Statewide Hazard Assessment

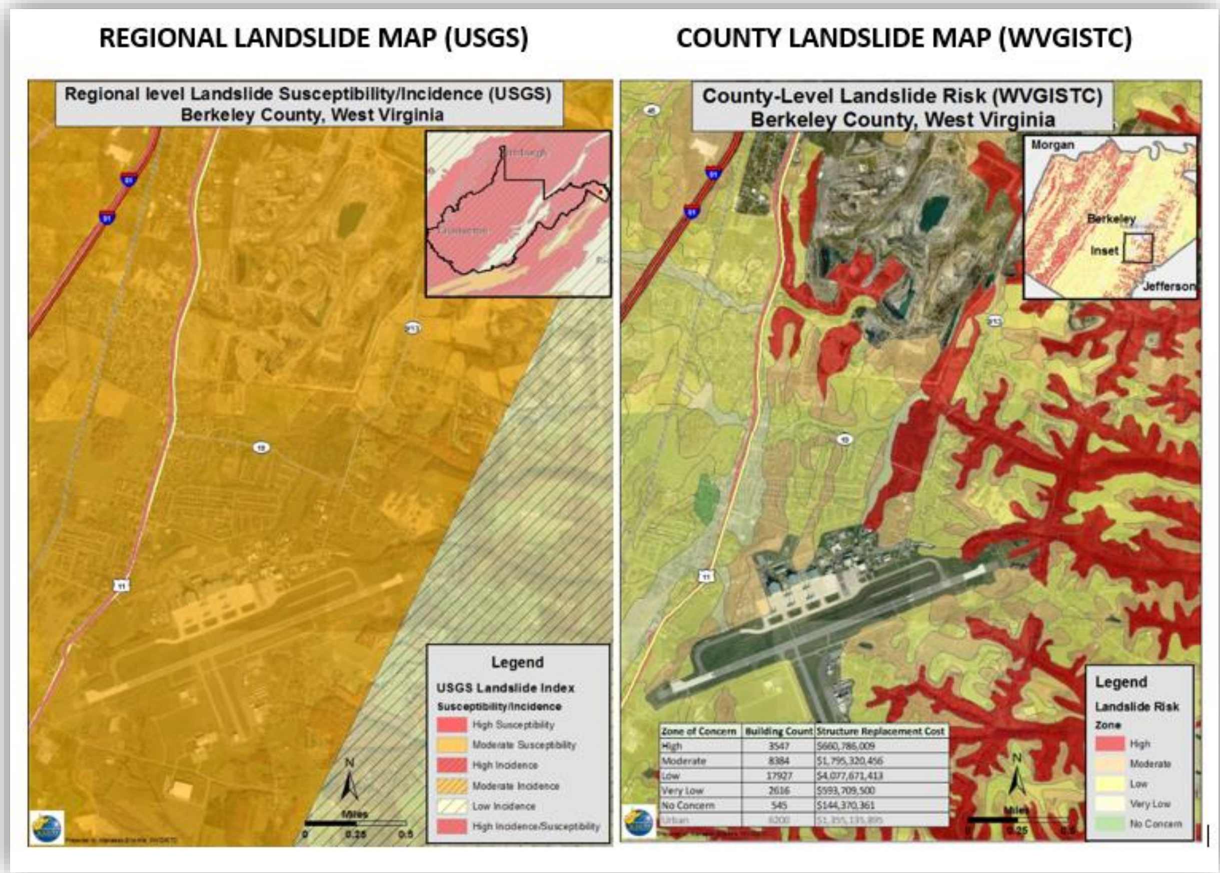
Landslide Risk Assessment

Presented to WV Geological & Economic Survey on 10/10/2019

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 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 Incident Inventory

Collected data from various sources

1. WVGES
   - Landers and Smosna, 1973
   - Lessing et al, 1976
   - Kite, 1985
2. NPS/WVGES
   - Yates and Kite, 2014-15
3. USGS
   - Ohlmacher et al, 1978-85
   - Jacobson et al, 1993
4. WVDHSEM
   - State Hazard Mitigation office
5. WVDOT
   - Geospatial Transportation Information (GTI) Section, 1973-2016
6. WVU
   - Kite, 1983-97
   - Konsoer et al, 2008
   - WVGISTC, 2018-ongoing

