Digital Surficial Geologic Map of New River Gorge National River, West Virginia (NPS, GRD, GRI, NERI, NERS digital map) adapted from a West Virginia University and West Virginia Geological and Economic Survey Open File Report map by Yates and Kite (and Gooding) (2015)	New River Gorge National River	Surficial Geology Mapping	212
10	WVDOT	**2016**	Geospatial Transportation Information (GTI) Section	Road landslide inventory	Statewide	Landslide inventory	1,406
11	WVDHSEM	**2017**	State Hazard Mitigation Office	FEMA Buyout Properties for Landslides	Southern West Virginia	Landslide mitigation	12
12	WVU	**2022**	WVGISTC	Statewide Landslide Risk Assessment; Funded by FEMA and WV Division of Homeland Security and Emergency Management	Statewide	Landslide risk assessment	66,151

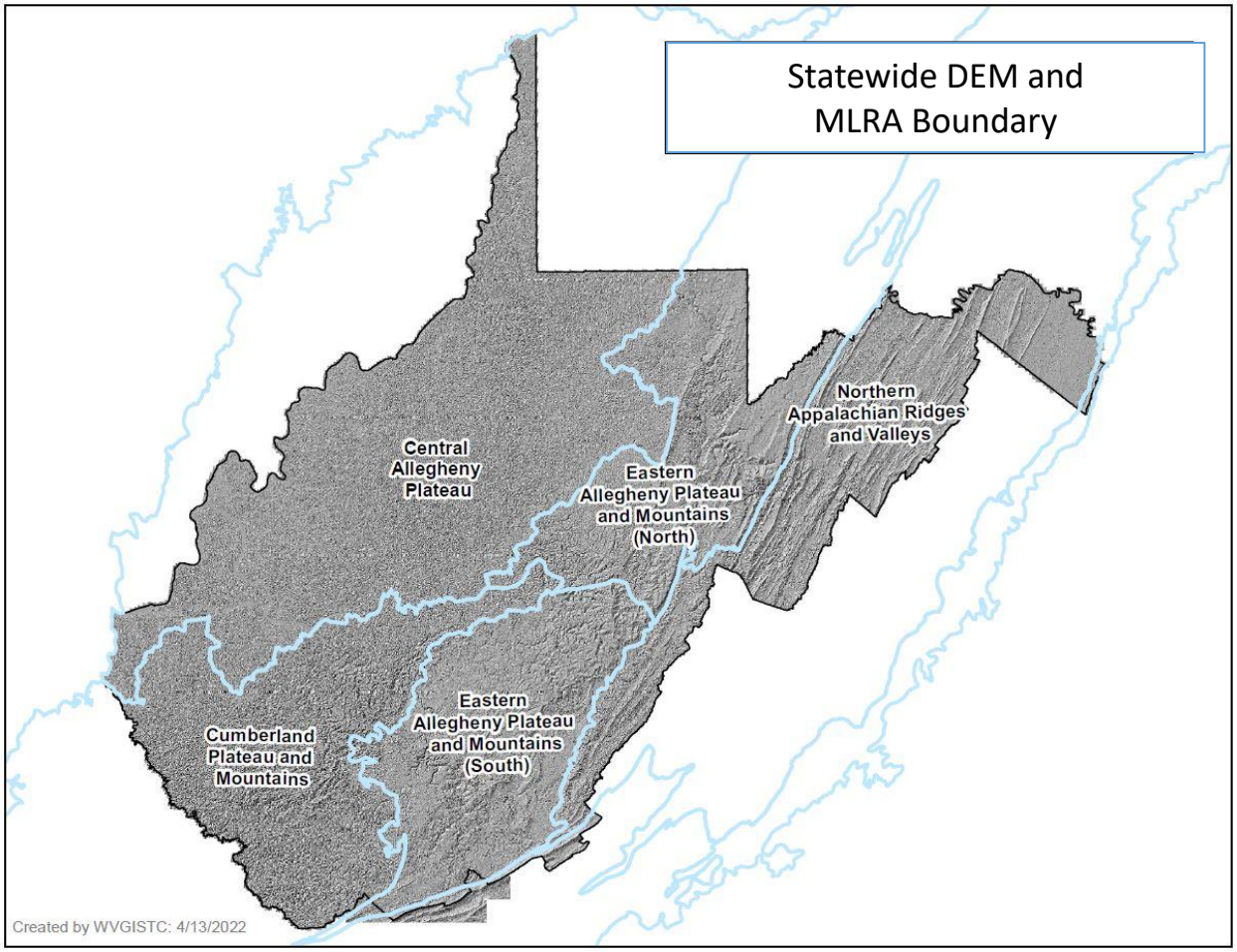
159,247 landslide features

Landslide Incident Inventory

Landslide mapping from new LiDAR-derived DEM

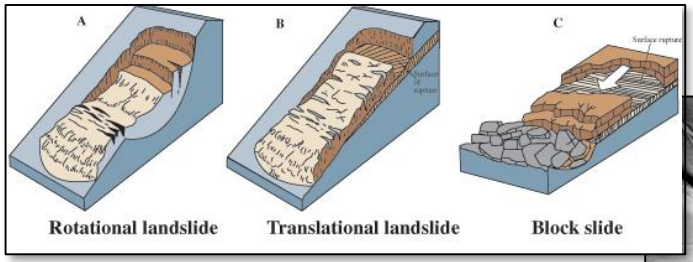
Identifying following types of landslides

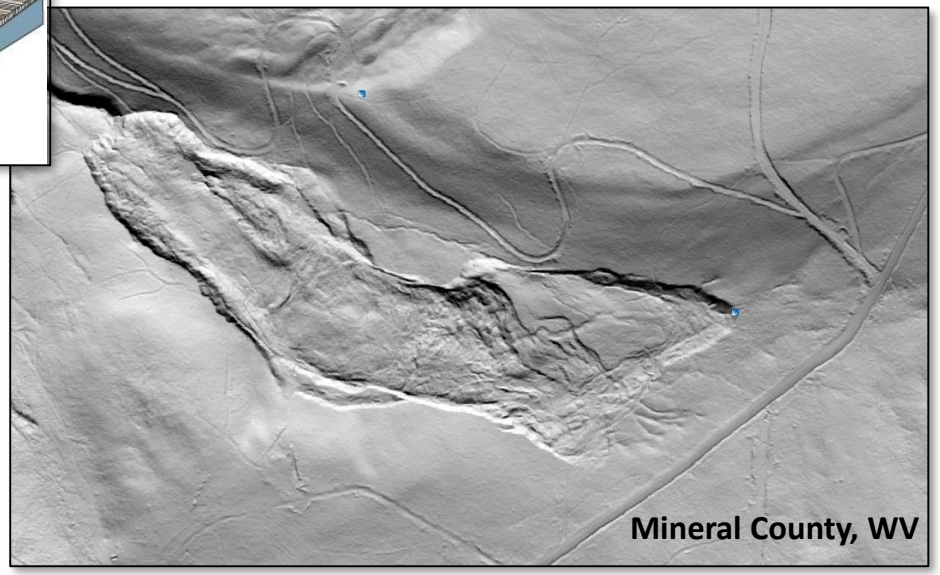
- Slide
- Fall
- Flow
- Lateral Spread
- Multiple Failures
- Unknown



Landslide Incident Inventory

- **Slide** (includes rotational and translational movement)*: mass movements, where there is a distinct zone of weakness that separates the slide material from more stable underlying material

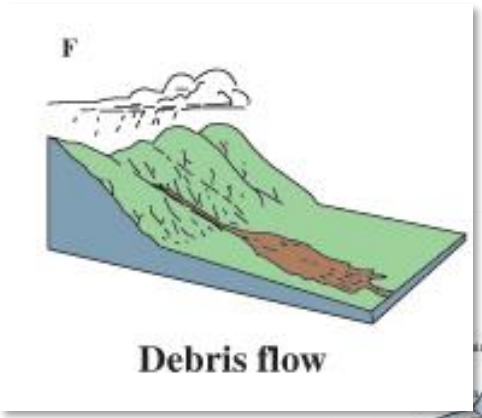


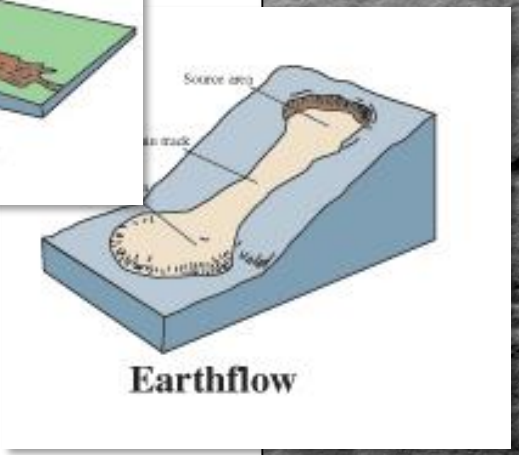


*Description from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html
Images from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

Landslide Incident Inventory

- **Debris Flow***: A form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as a slurry that flows downslope; they are often associated with steep gullies, and debris-flow deposits are usually indicated by the presence of debris fans at the mouths of gullies

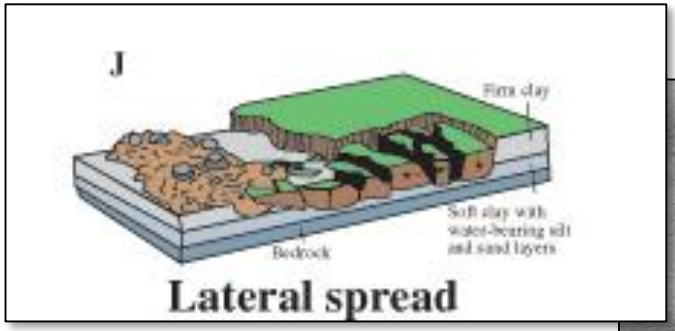


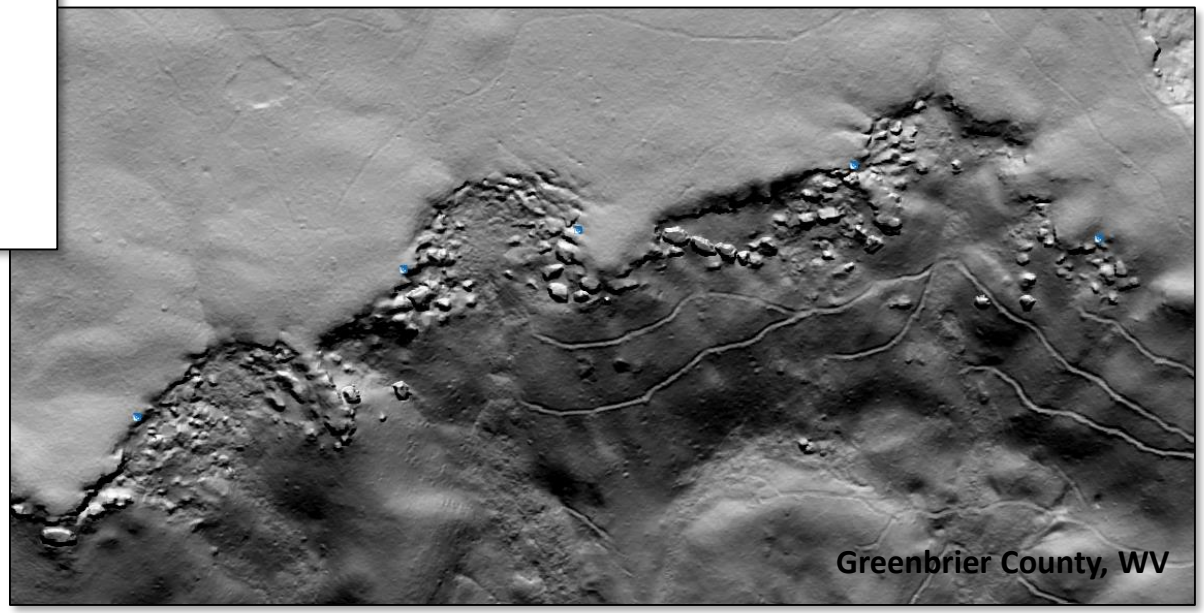


*Description from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html
Images from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

Landslide Incident Inventory

- **Lateral Spread***: When coherent material, either bedrock or soil, rests on materials that liquefy, the upper units may undergo fracturing and extension and may then subside, translate, rotate, disintegrate, or liquefy and flow; usually occur on very gentle slopes or flat terrain





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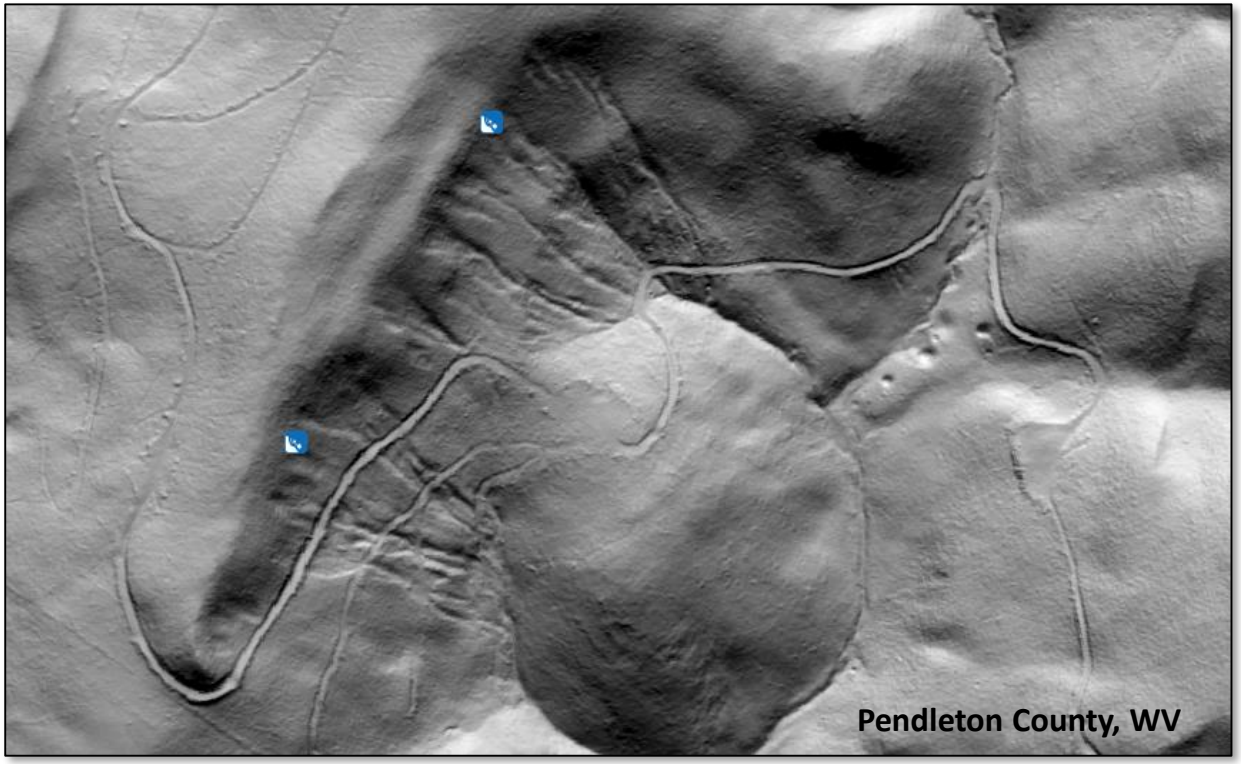
Images from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

Landslide Incident Inventory

- **Multiple Failures:** This classification is used when multiple (>4) failures, usually small debris flows, occur in a restricted area



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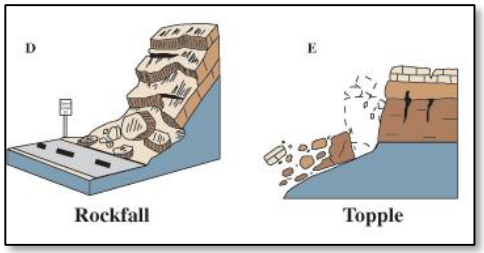
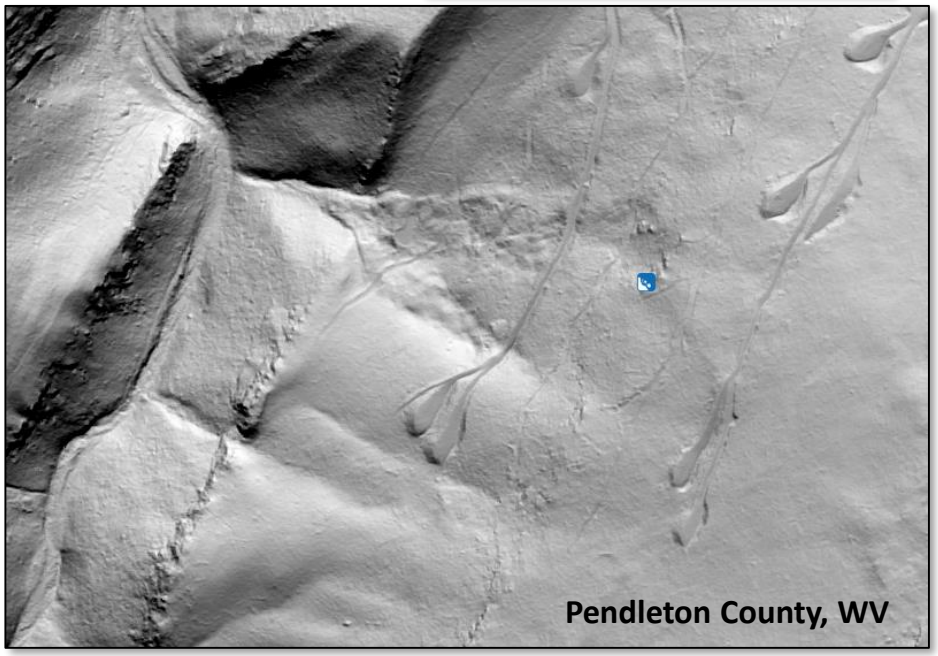
Images from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