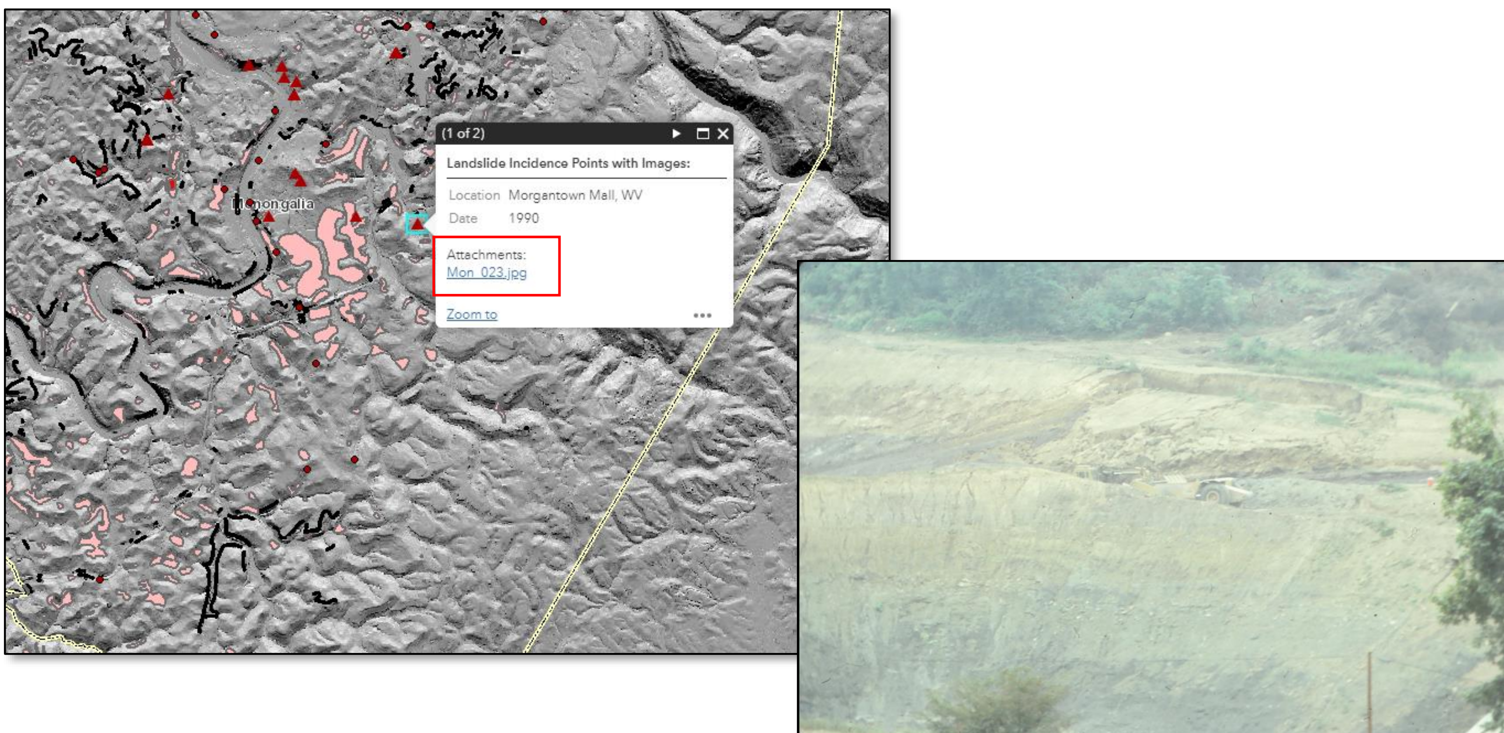
Landslide Incident Inventory

#	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 risk assessment	10
2	WVGES	**1976**	Lessing et al.	WV Landslides and Slide-Prone Areas; funded by Appalachian Regional Commission	Statewide (39 topo quads)	Landslide risk assessment	46,630
3	USGS	**1978-85**	Ohlmacher et al.	Landslide Quad Maps: Open File Maps	Statewide (382 topo quads)	Landslide risk assessment	41,307
4	WVGES	**1987**	Kite	SEFOP Field Guide, Open File Report 8801	Canaan Valley State Park	Research study (1985)	
5	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
6	WVU	**1983-97**	WVU	Landslide incidences with Images	Statewide	Landslide risk assessment	46
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	Landslide risk assessment	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	Landslide inventory	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	Landslide inventory	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	7
12	WVU	**2019**	WVGISTC	Statewide Landslide Risk Assessment; Funded by FEMA and WV Division of Homeland Security and Emergency Management	Statewide	Landslide risk assessment	10,071

103,114 landslide features

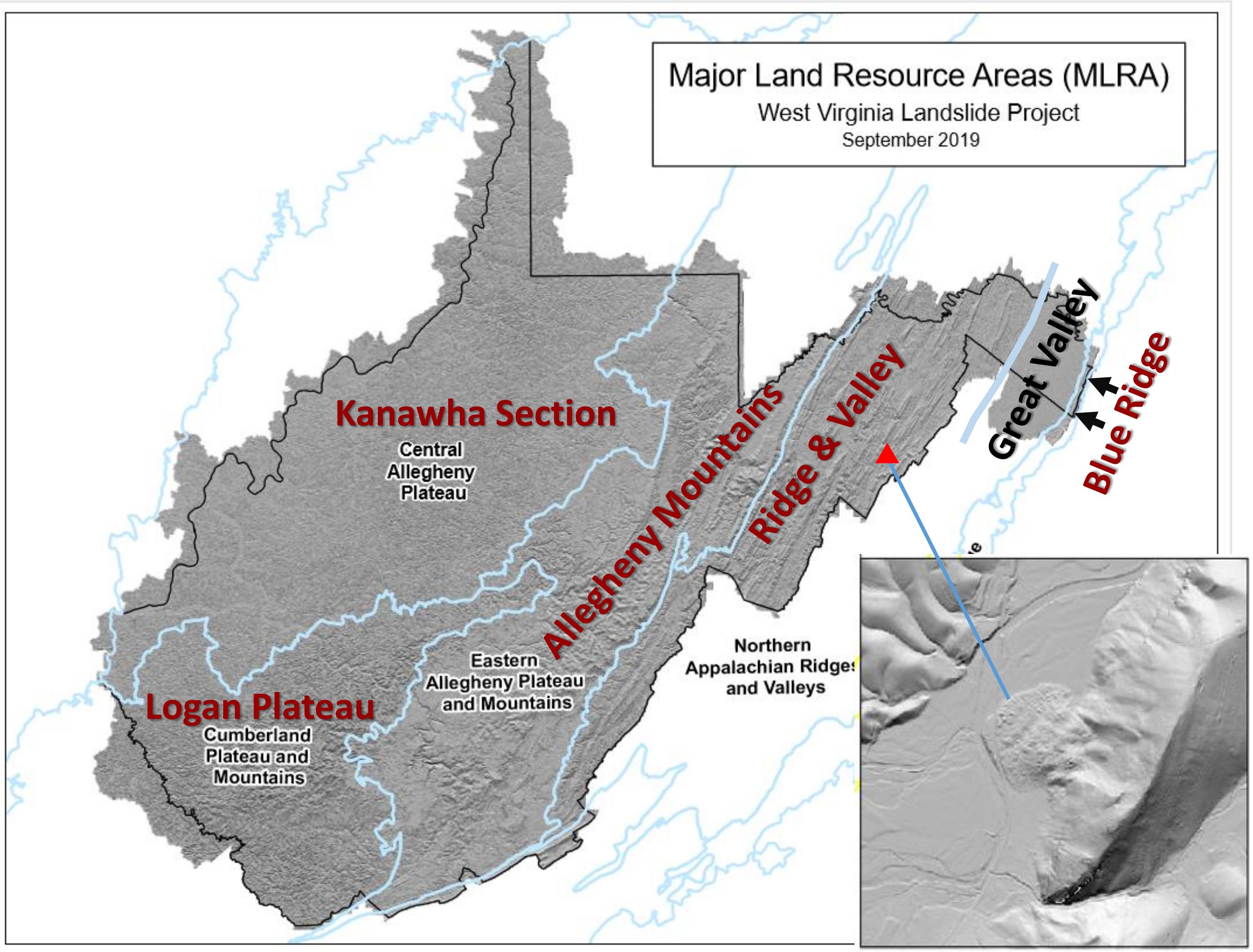
Landslide Incident Inventory

- Landslide Incidence Points with Images
  - From Dr. Kite
    - Slides were scanned and tagged with geographical information, dates taken, and descriptions
    - Added to the landslide incidence database