Landslide Incident Inventory

- **Fall*:** Abrupt movements of masses of geologic materials, such as rocks and boulders, that become detached from steep slopes or cliffs



- **Undetermined:** Some failure is present, but it is not possible to determine the type of movement



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Images from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

Landslide Incident Inventory

Type of Movement	Number of user identified points	Percentage of user identified points	Description
Slide	64,800	97.9	A zone of weakness separates the slide from the underlying material; can be translational or rotational
Fall	12	.02	Rocks or other geologic materials dislocate from steep slopes
Debris Flow	882	1.3	Fluid mobilizes material into a slurry that flows downslope; often associated with gullies or steep channels
Lateral Spread	313	0.5	Extension along very shallow or horizontal slopes which causes material to break into block-like shapes
Multiple Failures	125	0.2	Usually a combination of multiple small debris flows in a restricted location
Undetermined	19	0.03	Some failure is clearly present, but it is difficult to determine the type of movement

Landslide Incident Inventory

WV GIS TC Landslide Mapping
2018-April 2022

WV GIS TC Mapping on LiDAR-Based DEMs

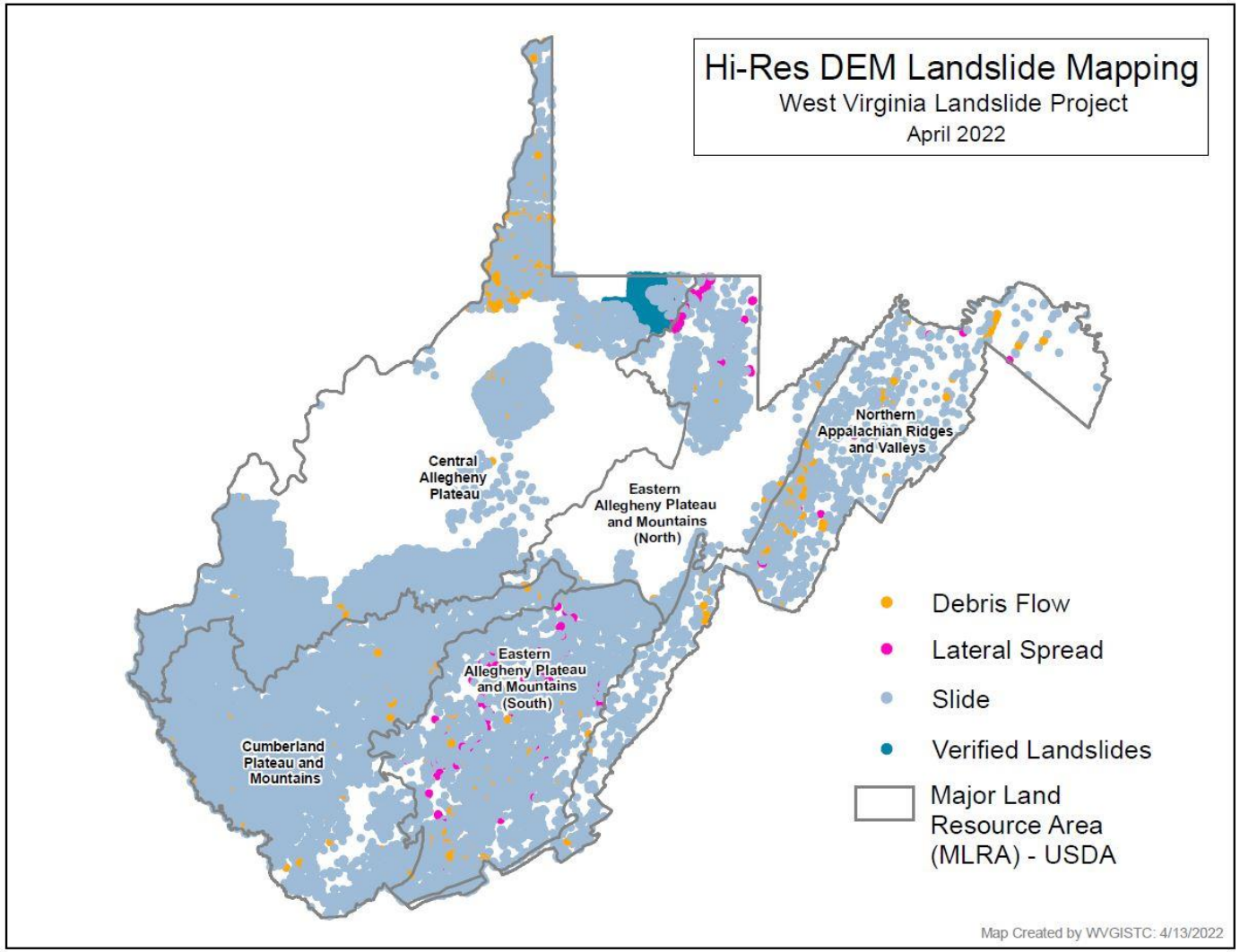
66,151 Failures *(≥10 m wide)* Most from 1 m DEMs

- **882 Debris Flows**
- **313 Lateral Spreads**
- **64,800 Other Failures**
  >97 % "Slides" (or *Slumps*)

Few Rock Falls Identified

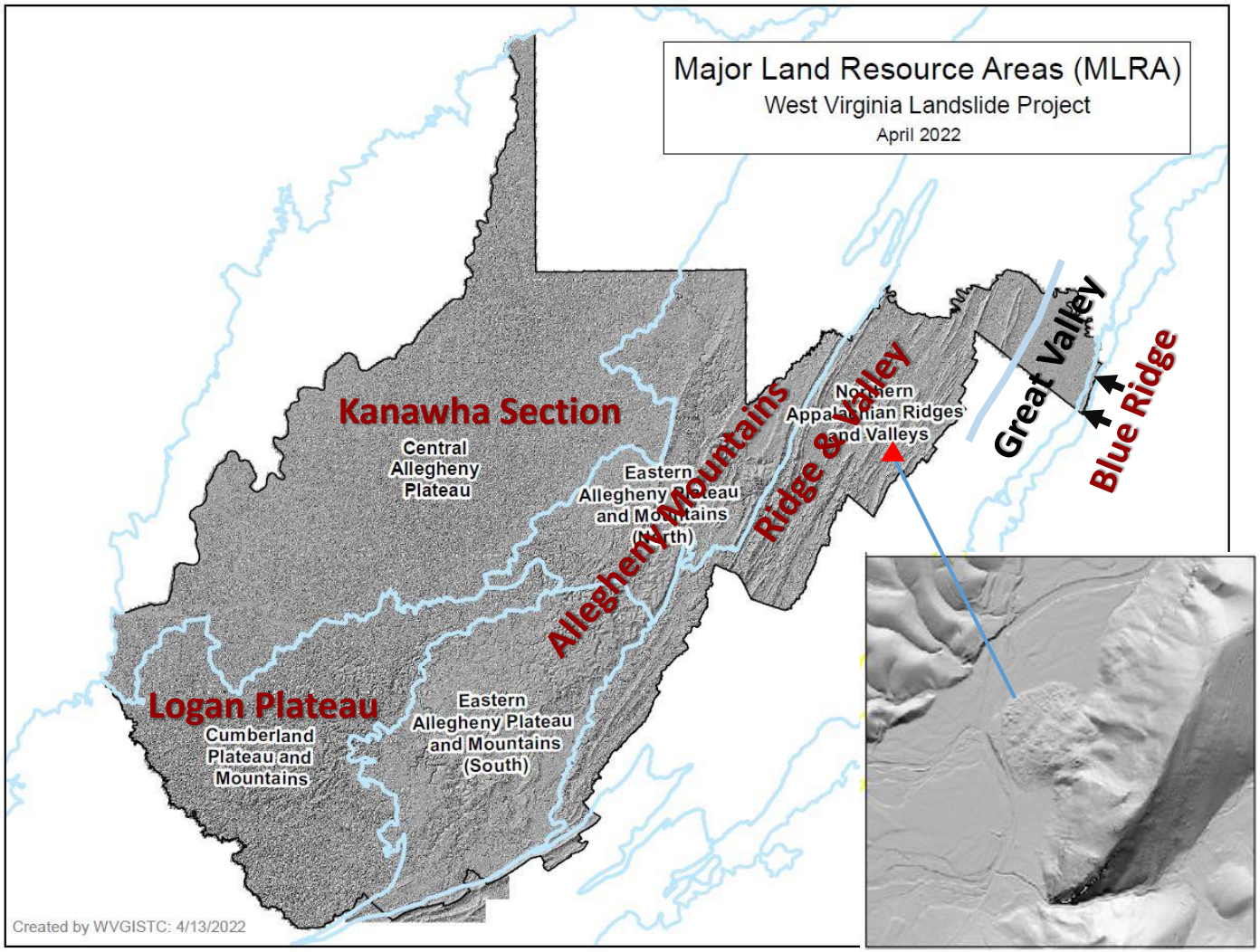
Mapped Landslides Verified on best available DEMs

- **1,082 WVGES (1976-80) Monongalia Co. Slides**

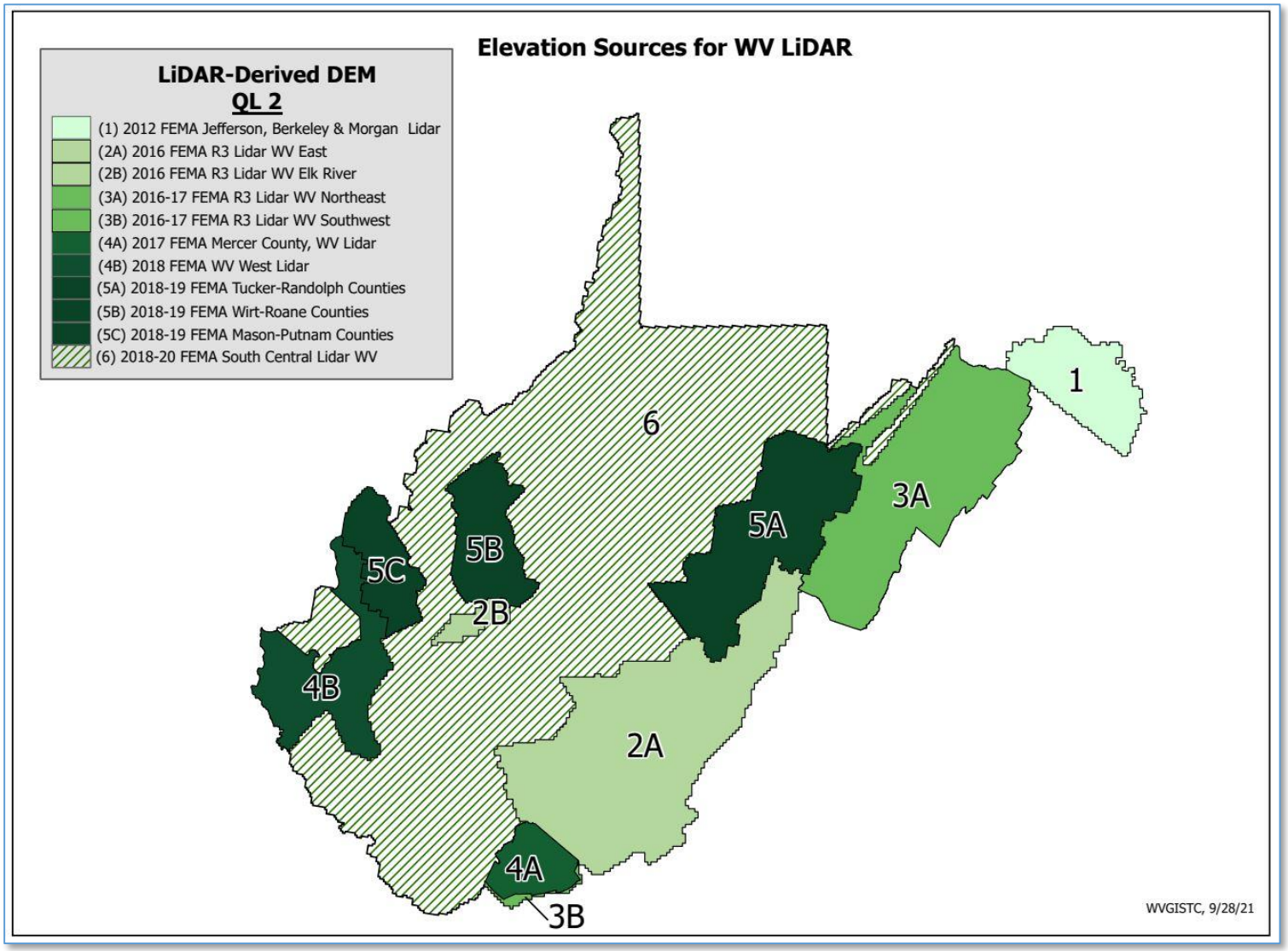


Mapping Landslides from new DEM

FEMA purchased statewide Quality Level 2 lidar for the entire State that will improve the mapping of existing landslides. Lidar-derived products include 1-meter DEM and 1-foot Contours



Mapping Landslides from new DEM

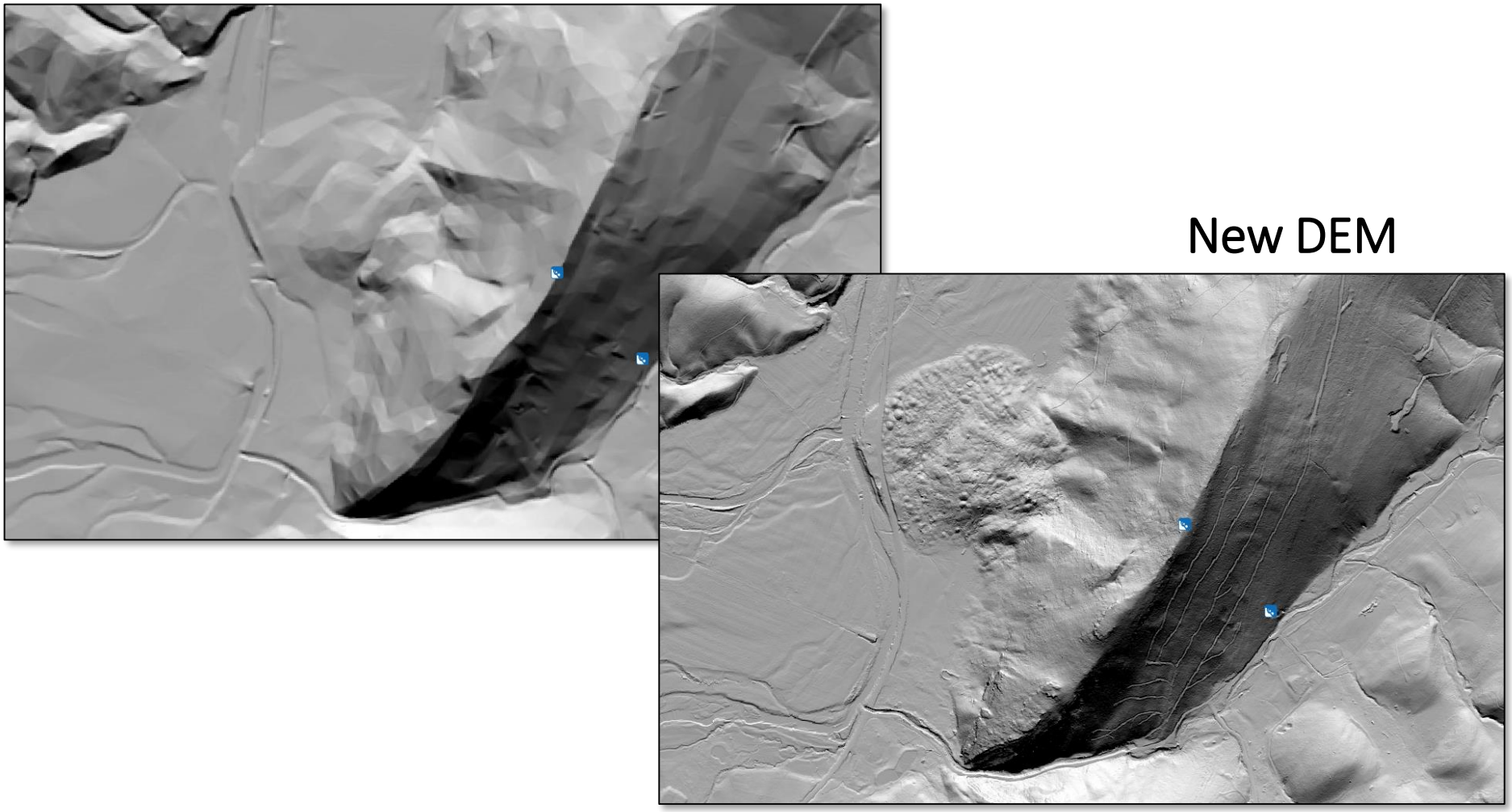


Best-Available Elevation Sources for West Virginia: https://www.mapwv.gov/flood/map/docs/WV_FloodTool_ElevationSource_Metadata.pdf