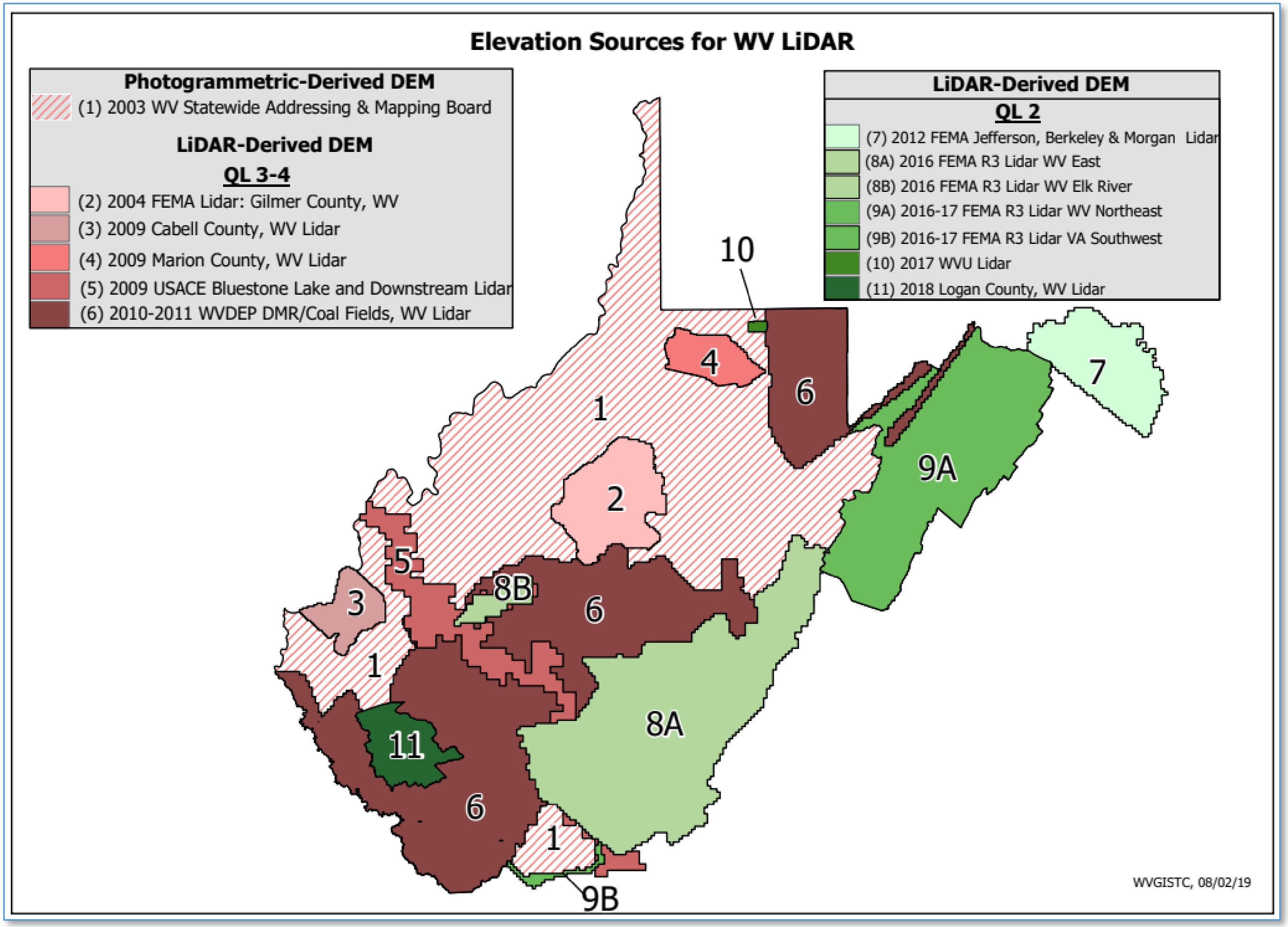


Mapping Landslides from new DEM

FEMA is purchasing 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



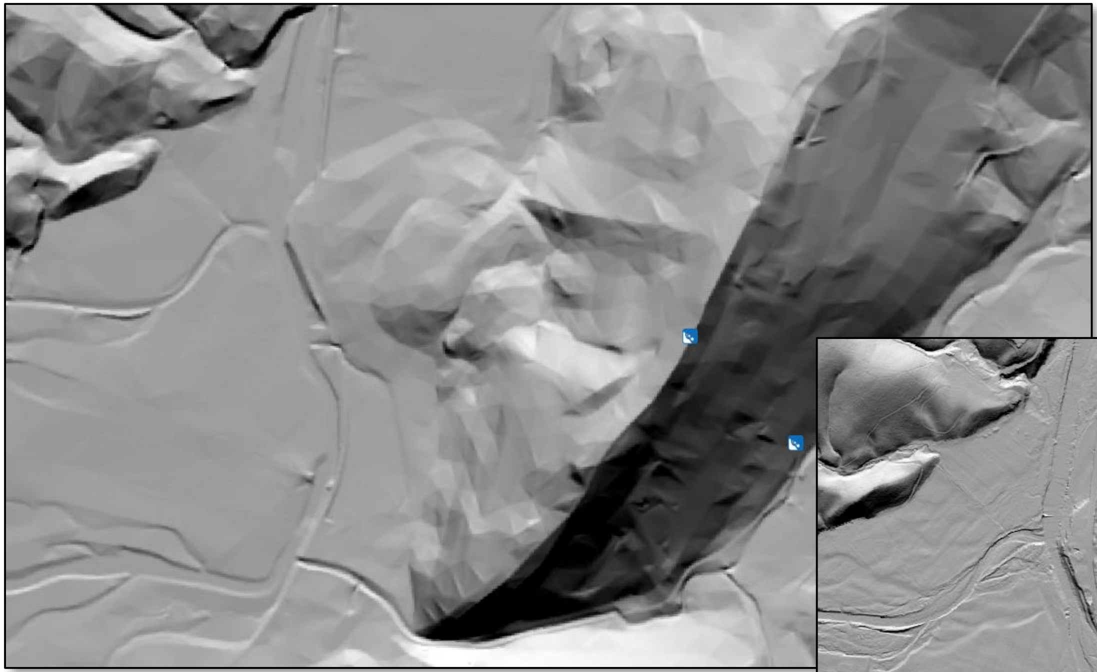
Mapping Landslides from new DEM



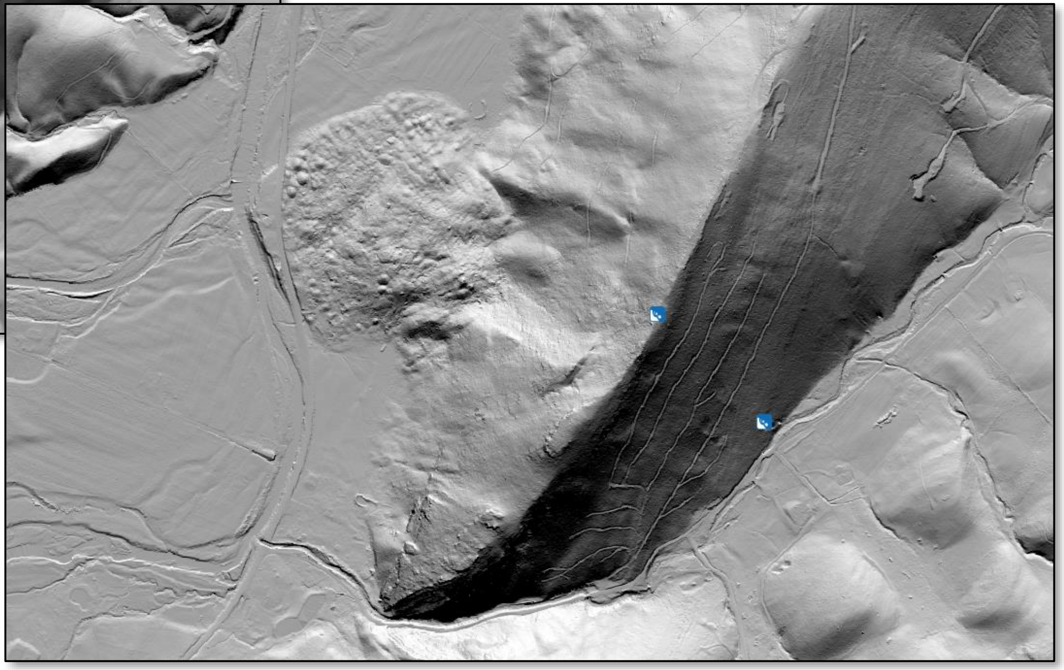
Best-Available Elevation Sources for West Virginia: https://www.mapwv.gov/floodtest/docs/WV_FloodTool_ElevationSource_Metadata.pdf

Mapping Landslides from new DEM

Old DEM



New DEM



Comparison of Old and New 1 meter DEM

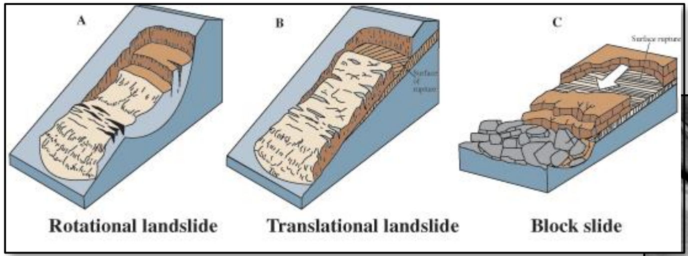
Landslide Incident Inventory

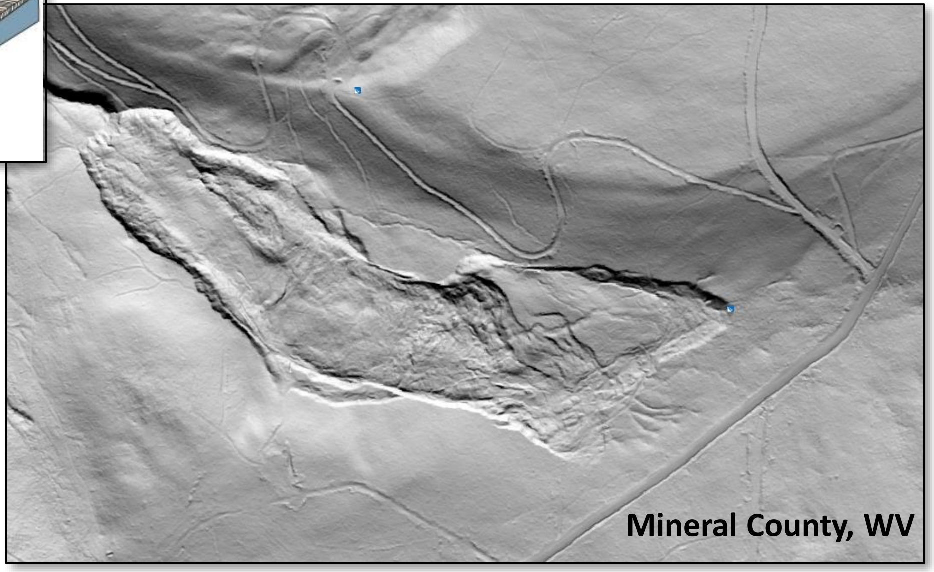
Landslide mapping from new LiDAR-derived DEM

- 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

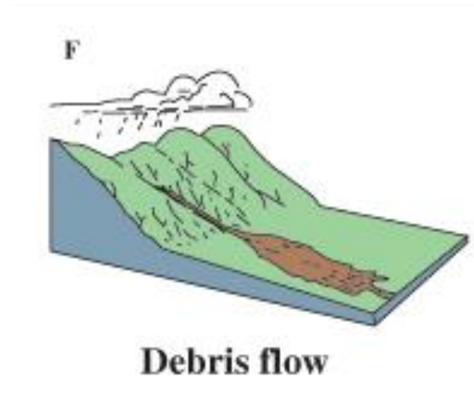


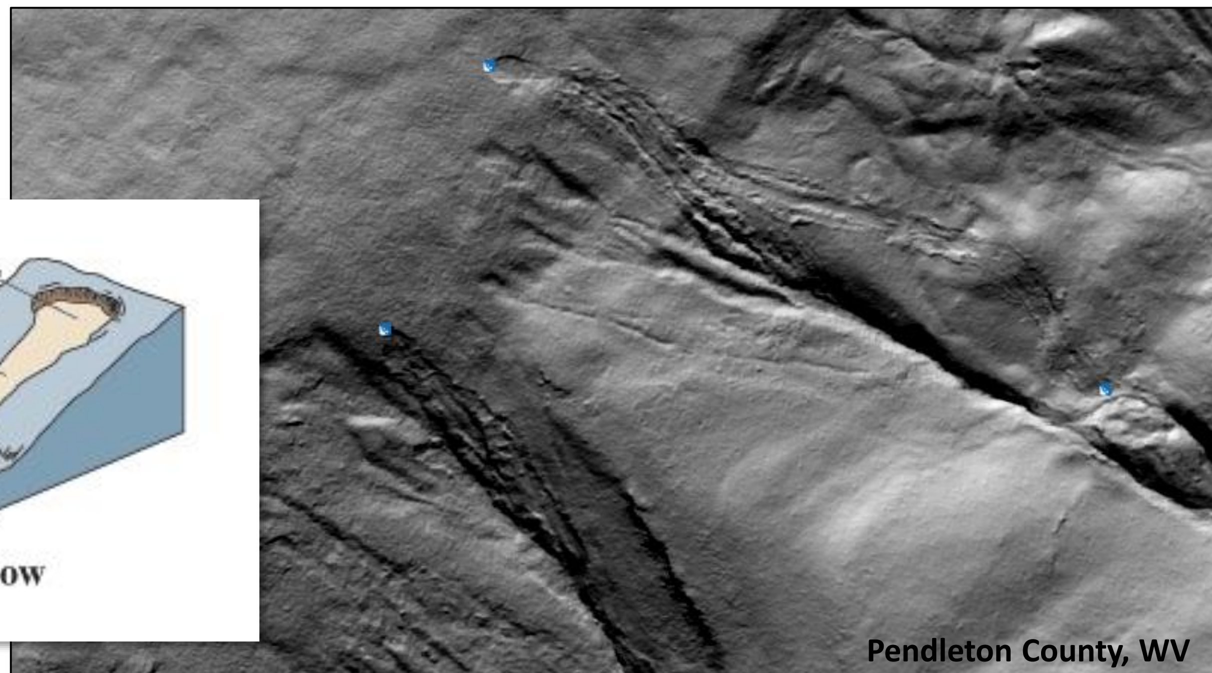


*Description from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html
Images from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