Mapping Landslides from new DEM

Old DEM

New DEM



Comparison of Old and New 1 meter DEM

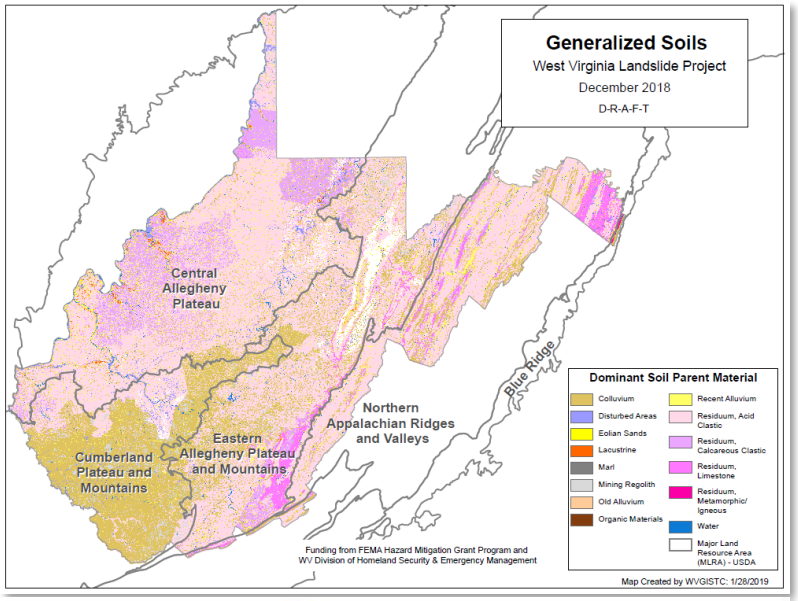
Landslide Method Development

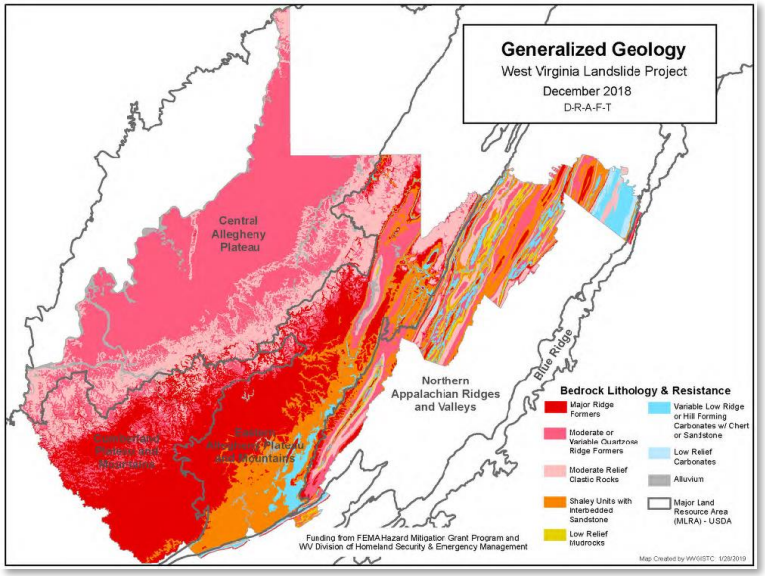
Key Takeaways

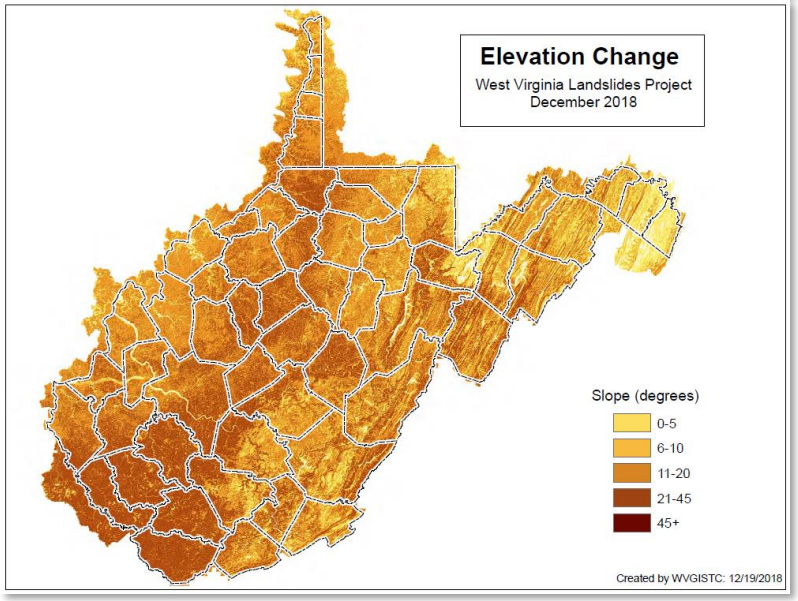
1. Landslide susceptibility modeling
    I. Performed using machine learning
        I. Random forest method most efficient
        II. Performed for various MLRA's to minimize heterogeneity in physiographic conditions that may influence landslide susceptibility
2. Main Landslide contributing factor- Slope, soil type, and geology
    I. Steeper slopes, unconsolidated soils, and less resistant rock units like shale and siltstone will increase landslide susceptibility.
3. Anthropogenic disturbance contributes heavily to landslide risk
4. Future work - Rerun models after new LiDAR-based landslide mapping is complete.

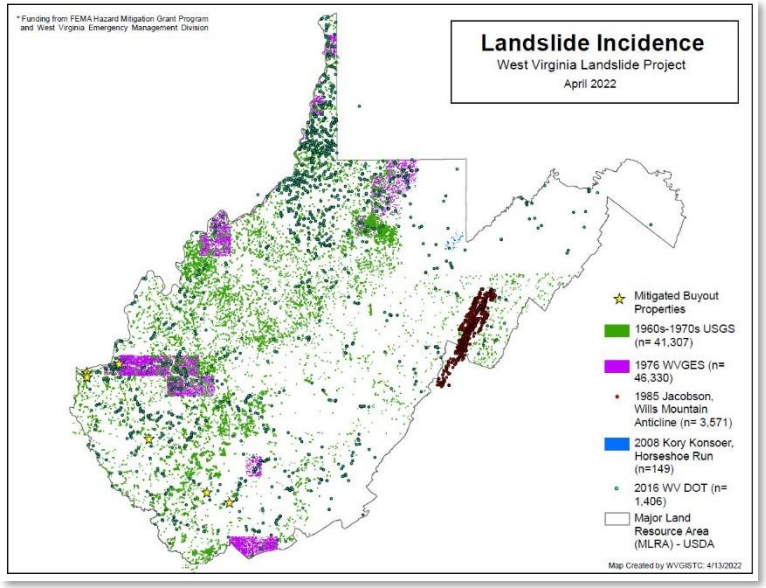
Landslide Method Development

The West Virginia University Study Team includes Dr. Steve Kite (Geomorphologist), Dr. James Thompson (Soil Scientist), **Dr. Aaron Maxwell** (Geologist/Modeler), and Dr. Maneesh Sharma (Geologist/GIS)









Landslide Method Development

West Virginia Physiography & NRCS MLRAs

Existing Physiographic Maps Inadequate for WV Landslide Project

MLRA Boundaries Better

Provinces & Subdivisions

Appalachian Plateaus

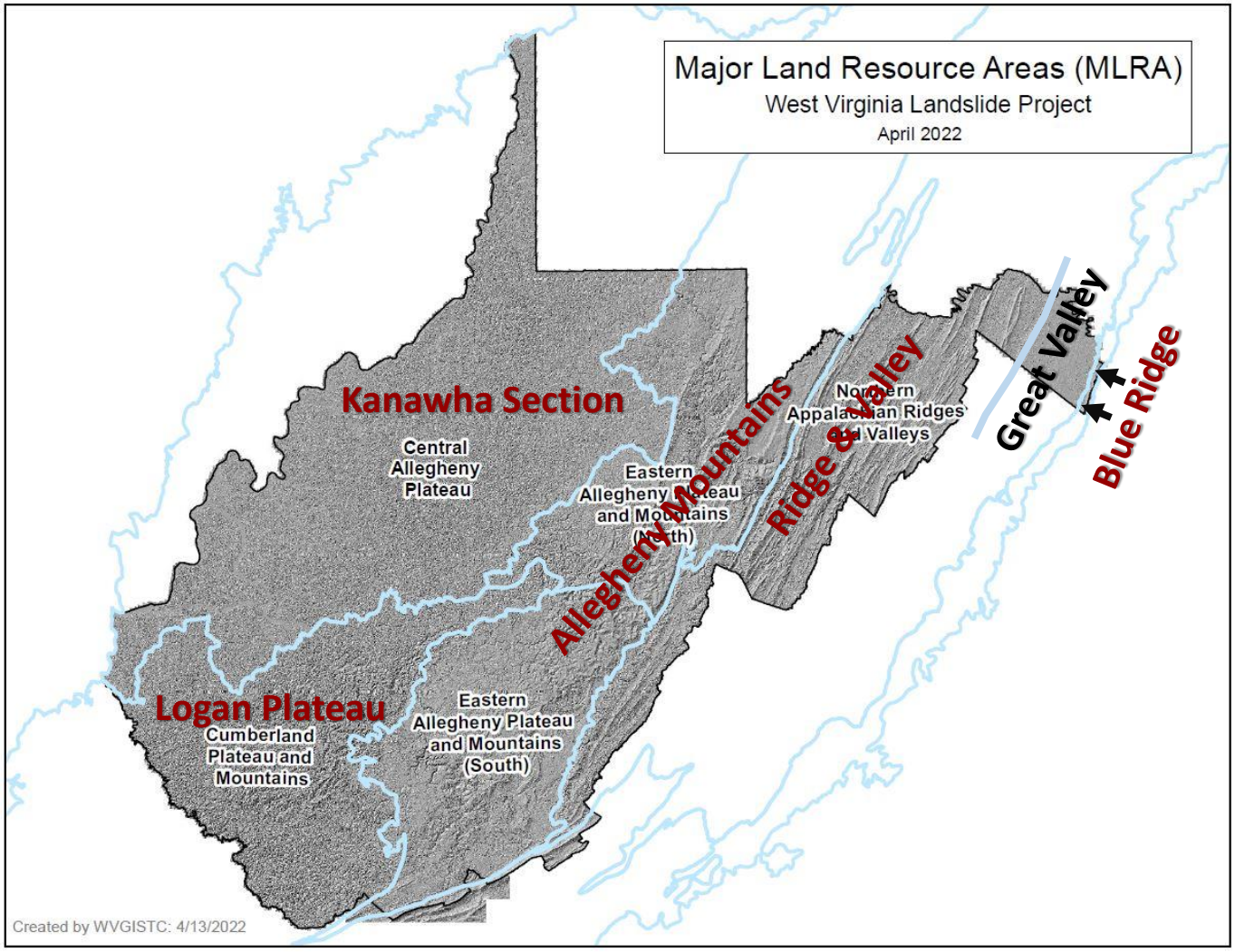
- **Kanawha Section**
- **Logan Plateau**
- **Allegheny Mountains**

Valley & Ridge

- **Ridge & Valley**
- **Great Valley**

Blue Ridge

Red = Landslide-Prone



Landslide Method Development

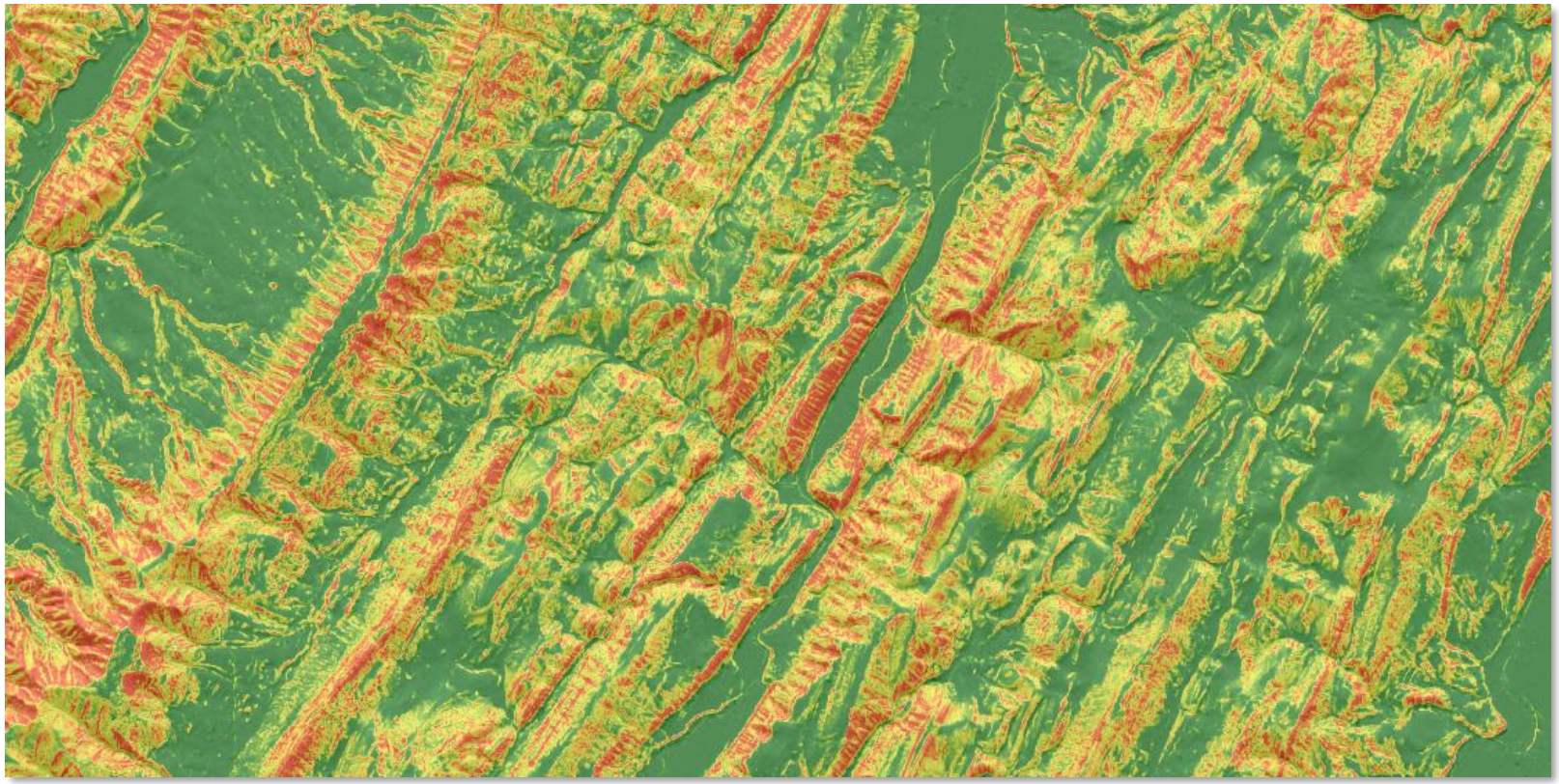
Summary of MLRA Landslide Characteristics