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

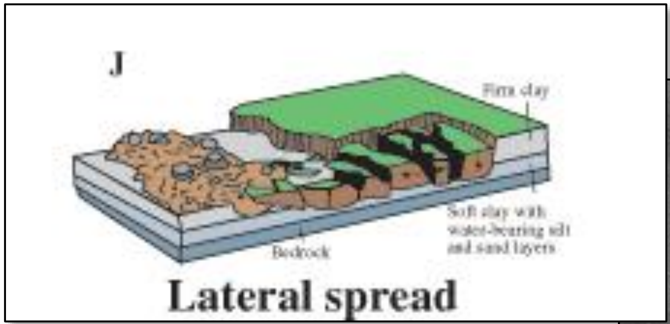


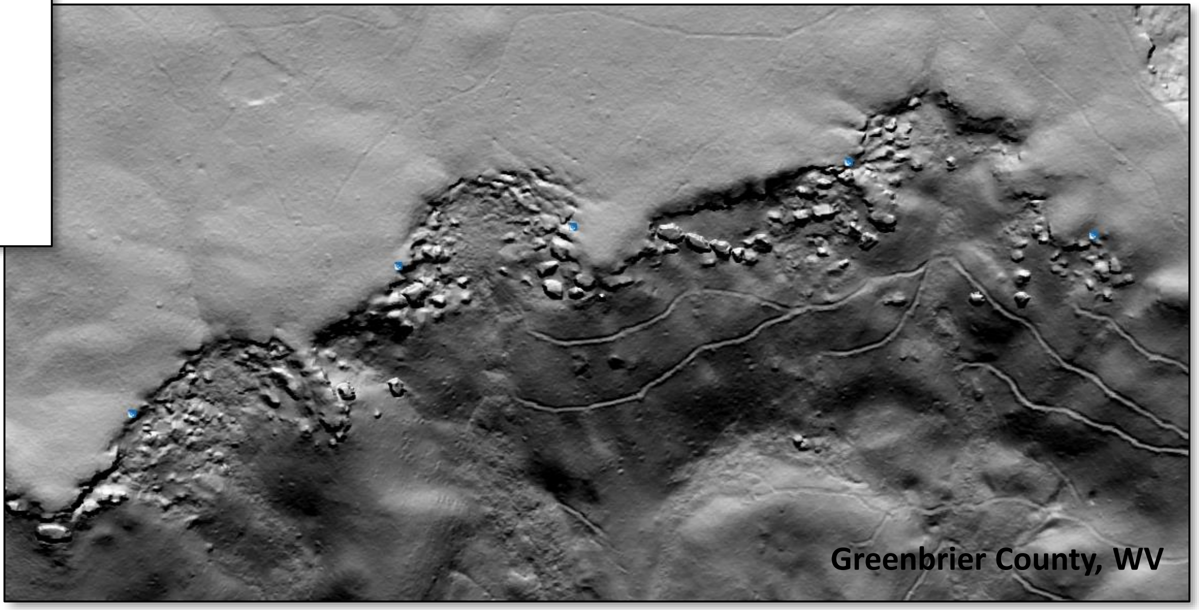


*Description from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html
Images from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

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

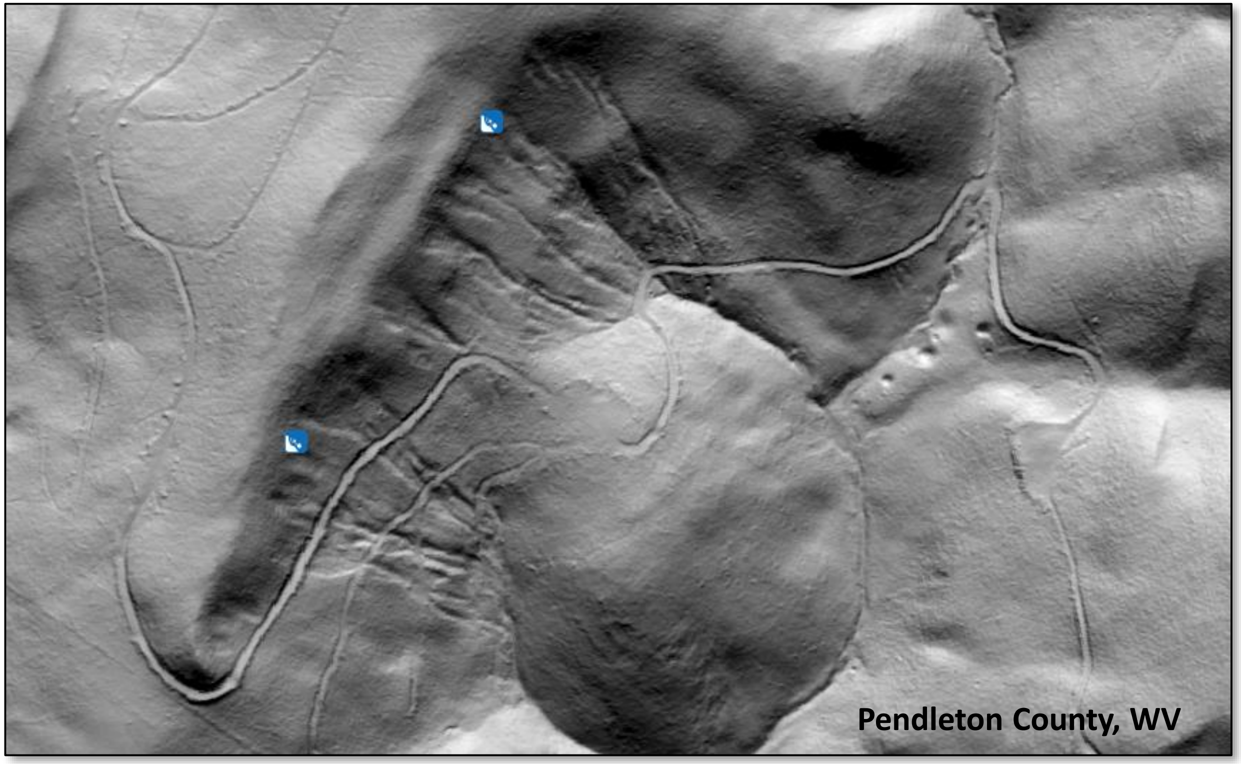




*Description from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html
Images from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

Landslide Incident Inventory

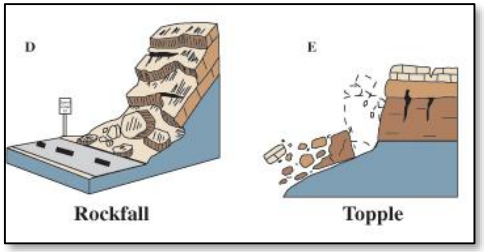
- **Multiple Failures:** This classification is used when multiple (>4) failures, usually small debris flows, occur in a restricted area



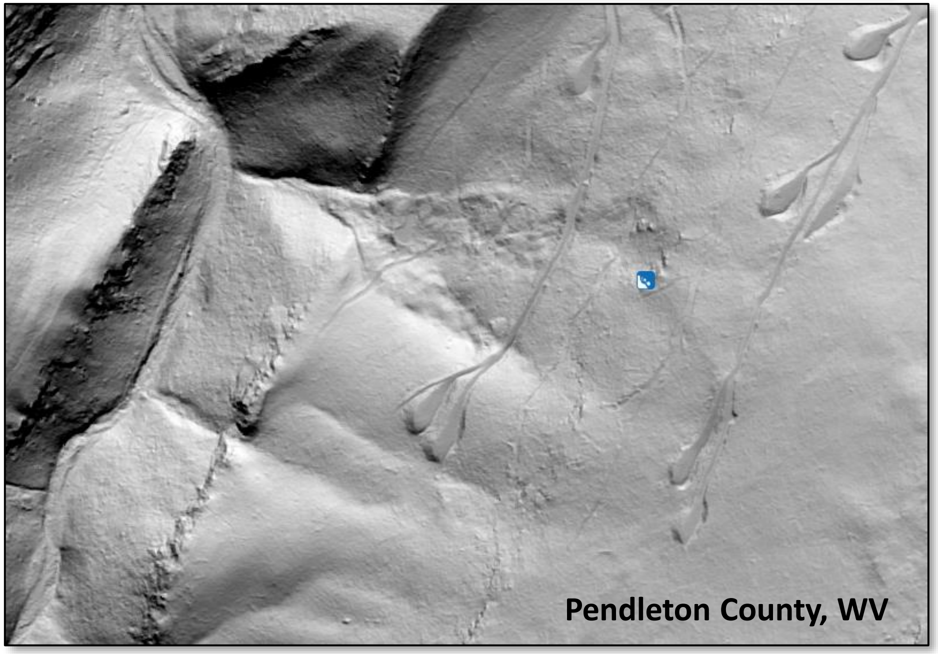
*Description from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html
Images from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

Landslide Incident Inventory

- **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



*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

WV GIS TC
Landslide Mapping
March-September 2019

WV GIS TC Mapping on LiDAR-Based DEMs

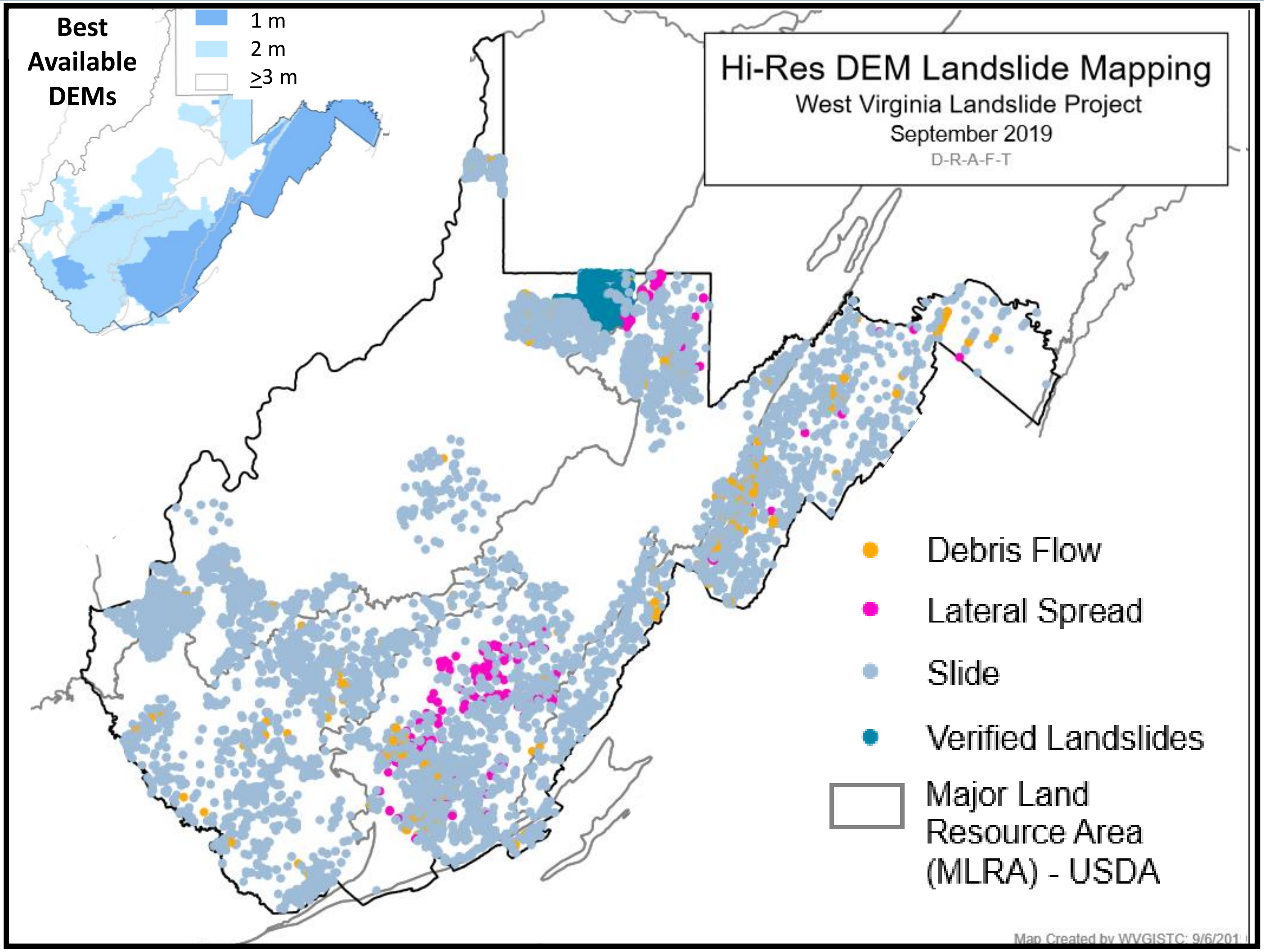
8,991 Failures *(≥10 m wide)*
Most from 1 m DEMs

- **334 Debris Flows**
- **241 Lateral Spreads**
- **8,416 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**