MLRA	No. LiDAR-Mapped Landslides	Types of Landslides	Slope	Geology	Soil	Other Landslide Factors
Central Allegheny Plateau	**Total:** 30,915* **Per sq. mile:** 3.6*	Most Common: • Slides • Slumps Less Common: • Rock falls • Debris flows • Lateral spreads	Majority of landslides on slopes greater than 14°	• Shale and siltstone dominated units most prone to landslides • Conemaugh Group most susceptible	Acid clastic residuum and mining regolith are the most slide-prone materials	• Urban/rural development • Timber harvesting
Cumberland Plateau and Mountains	**Total:** 20,714 **Per sq. mile:** 4.6	Most Common: • Slides • Slumps Less Common: • Rock falls • Debris flows • Lateral spreads	Majority of landslides on slopes greater than 21°	• Shale and siltstone dominated units most prone to landslides • Kanawha Formation most susceptible	Mining regolith is the most slide-prone material	• Unreclaimed mine sites • Timber harvesting
Eastern Allegheny Plateau and Mountains (North)	**Total:** 2,228* **Per sq. mile:** 0.66*	Most Common: • Slides • Slumps Less Common: • Rock falls • Debris flows	Majority of landslides on slopes greater than 17°	• Shale and siltstone dominated units most prone to landslides • Chemung and Mauch Chunk Groups most susceptible	Mining regolith and calcareous clastic residuum are the most slide-prone materials	• Urban/rural development • Unreclaimed mine sites • Timber harvesting
Eastern Allegheny Plateau and Mountains (South)	**Total:** 10,297 **Per sq. mile:** 2.8	Most Common: • Slides • Slumps Less Common: • Rock falls • Debris flows	Majority of landslides on slopes greater than 20°	• Shale and siltstone dominated units most prone to landslides • Allegheny and Hinton Formations most susceptible	Mining regolith is the most slide-prone material	• Unreclaimed mine sites • Timber harvesting
Northern Appalachian Ridges and Valleys	**Total:** 1,997 **Per sq. mile:** 0.48	Most Common: • Slides • Slumps Less Common: • Rock falls • Debris flows • Lateral spreads	Majority of landslides on slopes greater than 20°	• Sandstone and shale dominated units most prone to landslides • McKenzie Fm. and Clinton Group most susceptible	Acid clastic residuum is the most slide-prone material	• Limestone quarries • Timber harvesting

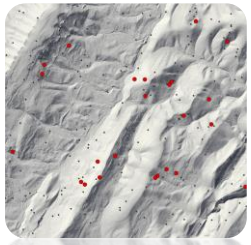
*Underrepresented due to incomplete LiDAR coverage

Landslide Method Development

Goal: Generate predictive models of slope failure probability/occurrence



Landslide Method Development



Thing you want to predict

Things you know that might help you predict the new thing

Machine learning algorithm

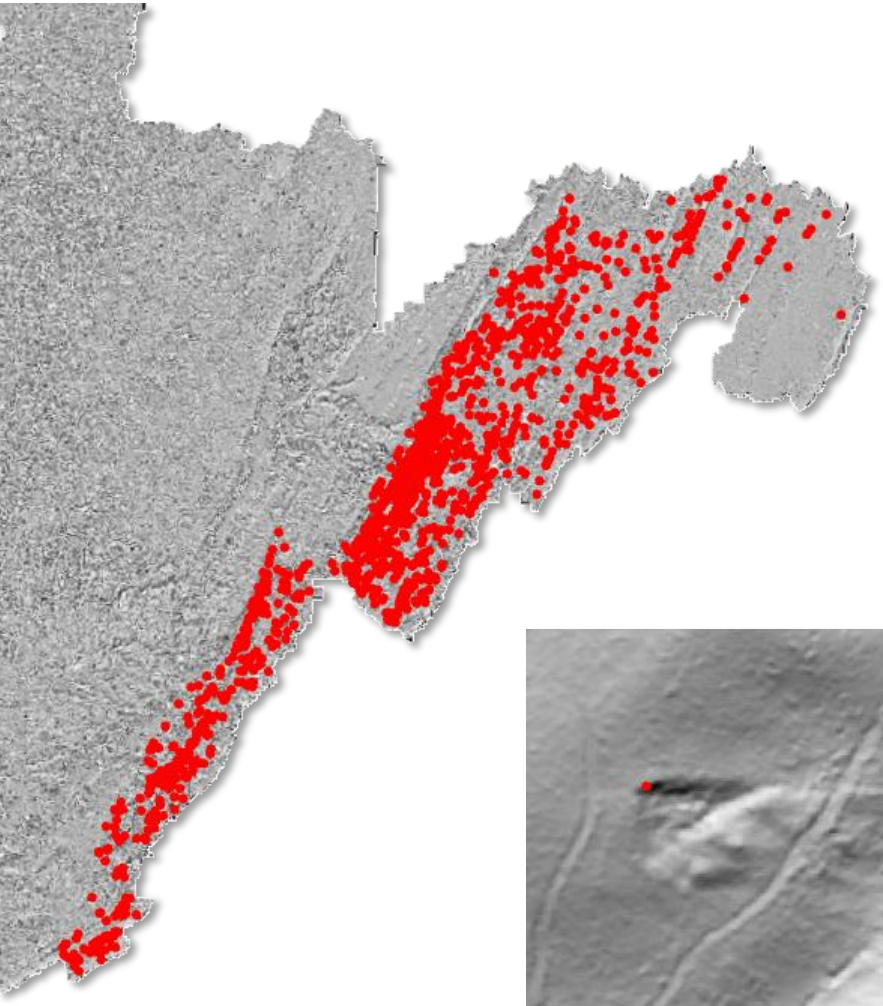
Trained Model

New things to predict

Predictions

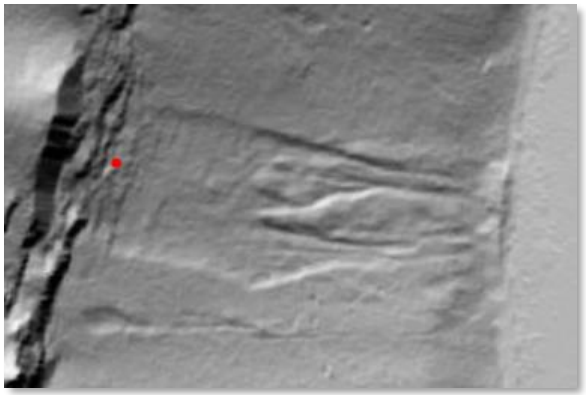
Machine Learning = Learning from Examples

Landslide Method Development



Training the Model

Based on visual interpretation of terrain data



Landslide Method Development

Modeling Methods: Predictor Variables

- Terrain Derivatives:
  - Topographic Slope
  - Mean Slope
  - Topographic Roughness
  - Slope Position
  - Topographic Dissection
  - Heat Load Index
  - Aspect Linear Transformation
  - Surface Area Ratio
  - Surface Relief Ratio
  - Site Exposure Index
  - Longitudinal Curvature
  - Cross Sectional Curvature
  - Profile Curvature
  - Plan Curvature

Landslide Method Development

Modeling Methods: Predictor Variables

- Non-Terrain:
  - Roads
    - Distance from US Roads
    - Distance from State Roads
    - Distance from Local Roads
    - Cost Distance from US Roads
    - Cost Distance from State Roads
    - Cost Distance from Local Roads
  - Hydrology
    - Distance from Streams
    - Cost Distance from Streams
  - Geology
    - Geologic Rock Type (Categorical)
    - Modified Geologic Rock Type (Categorical)
  - Soils
    - DPSM (Categorical)
    - Drainage Class (Categorical)

Landslide Method Development

Modeling Method

- **Random Forest**
- Provide predictor variables
- Provide presence and absence data

```
#Run RF models
train1_m <- randomForest(y= factor(train1[,1]), train1[,2:ncol(train1)], ntree=501, importance=T, confusion=T, err.rate=T)
train2_m <- randomForest(y= factor(train2[,1]), train2[,2:ncol(train2)], ntree=501, importance=T, confusion=T, err.rate=T)
train3_m <- randomForest(y= factor(train3[,1]), train3[,2:ncol(train3)], ntree=501, importance=T, confusion=T, err.rate=T)
train4_m <- randomForest(y= factor(train4[,1]), train4[,2:ncol(train4)], ntree=501, importance=T, confusion=T, err.rate=T)
train5_m <- randomForest(y= factor(train5[,1]), train5[,2:ncol(train5)], ntree=501, importance=T, confusion=T, err.rate=T)
model <- combine(train1_m, train2_m, train3_m, train4_m, train5_m)
```

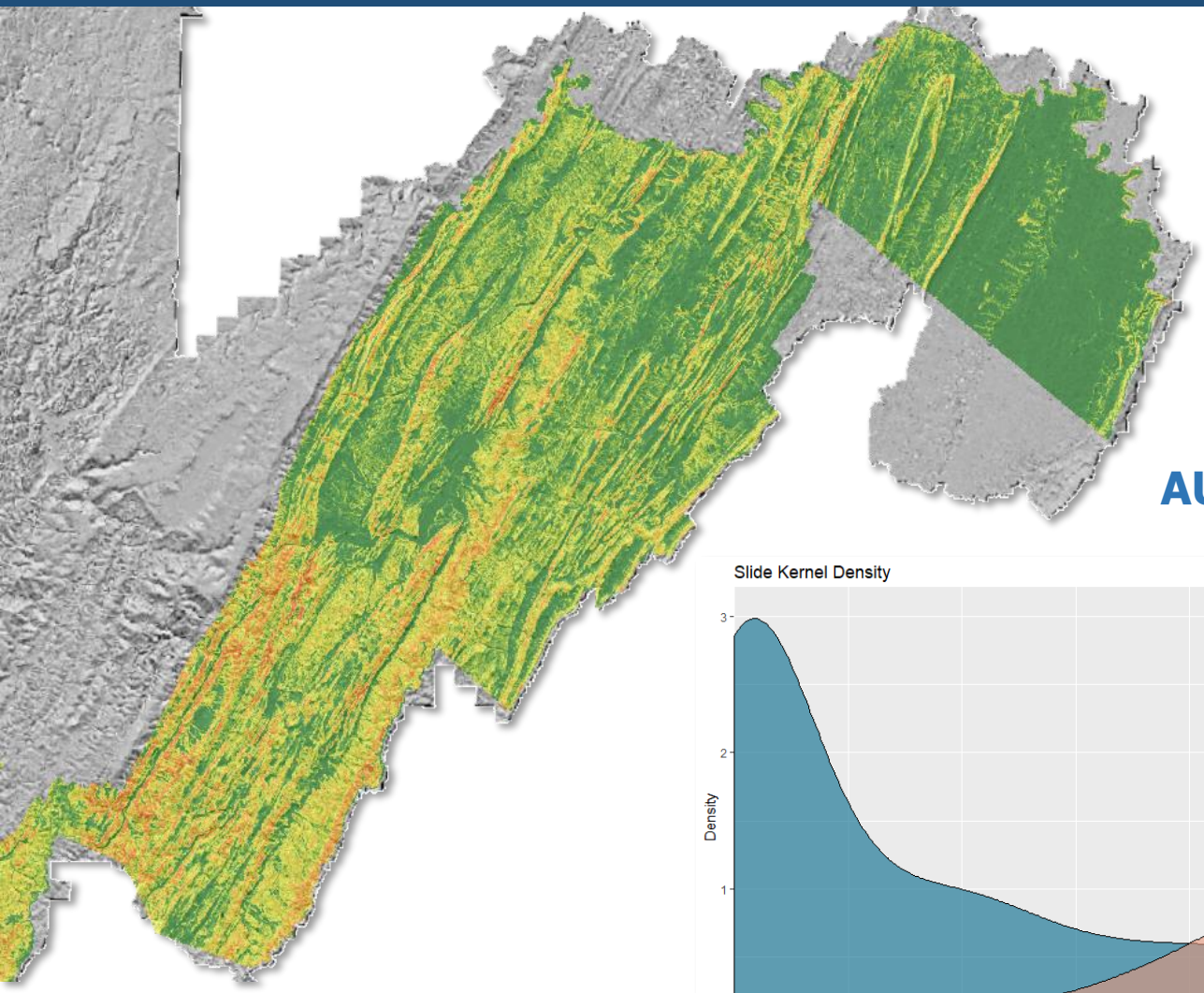
Landslide Method Development

Predict to Entire Extent

- Tile-by-tile
- Python scripts
- ~1 week to process

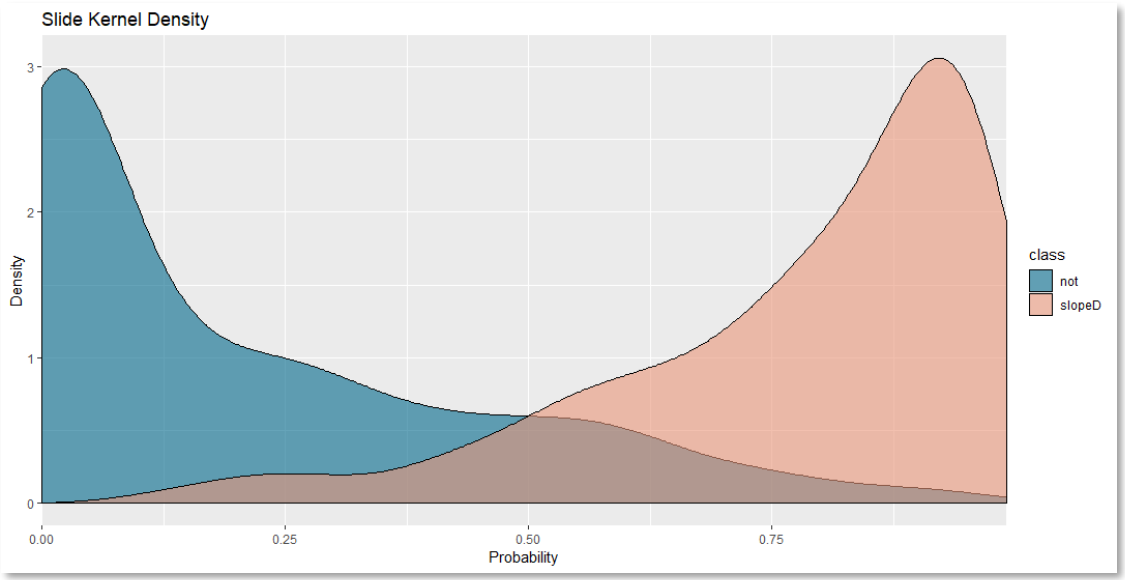
```
for shp in shp_lst:
    name = str(shp)
    tile = [shp]
    subprocess.call(["python", "predict_to_grid_subscript3.py"] + tile, shell=True)
    arcpy.CopyRaster_management("D:/v_r_landslide/stack/pred_out.tif", "D:/v_r_landslide/pred_out/"
                                + str(os.path.splitext(shp)[0]) + ".tif")
    print("Process complete for " + name + "!")
```

Landslide Method Development



Results

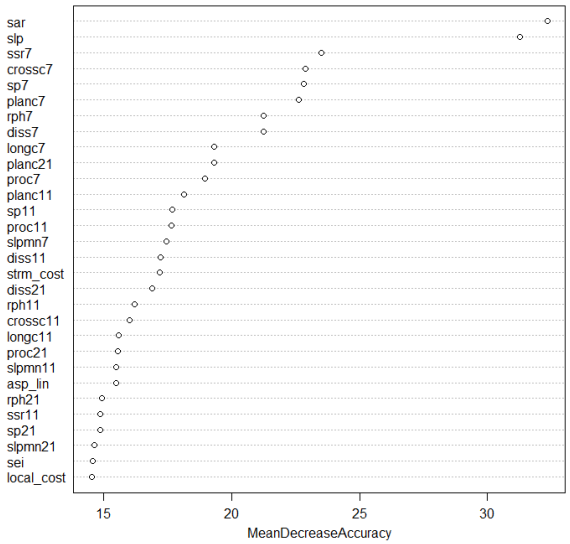
AUC – 0.94

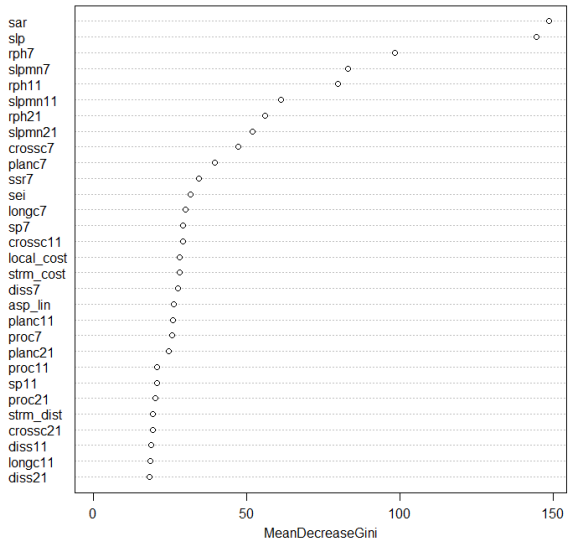


Landslide Method Development

Important Variables

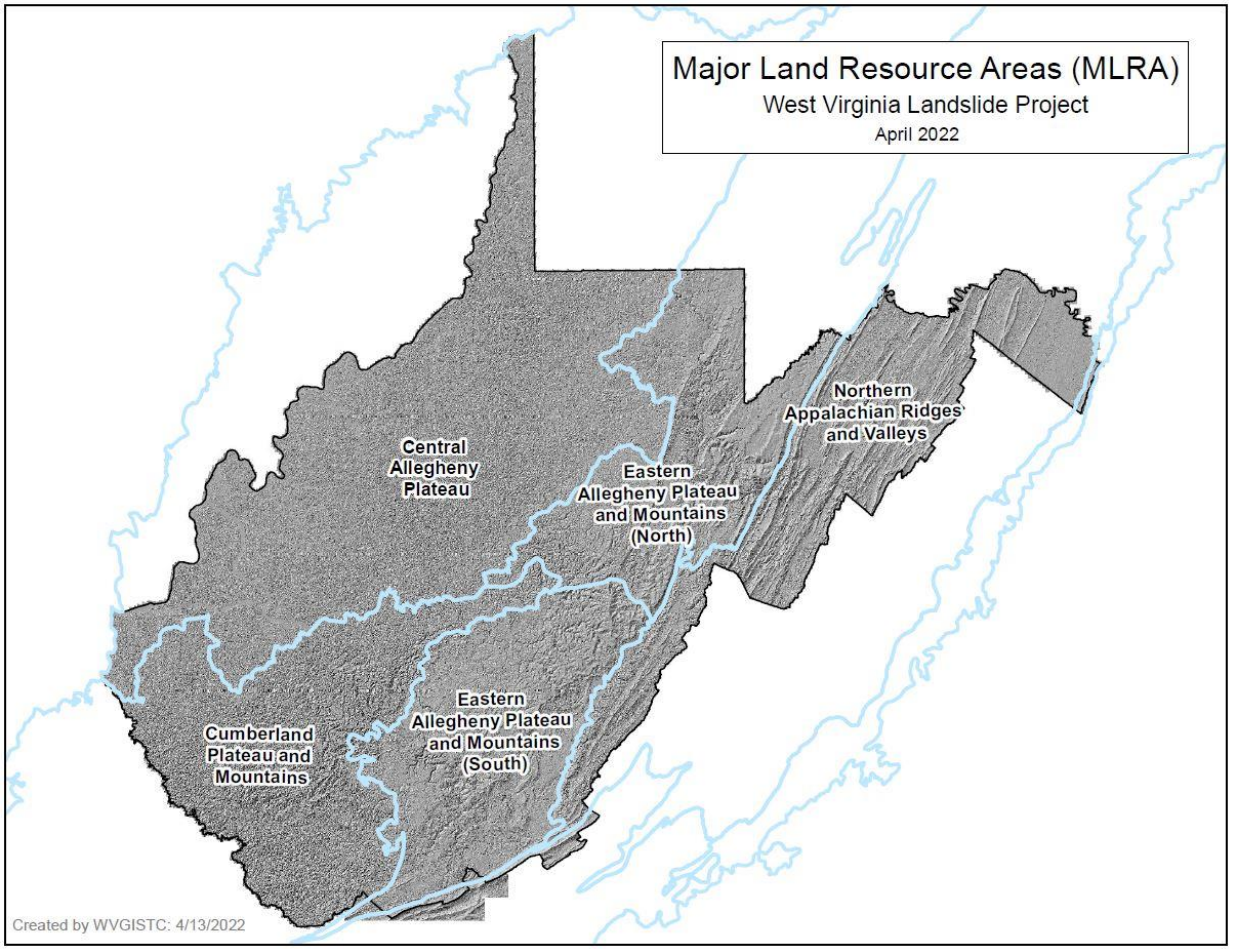
- Surface Area Ratio
- Slope
- Surface Relief Ratio
- Slope Position
- Curvature
- Topographic Roughness
- Topographic Dissection





Landslide Method Development

- Semi-automated with scripting
- Developed models for different physiographic regions
- Predicted entire state



Landslide Risk Assessment Results

Key Takeaways

1. Risk assessment performed at sub-county scale
2. 53% area in high/medium susceptibility
3. 11% roads in high/medium risk*
4. Structures- majority located in high medium landslide susceptibility area are Residential
    I. Kanawha and Monongalia counties rank 1st or 2nd
    II. Harrison and Ohio counties rank 1st and 2nd for Commercial asset values
5. Essential Facilities – 14 located in high/medium susceptibility area
6. Relative risk to humans and related infrastructure is highest in Region 6, which ranks either 1st or 2nd in all five road and structure risk analysis categories

Landslide Risk Assessment Results

Key Takeaways

State Summary					
At-Risk State Total					
Total Road Miles in High/Medium risk Areas	**Number of Structure/Parcel in High/Medium Risk Areas**	**Total Replacement Costs for Structures in High/Medium Risk Areas***	**Number of Essential Facilities in High/Medium Risk Areas**	**Total Replacement cost for Critical Infrastructure in High/Medium Risk Areas**	**Total Land Area in High/Medium Risk (Acres)**
4,346	29,618	$1,979,392,672	14	$241,432,300	8,261,236
State Total					
Total Road Miles in State	**Total Number of Structure/Parcel in State**	**Total Cost of Strucutre in State**	**Total Number of Essential Facilities in the State**	**Total Replacement Cost for Critical Infrastructure***	**Total area in the State (Acres)**
39,287	800,758	$85,823,642,303	1930	$6,694,090,205	15,499,505
Percentage at Risk					
Percent Road Miles in High/Medium risk Areas	**Percent Structure/Parcel in High/Medium Risk Areas**	**Percent Replacement Cost for Structures in High/Medium Risk Areas***	**Percent Essential Facilities in High/Medium Risk Areas**	**Percent Replacement cost for Critical Infrastructure in High/Medium Risk Areas***	**Percent of Land Area in High/Medium Risk**
11%	4%	2%	1%	4%	53%

Landslide Risk Assessment Results

Key Takeaways

	REGION RANKINGS					
Region	Road Miles in High/Medium Risk Areas	Number of Structures in High/Medium Risk Areas	Total Replacement Costs for Structures in High/Medium Risk Areas	Number of Essential Facilities in High/Medium Risk Areas	Total Replacement Costs for Essential Facilities in High/Medium Risk Areas	Percent of Land Area Classified as High/Medium Risk
1	4	3	9	3	3	5
2	6	4	7	2	4	4
3	7	1	2	3	5	3
4	5	9	6	-	-	2
5	3	8	10	3	-	8
6	2	2	1	1	1	7
7	1	5	8	-	-	6
8	8	7	5	-	-	1
9	10	10	3	3	2	11
10	9	6	4	3	6	9
11	11	11	11	-	-	10

Landslide Risk Assessment Results

Road risk analysis

1. Risk assessment performed using DOT data
    I. For Interstates, US Roads, State, and Other roads (county roads, N/A, state parks, and forests road, FANS, HARP, and Others)
    II. Municipal non-state roads, railroads, and trail features not included
2. Roads were analyzed at two scales
    I. An overview level on all roads without any distinction between road types to get the total risk to roads
        I. Result used to rank Regions based on the total length of susceptible road segments.
    II. The second set of analyses contains susceptibility details relating to different types of roads

Landslide Risk Assessment Results

Road length susceptible to High/Medium Landslide Risk

Region	Roads Total (miles)	Roads Total (miles)-High/Medium Risk	Percent of Roads in High/Medium Risk Areas	Rank[1]
1	4975.6	556.4	11.2%	4
2	4471	339.6	7.6%	6
3	3441.8	318.2	9.2%	7
4	4148.6	475.6	11.5%	5
5	5287.5	599.5	11.3%	3
6	5227.2	696.7	13.3%	2
7	5170.2	793.6	15.3%	1
8	2835.4	247.1	8.7%	8
9	1658.2	46.9	2.8%	10
10	1591.9	228.3	14.3%	9
11	479.4	44.2	9.2%	11

[1]Rank based on total road miles at risk

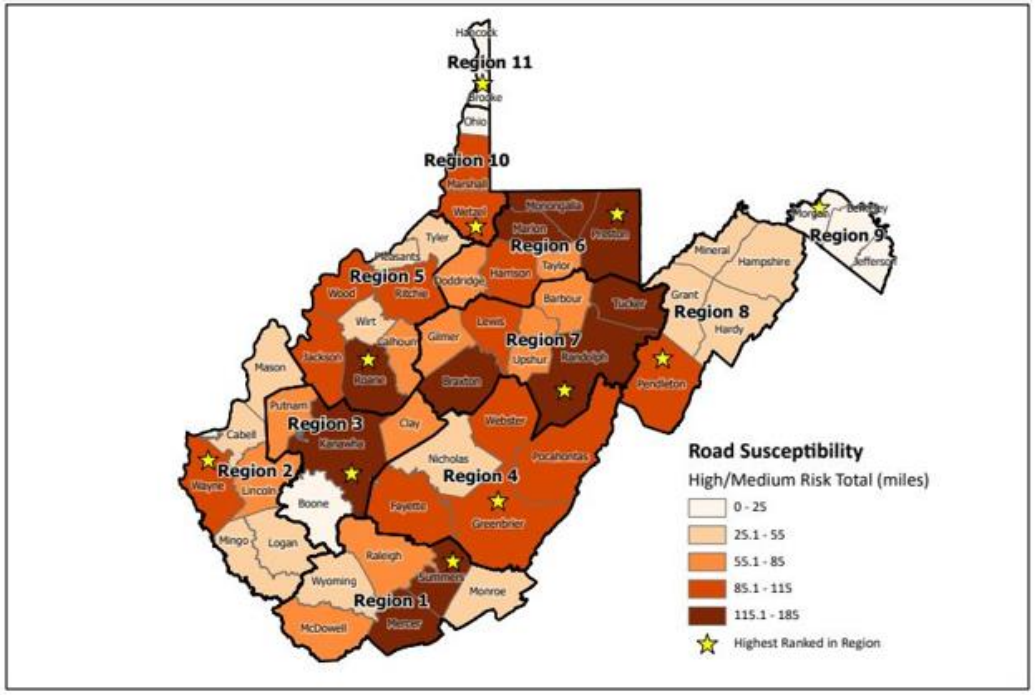
Road length susceptible to High/Medium Landslide Risk

Region	County	Roads Total (miles)	Roads Total (miles)-High/Medium Risk	Percent of Roads in High/Medium Risk Areas in the County	Percent of Total Roads in High/Medium Risk Areas in the Region
1	Summers	633.4	150.1	23.7%	27%
2	Wayne	999.3	103.8	10.4%	31%
3	Kanawha	1725.1	152.5	8.8%	48%
4	Greenbrier	1145.6	109.9	9.6%	23%
5	Roane	903.2	123.5	13.7%	21%
6	Preston	1312.3	172.8	13.2%	25%
7	Randolph	998.9	181.1	18.1%	23%
8	Pendleton	641.4	85.5	13.3%	35%
9	Morgan	431.1	21.3	4.9%	45%
10	Wetzel	644.2	105.1	16.3%	46%
11	Brooke	244.9	22.9	9.4%	52%

Landslide Risk Assessment Results

Top 10 counties statewide by road miles in High/Medium Susceptibility Areas

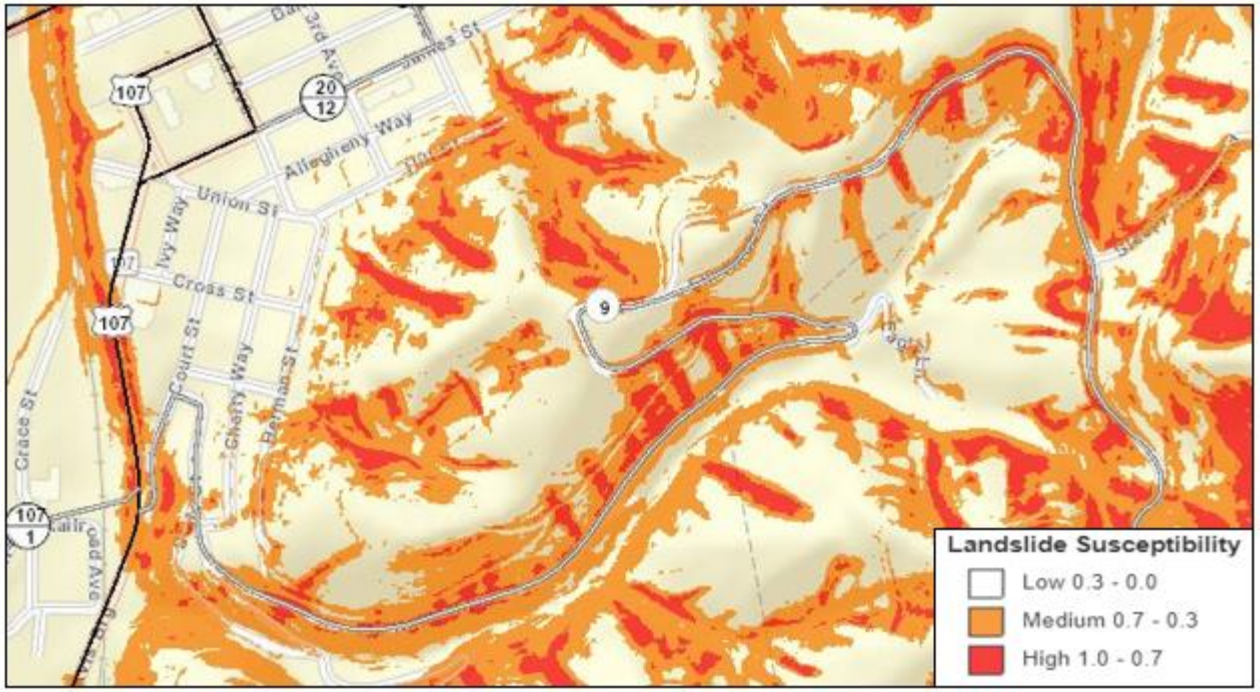
Region	County	Roads Total (miles)	Roads Total (miles)-High/Medium Risk	Percent of Roads in High/Medium Risk Areas
7	Randolph	998.9	181.1	18.1%
6	Preston	1312.3	172.8	13.2%
7	Braxton	896.2	165.7	18.5%
3	Kanawha	1725.1	152.5	8.8%
1	Summers	633.4	150.1	23.7%
1	Mercer	1127.7	138.1	12.2%
6	Marion	854.5	136.7	16.0%
6	Monongalia	1001	132	13.2%
7	Tucker	526.3	131.7	25.0%
5	Roane	903.2	123.5	13.7%



Total road miles in High/Medium Susceptibility Areas

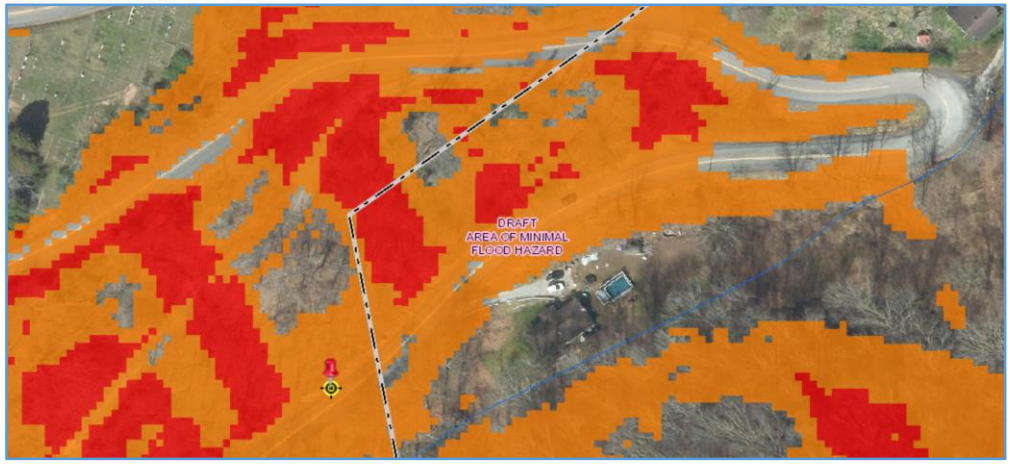
Landslide Risk Assessment Results

Landslide risk near Hinton, WV in Summers County



[WV Flood Tool]

[WV Landslide Tool]