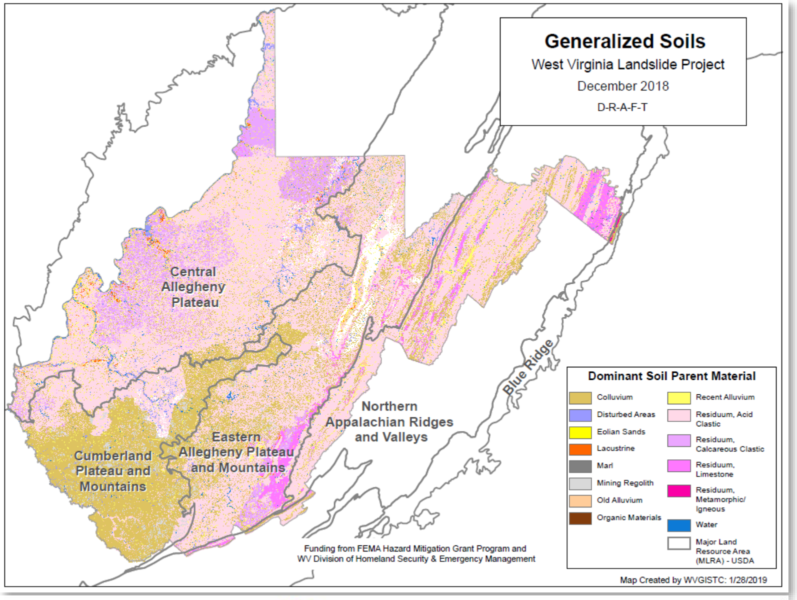


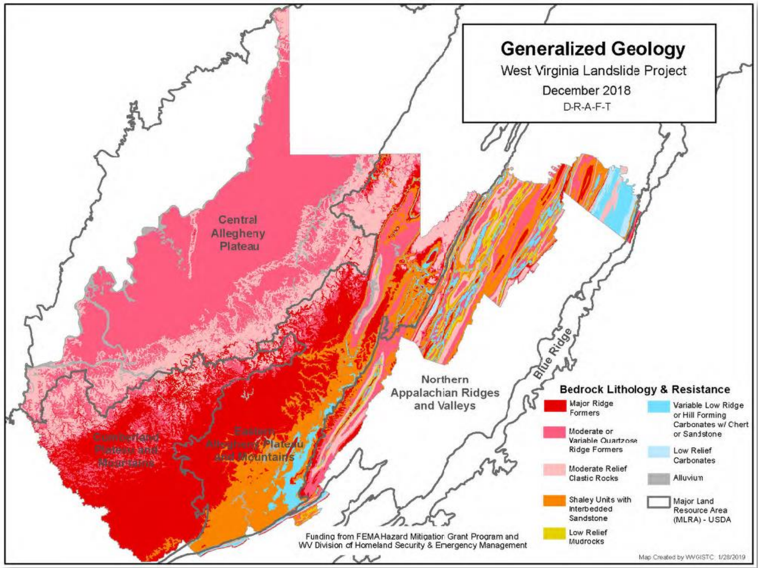
Landslide Incident Inventory

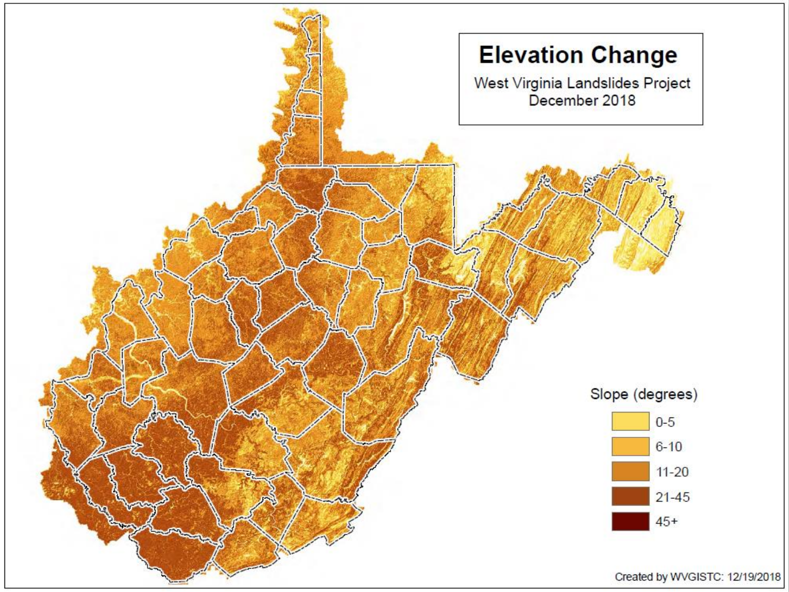
Type of Movement	Number of user identified points	Percentage of user identified points	Description
Slide	8232	92.2	A zone of weakness separates the slide from the underlying material; can be translational or rotational
Fall	5	0	Rocks or other geologic materials dislocate from steep slopes
Debris Flow	334	3.7	Fluid mobilizes material into a slurry that flows downslope; often associated with gullies or steep channels
Lateral Spread	241	2.7	Extension along very shallow or horizontal slopes which causes material to break into block-like shapes
Multiple Failures	97	1.2	Usually a combination of multiple small debris flows in a restricted location
Undetermined	16	0.2	Some failure is clearly present, but it is difficult to determine the type of movement