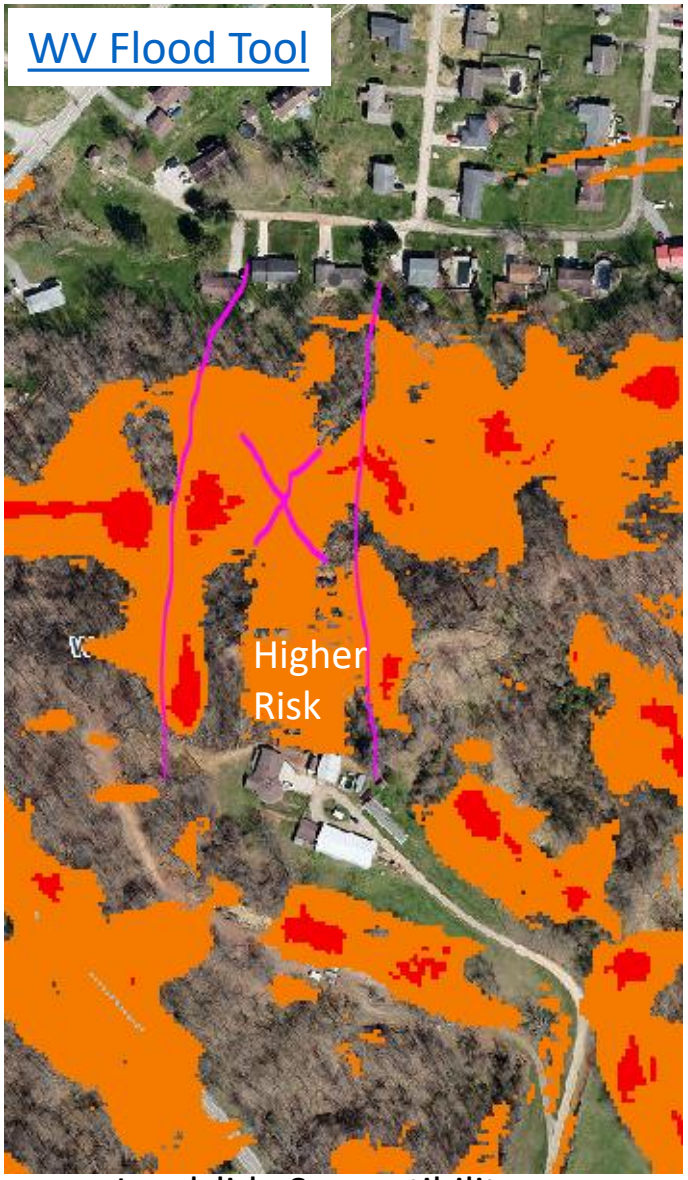


Landslide Risk Assessment Results

Structure/Parcel Risk Analysis

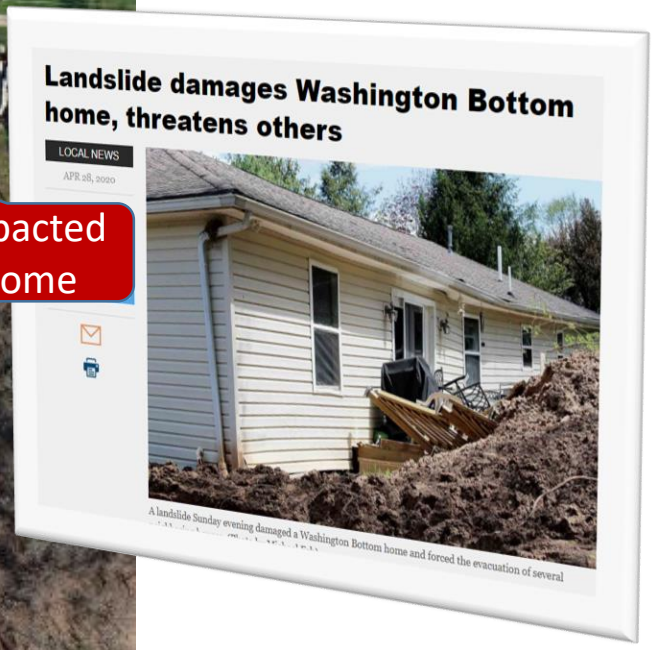
1. Risk assessment performed on parcel level data
    I. Primary structure point used within 1% annual chance floodplain
    II. Parcel with site address points used outside floodplain
2. *Limitations*
    I. Parcels containing no addressing points assigned a building value of zero ($0).
    II. Building values for some structures are less than the values recorded
        I. 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.
    III. Some government and other property values do not get pulled in from the statewide assessment database, resulting in a lower value of at-risk structures.
    IV. This study is NOT intended for regulatory use and is NOT the final authoritative source of all landslide risk data in the community

Landslide Risk Assessment Results



Landslide Susceptibility

Spring 2020 Aerial Imagery



April 2020
Landslide

Wood County

Impacted home moved from foundation

Landslide Risk Assessment Results

Structures with High/Medium Risk Landslide Susceptibility

Region	Total Count	Total Value	Ranking (Count)	Ranking (Value)
1	3,489	$76,729,607	3	9
2	3,130	$95,832,732	4	7
3	6,956	$455,472,095	**1**	2
4	1,301	$104,555,980	9	6
5	1,476	$49,211,106	8	10
6	5,805	$725,657,563	2	**1**
7	2,327	$80,007,169	5	8
8	1,597	$111,771,975	7	5
9	1,195	$142,031,474	10	3
10	1,650	$119,190,690	6	4
11	692	$18,932,281	11	11

Highest ranked county in each Region by structure count & by value

Region	HIGHEST RANK BY COUNT		HIGHEST RANK BY VALUE	
	County	Total Count	County	Total Value
1	McDowell	1,205	Mercer	$29,675,908
2	Cabell	772	Cabell	$54,280,453
3	Kanawha	5,751	Kanawha	$399,596,198
4	Fayette	305	Greenbrier	$61,943,791
5	Wood	392	Wood	$20,735,403
6	Monongalia	2,967	Monongalia	$344,409,948
7	Lewis	757	Randolph	$25,428,143
8	Hampshire	402	Mineral	$34,302,956
9	Berkeley	516	Berkeley	$57,360,557
10	Ohio	887	Ohio	$90,742,380
11	Hancock	381	Hancock	$11,926,699

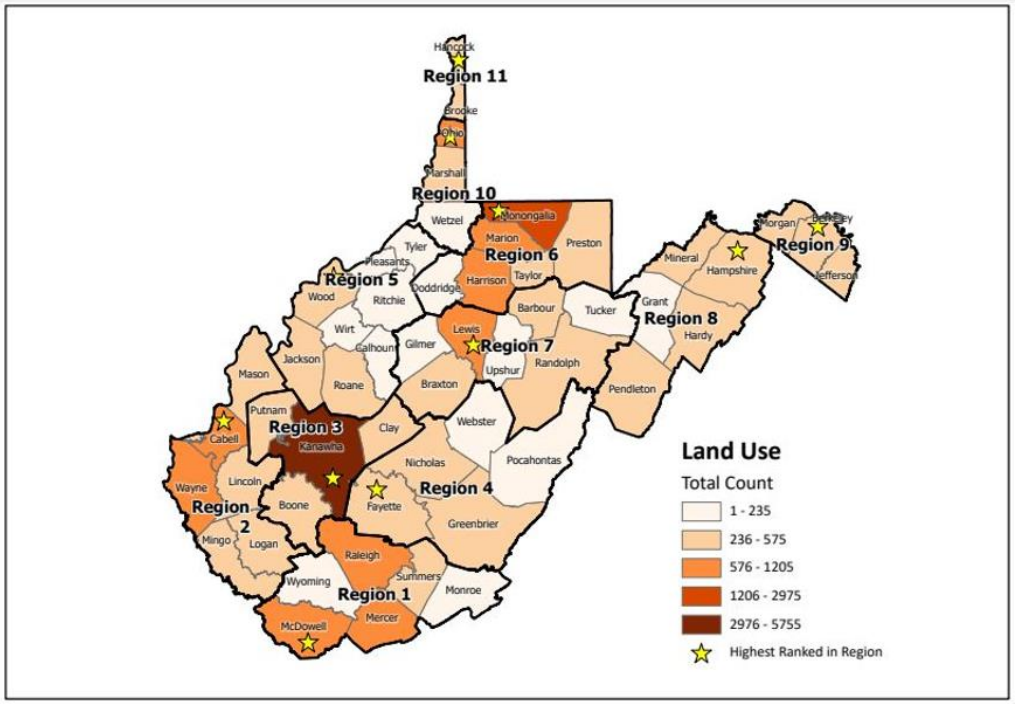
Landslide Risk Assessment Results

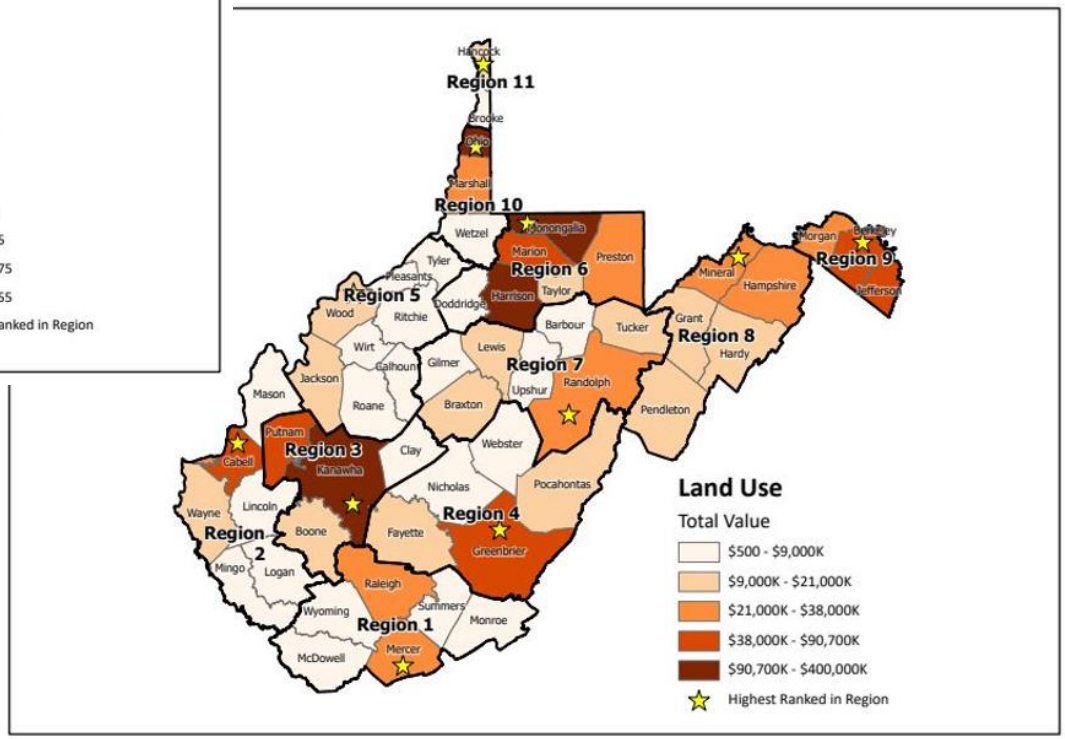
Top 10 counties statewide by structure count & by value

HIGHEST RANK BY COUNT			HIGHEST RANK BY VALUE		
Region	County	Total Count	Region	County	Total Value
3	Kanawha	5,751	3	Kanawha	$399,596,198
6	Monongalia	2,967	6	Monongalia	$344,409,948
1	McDowell	1,205	6	Harrison	$256,888,640
6	Harrison	1,069	10	Ohio	$90,742,380
1	Mercer	992	6	Marion	$71,733,187
6	Marion	941	4	Greenbrier	$61,943,791
10	Ohio	887	9	Berkeley	$57,360,557
2	Cabell	772	2	Cabell	$54,280,453
7	Lewis	757	9	Jefferson	$52,730,494
2	Wayne	728	3	Putnam	$38,146,493

Landslide Risk Assessment Results

Number of structures in High/Medium Susceptibility Areas





Total Value of structures in High/Medium Susceptibility Areas

Landslide Risk Assessment Results

Essential Facility Risk Analysis

1. Risk assessment performed on parcel level data
   I. Facilities included in this analysis include: police departments, fire departments, 911 centers, nursing homes, hospitals, and K-12 schools

2. *Limitations*
   I. This study is not intended for site-specific analysis or remediation measures and is only suitable for planning-level analysis
   II. Some government and other property values do not get pulled in from the statewide assessment database, resulting in a lower value of at-risk structures.
   III. This study is NOT intended for regulatory use and is NOT the final authoritative source of all landslide risk data in the community

Landslide Risk Assessment Results

Essential facilities with High/Medium Risk Landslide Susceptibility

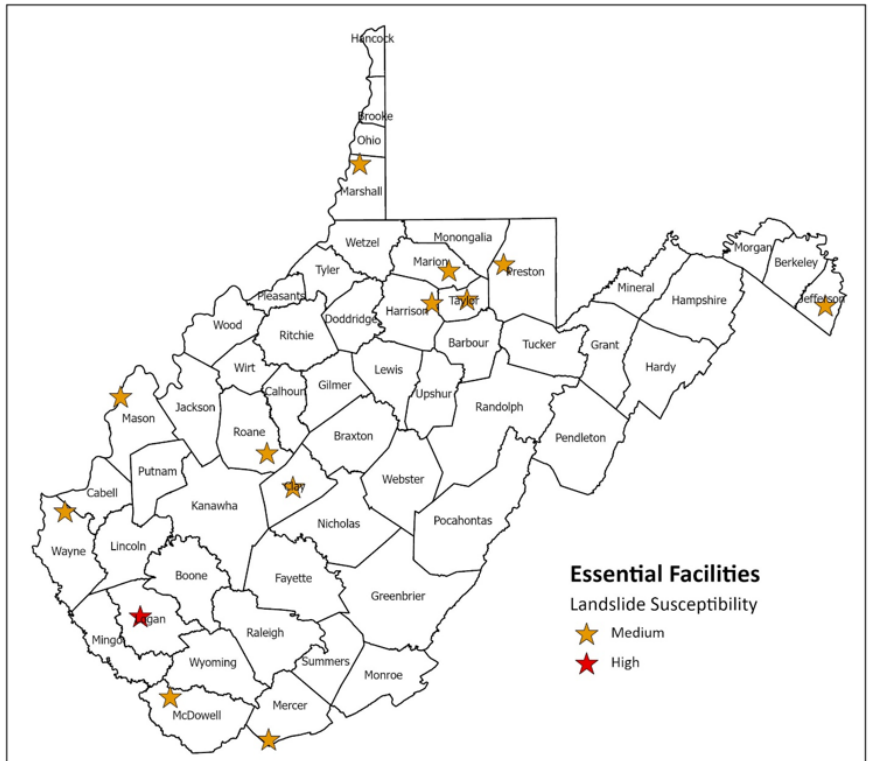
Region	Total Count	Total Value	Ranking (Count)	Ranking (Value)
1	3	$1,125,700	2	4
2	3	$1,371,400	2	3
3	1	$554,100	3	5
4	0	-	-	-
5	1	-	3	-
6	4	$236,413,800	1	1
7	0	-	-	-
8	0	-	-	-
9	1	$1,951,400	3	2
10	1	$15,900	3	6
11	0	-	-	-

Types of essential facilities in High/Medium Risk Areas

Region	911 Centers	Police Departments	Fire Departments	Hospitals	Nursing Homes	Schools (K-12)
1	0	1	2	0	0	0
2	1	0	1	1	0	0
3	0	0	0	0	0	1
4	0	0	0	0	0	0
5	0	0	0	0	0	1
6	0	1	0	1	2	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	1	0
10	0	0	1	0	0	0
11	0	0	0	0	0	0

Landslide Risk Assessment Results

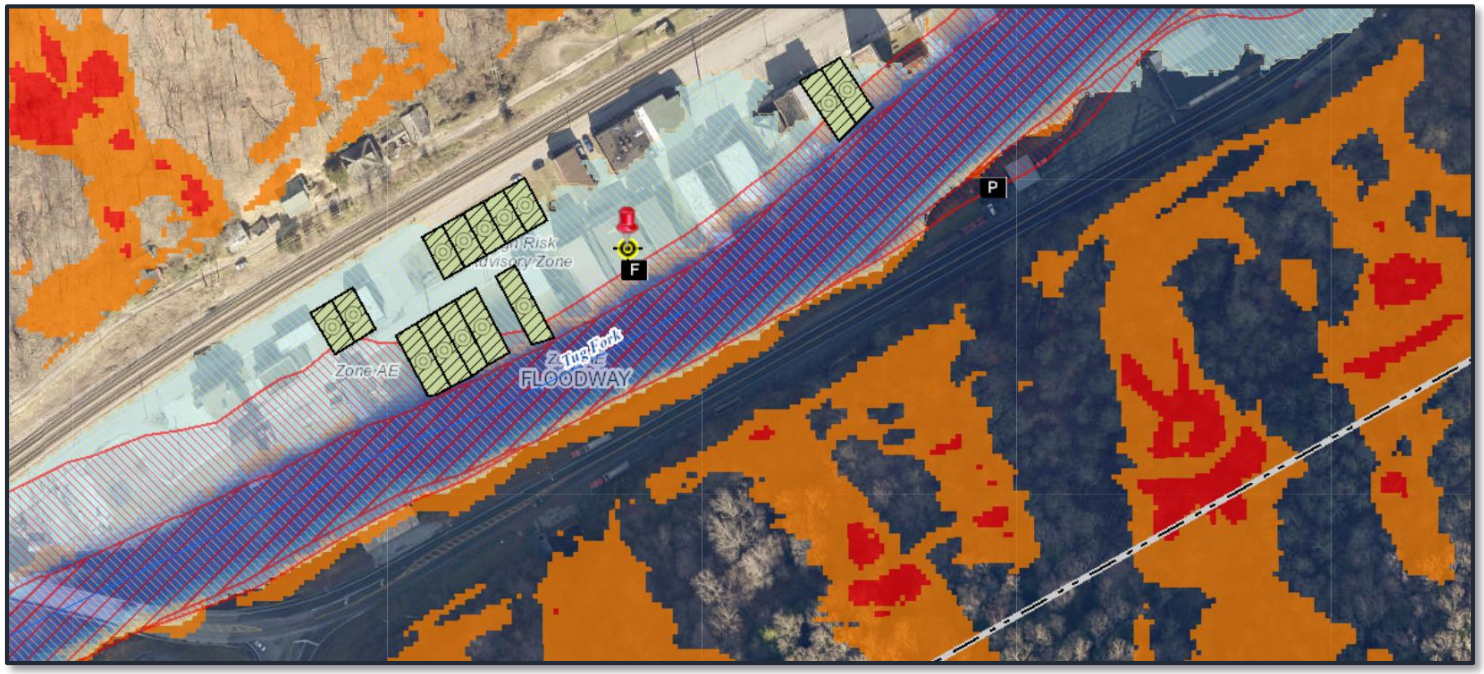
Essential facilities located in High/Medium Landslide Susceptibility Areas



County	Name	Landslide Susceptibility
Clay	Clay County Elementary School	Medium
Harrison	United Hospital Center, Inc.	Medium
Jefferson	Willow Tree Healthcare Center - Communicare	Medium
Logan	Logan General Hospital and Regional Medical Center	High
Marion	John Manchin Sr. Health Care Center	Medium
Marshall	Sherrard Volunteer Fire Department	Medium
Mason	Mason County 911 Center	Medium
McDowell	Iaeger Volunteer Fire Department	Medium
Mercer	Bluefield Police Department	Medium
Mercer	Bluefield Fire Department Station 1	Medium
Preston	Reedsville Police Department	Medium
Roane	Geary Elementary & Middle School	Medium
Taylor	Taylor Health Care Center - AMFM Nursing & Rehab Centers	Medium
Wayne	Lavalette Volunteer Fire Department	Medium

Landslide Risk Assessment Results

Iaeger Volunteer Fire Department. McDowell County



[WV Flood Tool]

[WV Landslide Tool]

Landslide Risk Assessment Results

AMFM Nursing & Rehab Centers, Taylor County

WV Flood Tool

WV Landslide Tool

Landslide Risk Assessment Results

Total Area Risk Analysis

1. Total area risk analysis assesses the total area of land classified as high/medium risk of landslide susceptibility in West Virginia
2. *Limitations*
   - I. *This study is not intended for site-specific analysis or remediation measures and is only suitable for planning-level analysis*
   - II. *This study is NOT intended for regulatory use and is NOT the final authoritative source of all landslide risk data in the community*

Landslide Risk Assessment Results

Total area of land classified as High/Medium Landslide Susceptibility

Region	Area Total (acres)	Area Total (acres)- High/Medium Risk	Percent of Area Classified as High/Medium Risk	Rank[1]
1	1,859,569	1,042,500	56.1%	5
2	1,640,167	969,248	59.1%	4
3	1,348,345	799,345	59.3%	3
4	2,459,430	1,468,436	59.7%	2
5	1,724,768	786,722	45.6%	8
6	1,433,742	672,012	46.9%	7
7	2,177,502	1,120,046	51.4%	6
8	1,751,413	1,076,990	61.5%	**1**
9	488,638	99,211	20.3%	11
10	500,188	187,382	37.5%	9
11	115,743	33,661	29.1%	10

[1]Rank based on percent of area classified as high/medium risk

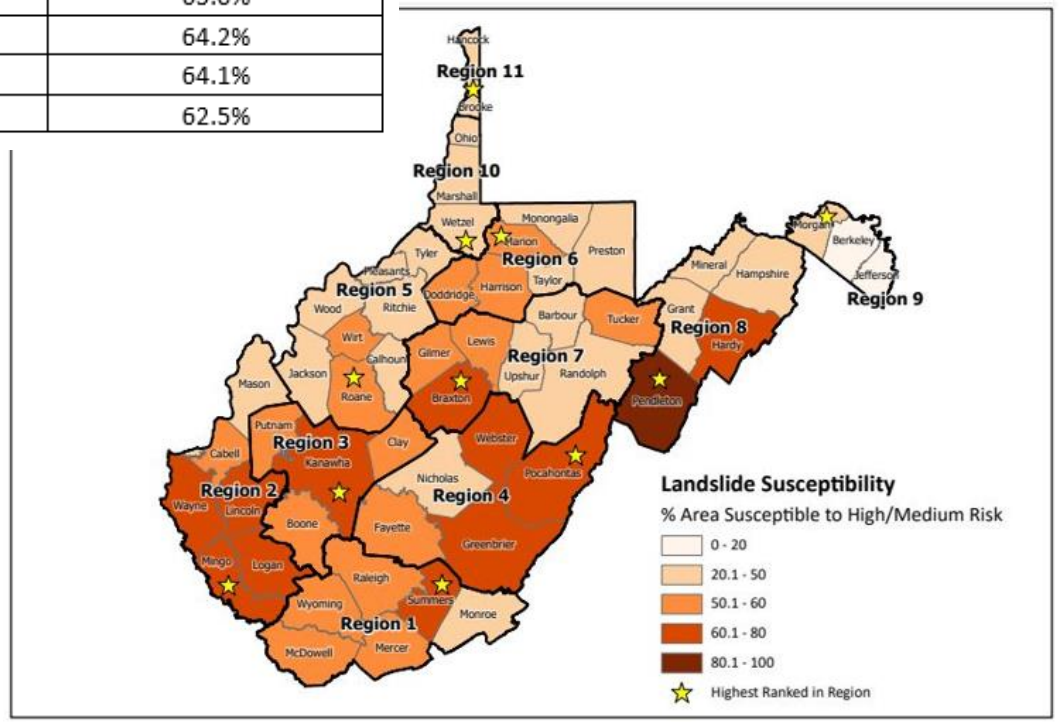
Highest ranked county in each Region by percent of area classified as High/Medium Susceptibility

Region	County	Total Area (acres)	Total Area (acres)- High/Medium Risk	Percent of County Area Classified as High/Medium Risk	Percent of High/Medium Risk Area in Region
1	Summers	235,138	169,495	72.1%	16%
2	Mingo	271,217	188,202	69.4%	19%
3	Kanawha	582,509	373,549	64.1%	47%
4	Pocahontas	602,346	417,884	69.4%	28%
5	Roane	309,396	173,100	55.9%	22%
6	Marion	199,219	109,559	55.0%	16%
7	Braxton	330,400	224,049	67.8%	20%
8	Pendleton	446,660	401,531	89.9%	37%
9	Morgan	147,140	57,403	39.0%	58%
10	Wetzel	231,050	114,114	49.4%	61%
11	Brooke	59,353	18,047	30.4%	54%

Landslide Risk Assessment Results

Top 10 counties statewide by percent of area in High/Medium Susceptibility Areas

Region	County	Total Area (acres)	Total Area (acres) - High/Medium Risk	Percent of County Area Classified as High/Medium Risk
8	Pendleton	446,660	401,531	89.9%
1	Summers	235,138	169,495	72.1%
2	Mingo	271,217	188,202	69.4%
4	Pocahontas	602,346	417,884	69.4%
7	Braxton	330,400	224,049	67.8%
2	Logan	291,411	194,254	66.7%
4	Webster	355,723	231,396	65.0%
8	Hardy	374,055	239,996	64.2%
3	Kanawha	582,509	373,549	64.1%
2	Lincoln	280,780	175,372	62.5%

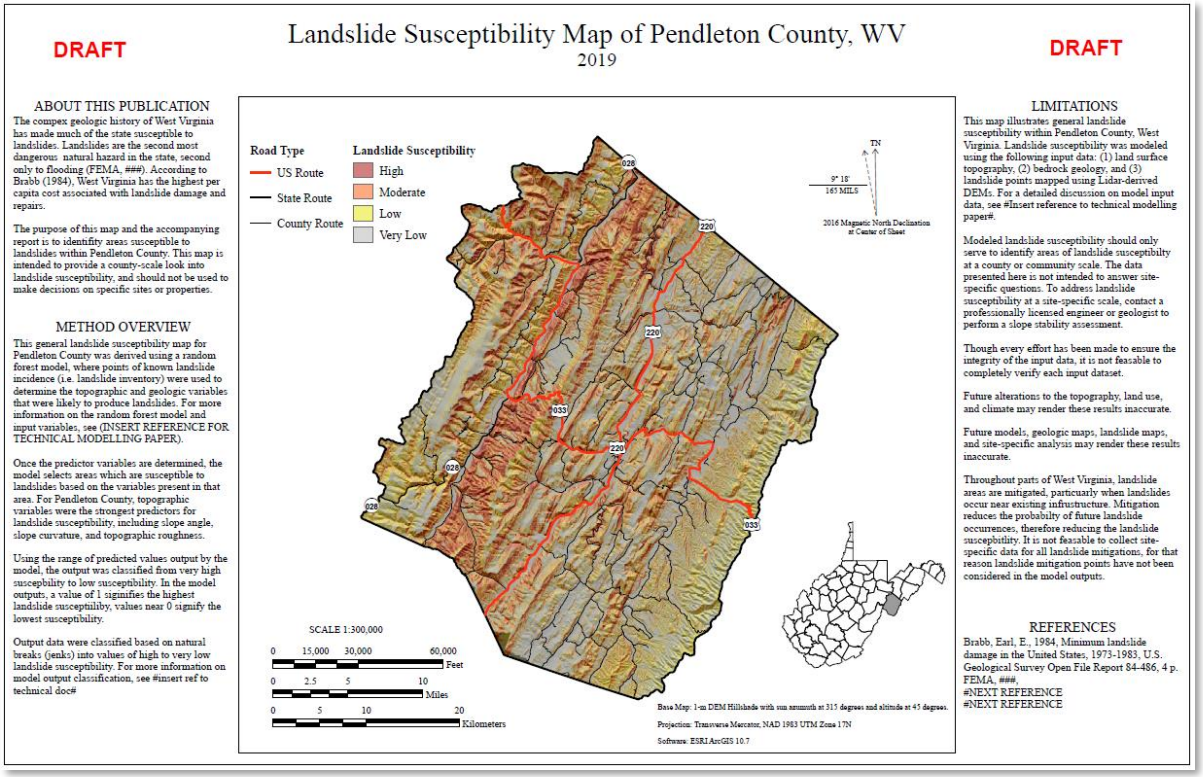


Percent of total land area in High/Medium Susceptibility Areas

Landslide Susceptibility Prediction

Susceptibility and Hazard Assessment

- Produced landslide susceptibility map by county
- Calculate at risk properties for each county/region



DRAFT

Landslide Susceptibility Map of Pendleton County, WV
2019

DRAFT

ABOUT THIS PUBLICATION

The compex geologic history of West Virginia has made much of the state susceptible to landslides. Landslides are the second most dangerous natural hazard in the state, second only to flooding (FEMA, ###). According to Brabb (1984), West Virginia has the highest per capita cost associated with landslide damage and repairs.

The purpose of this map and the accompanying report is to identifity areas susceptible to landslides within Pendleton County. This map is intended to provide a county-scale look into landslide susceptibility, and should not be used to make decisions on specific sites or properties.

METHOD OVERVIEW

This general landslide susceptibility map for Pendleton County was derived using a random forest model, where points of known landslide incidence (i.e. landslide inventory) were used to determine the topographic and geologic variables that were likely to produce landslides. For more information on the random forest model and input variables, see (INSERT REFERENCE FOR TECHNICAL MODELLING PAPER).

Once the predictor variables are determined, the model selects areas which are susceptible to landslides based on the variables present in that area. For Pendleton County, topographic variables were the strongest predictors for landslide susceptibility, including slope angle, slope curvature, and topographic roughness.

Using the range of predicted values output by the model, the output was classified from very high susceptibility to low susceptibility. In the model outputs, a value of 1 signifies the highest landslide susceptibiloby, values near 0 signify the lowest susceptibility.

Output data were classified based on natural breaks (jenks) into values of high to very low landslide susceptibility. For more information on model output classification, see #insert ref to technical doc#

Road Type
US Route
State Route
County Route

Landslide Susceptibility
High
Moderate
Low
Very Low

TN
9° 18'
165 MILS
2016 Magnetic North Declination at Center of Sheet

SCALE 1:300,000
0 15,000 30,000 60,000 Feet
0 2.5 5 10 Miles
0 5 10 20 Kilometers

Base Map: 1-m DEM Hillshade with sun azumuth at 315 degrees and altitude at 45 degrees.
Projection: Transverse Mercator, NAD 1983 UTM Zone 17N
Software: ESRI ArcGIS 10.7

LIMITATIONS

This map illustrates general landslide susceptibility within Pendleton County, West Virginia. Landslide susceptibility was modeled using the following input data: (1) land surface topography, (2) bedrock geology, and (3) landslide points mapped using Lidar-derived DEMs. For a detailed discussion on model input data, see #Insert reference to technical modelling paper#.

Modeled landslide susceptibility should only serve to identify areas of landslide susceptibility at a county or community scale. The data presented here is not intended to answer site-specific questions. To address landslide susceptibility at a site-specific scale, contact a professionally licensed engineer or geologist to perform a slope stability assessment.

Though every effort has been made to ensure the integrity of the input data, it is not feasable to completely verify each input dataset.

Future alterations to the topography, land use, and climate may render these results inaccurate.

Future models, geologic maps, landslide maps, and site-specific analysis may render these results inaccurate.

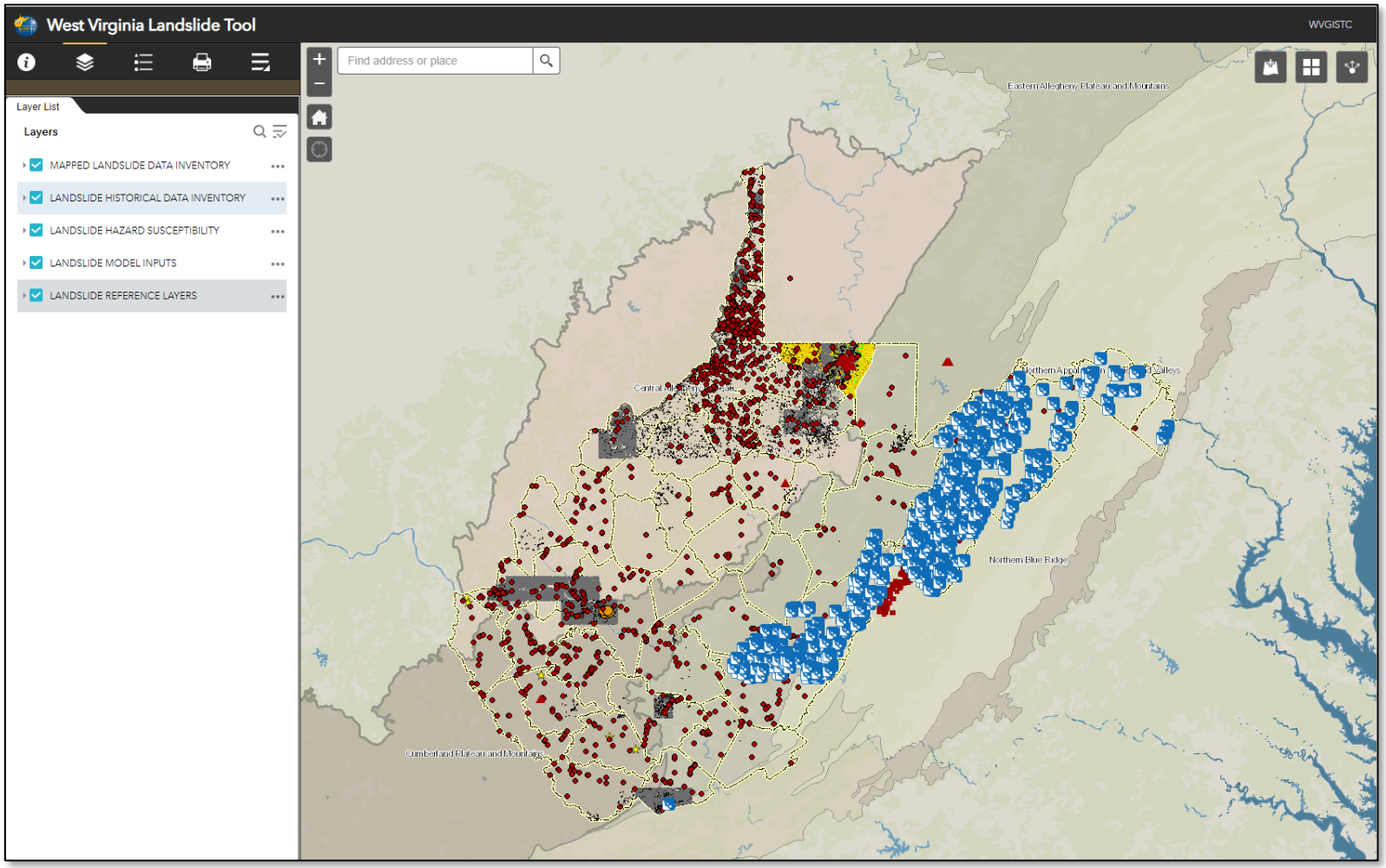
Throughout parts of West Virginia, landslide areas are mitigated, particularly when landslides occur near existing infrustructure. Mitigation reduces the probabilty of future landslide occurrences, therefore reducing the landslide susceptibility. It is not feasable to collect site-specific data for all landslide mitigations, for that reason landslide mitigation points have not been considered in the model outputs.

REFERENCES

Brabb, Earl, E., 1984, Minimum landslide damage in the United States, 1973-1983, U.S. Geological Survey Open File Report 84-486, 4 p.
FEMA, ###,
#NEXT REFERENCE
#NEXT REFERENCE

Landslide Incident Inventory

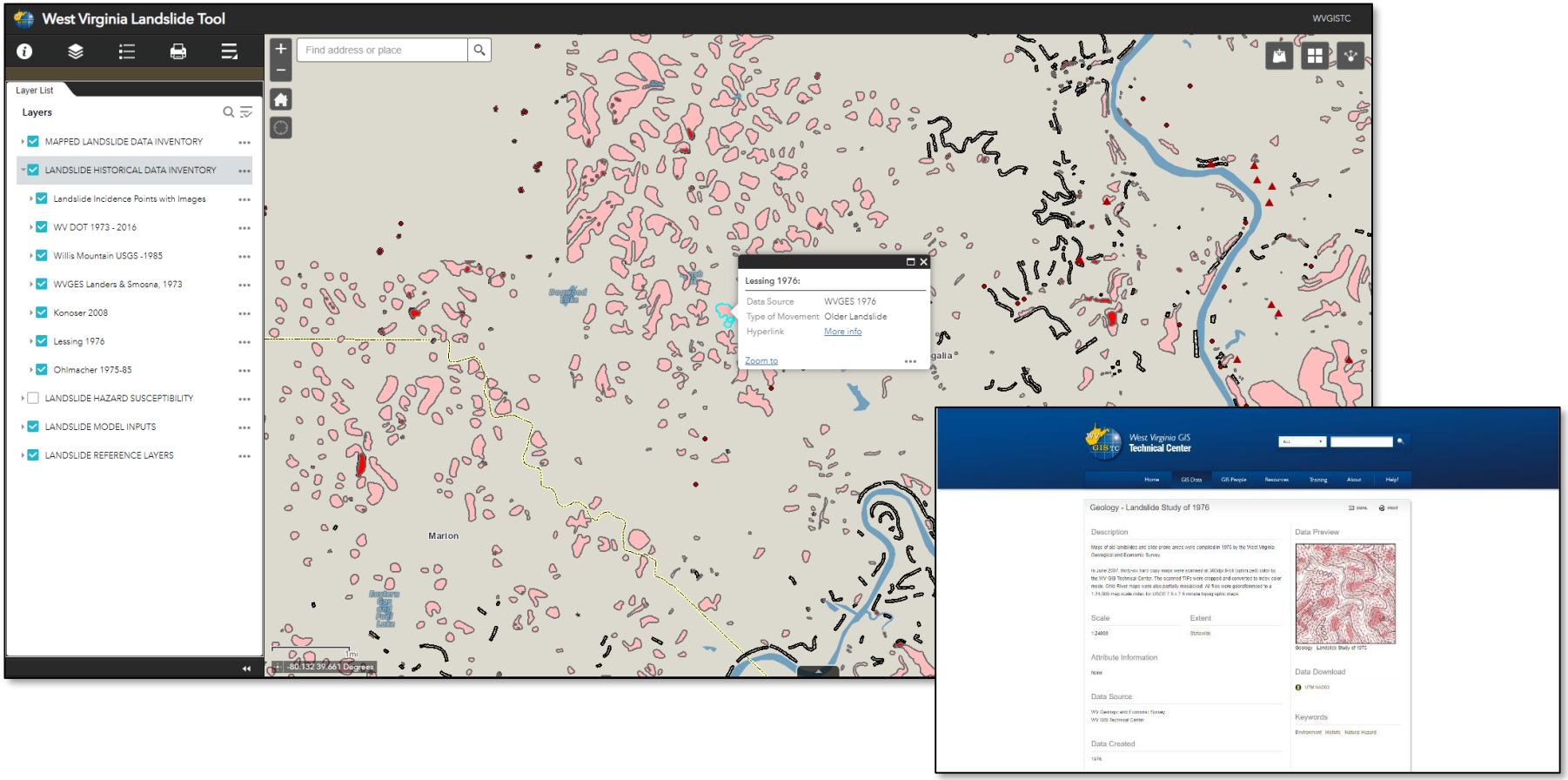
www.mapWV.gov/Landslide



Over 100,000 landslide incident point and polygon features have been inventoried into a digital geodatabase

Landslide Incident Inventory

www.mapWV.gov/Landslide



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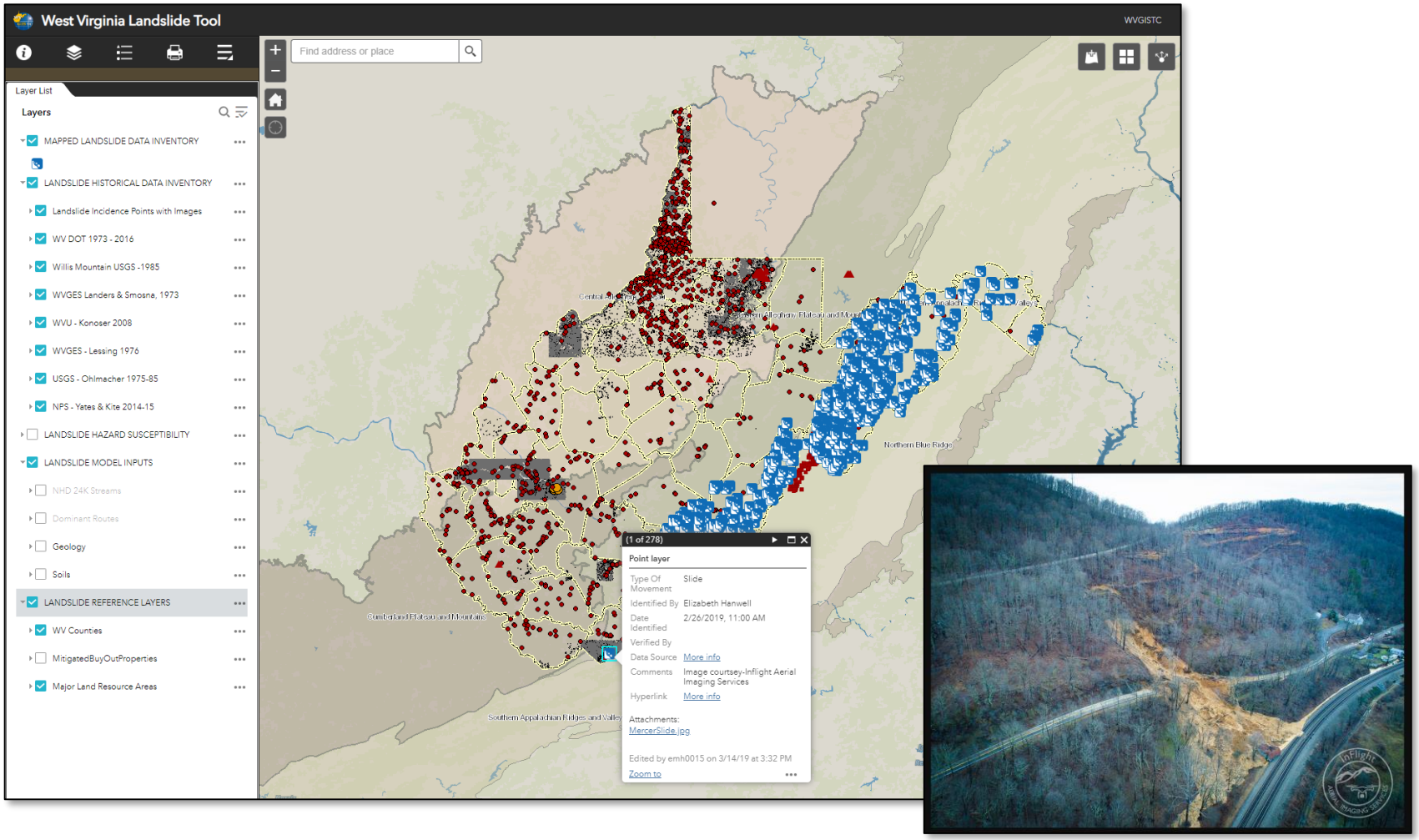
Landslide Incident Inventory

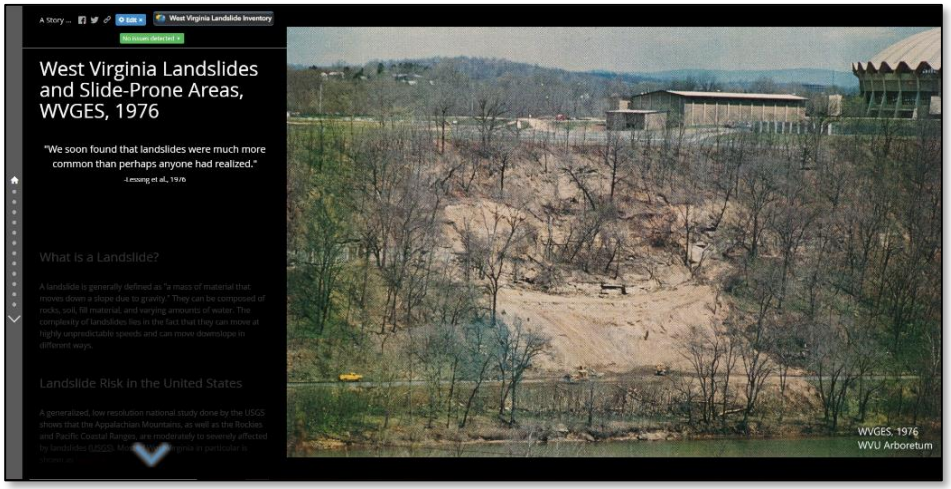
www.mapWV.gov/Landslide



Landslide Outreach Material

StoryMaps

West Virginia Landslides and Slide-Prone Areas, WVGES 1976



https://arcg.is/1KDnvq

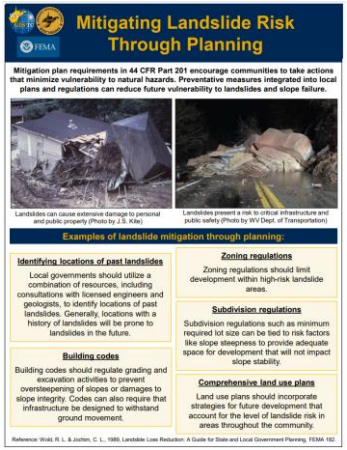
Causes of Landslides in Mountain State, West Virginia

https://arcg.is/1SW0Sn

Landslide Outreach Material

Brochures

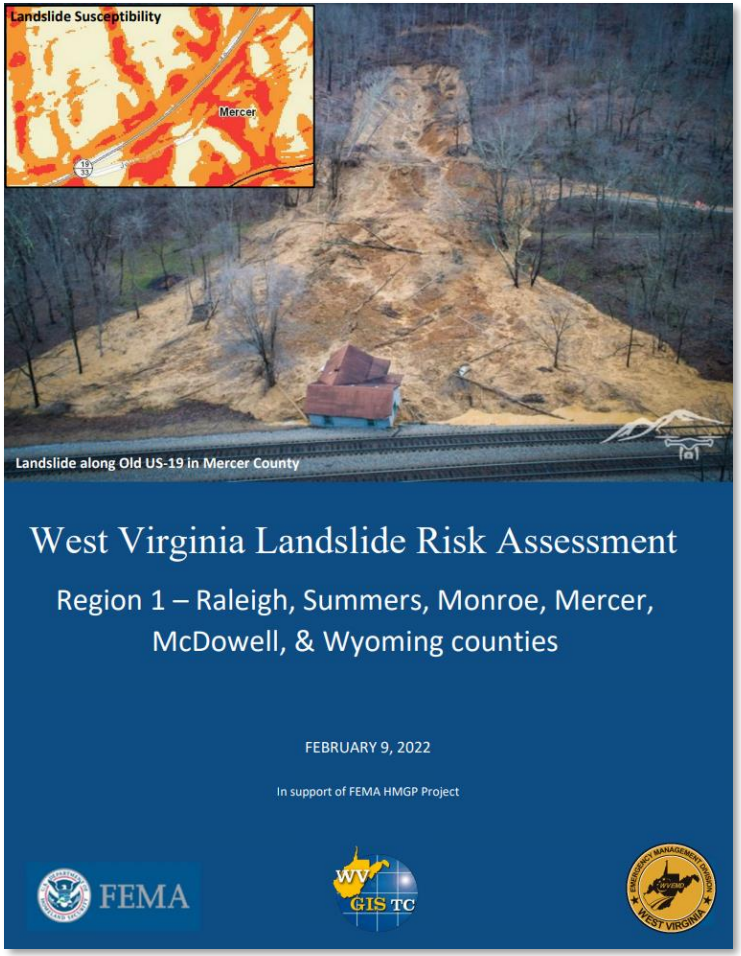
About identifying signs of slope instability and mitigation measures that may help reduce landslide risk at the community level



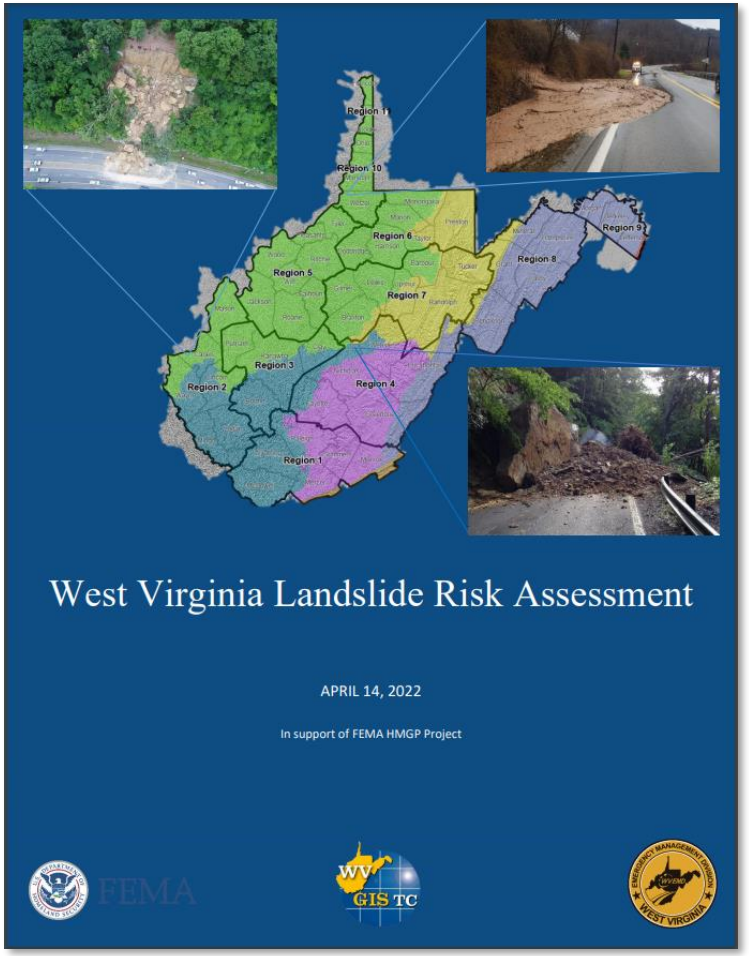
About identifying signs of slope instability and mitigation measures that may help reduce landslide risk at the individual property level

Landslide Outreach Material

Regional Reports



Statewide Report



Landslide Risk Assessment

Goals

- Develop a landslide inventory
- Create valid landslide models for specific WV regions
- Generate county-level resolution landslide maps
- Create an interactive web map application for displaying landslide models and variables
- Use the new landslide models and information to update the State Hazard Mitigation Plan

QUESTIONS?

2015 Yeager Airport Slide