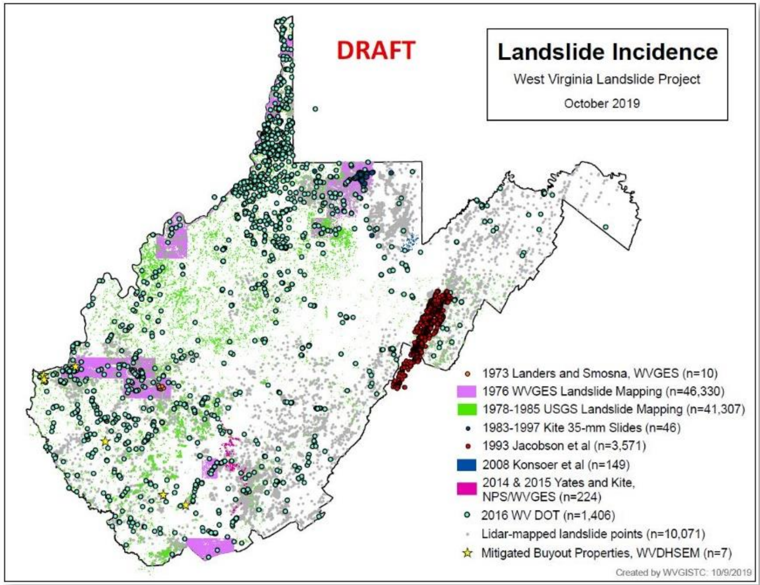
Landslide Method Development

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

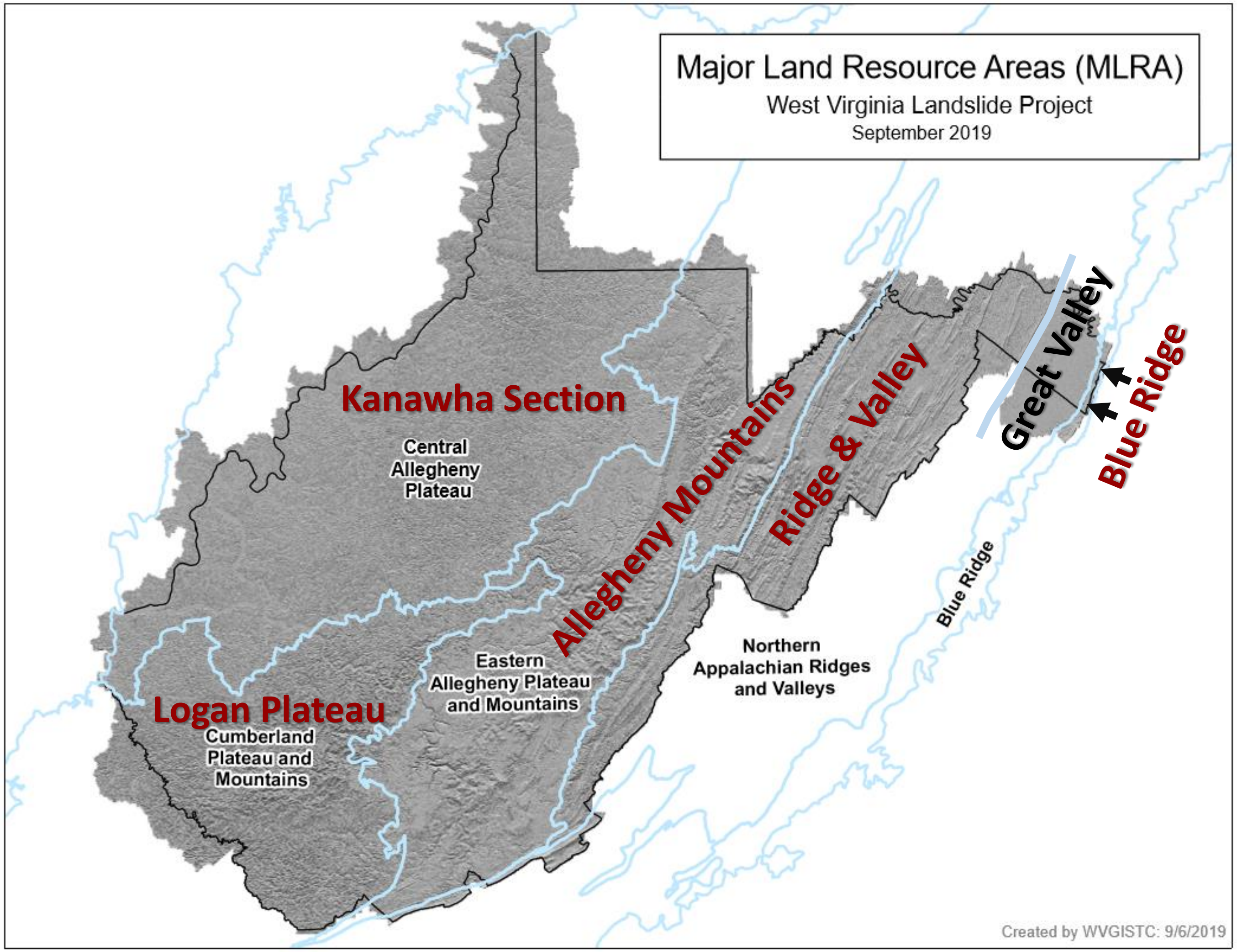
Provinces & Subdivisions

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

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

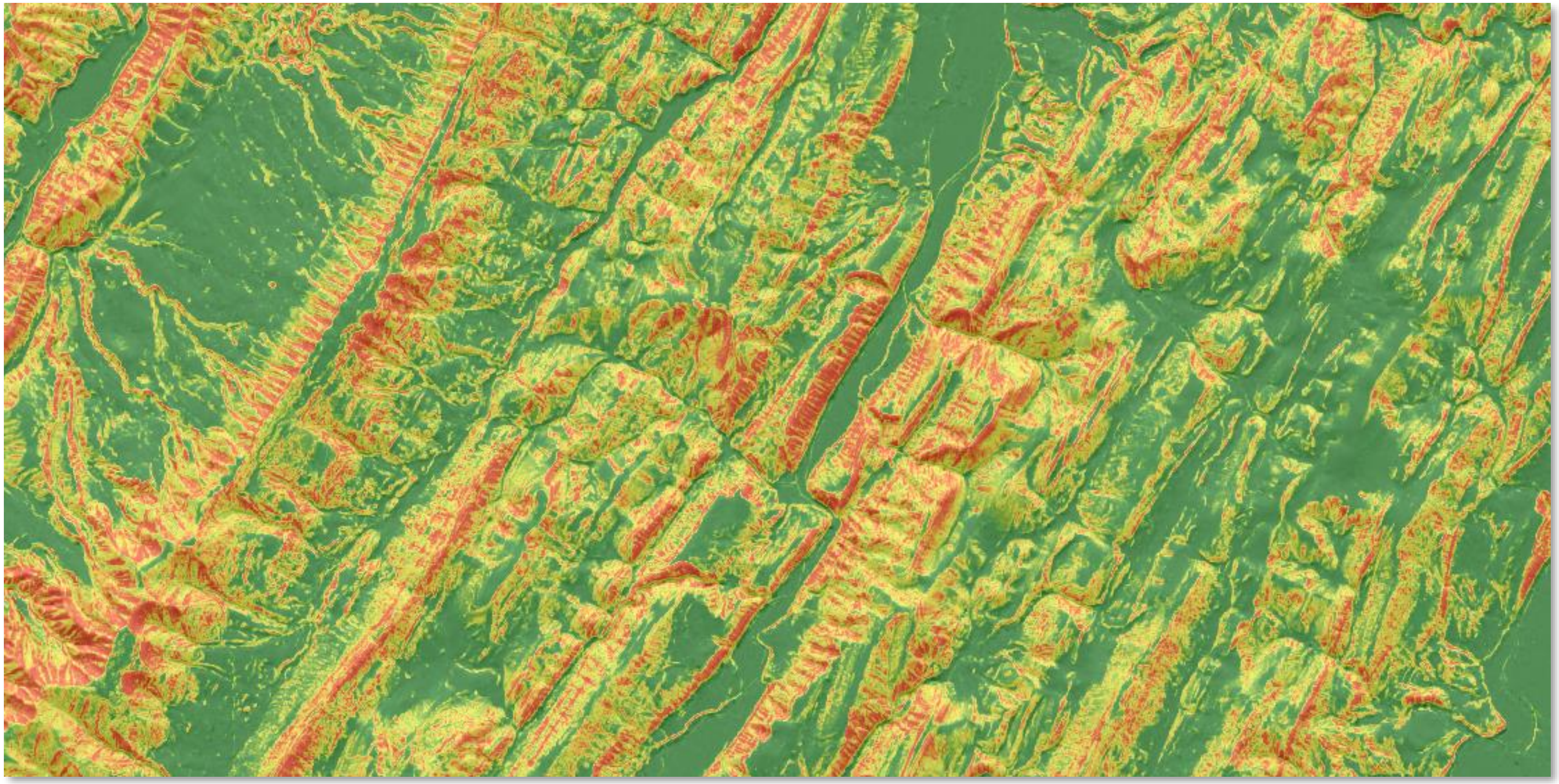
Blue Ridge

Red = Landslide-Prone

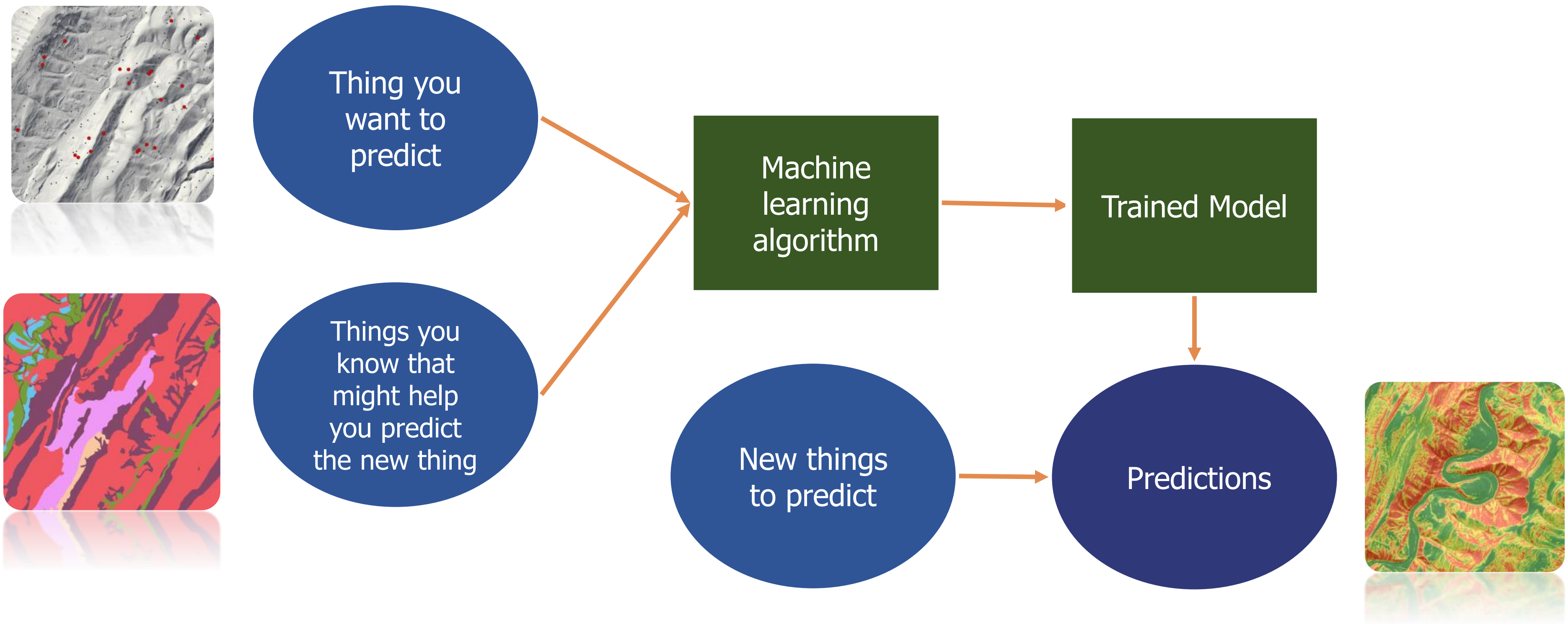


Landslide Method Development

Goal: Generate predictive models of slope failure probability/occurrence

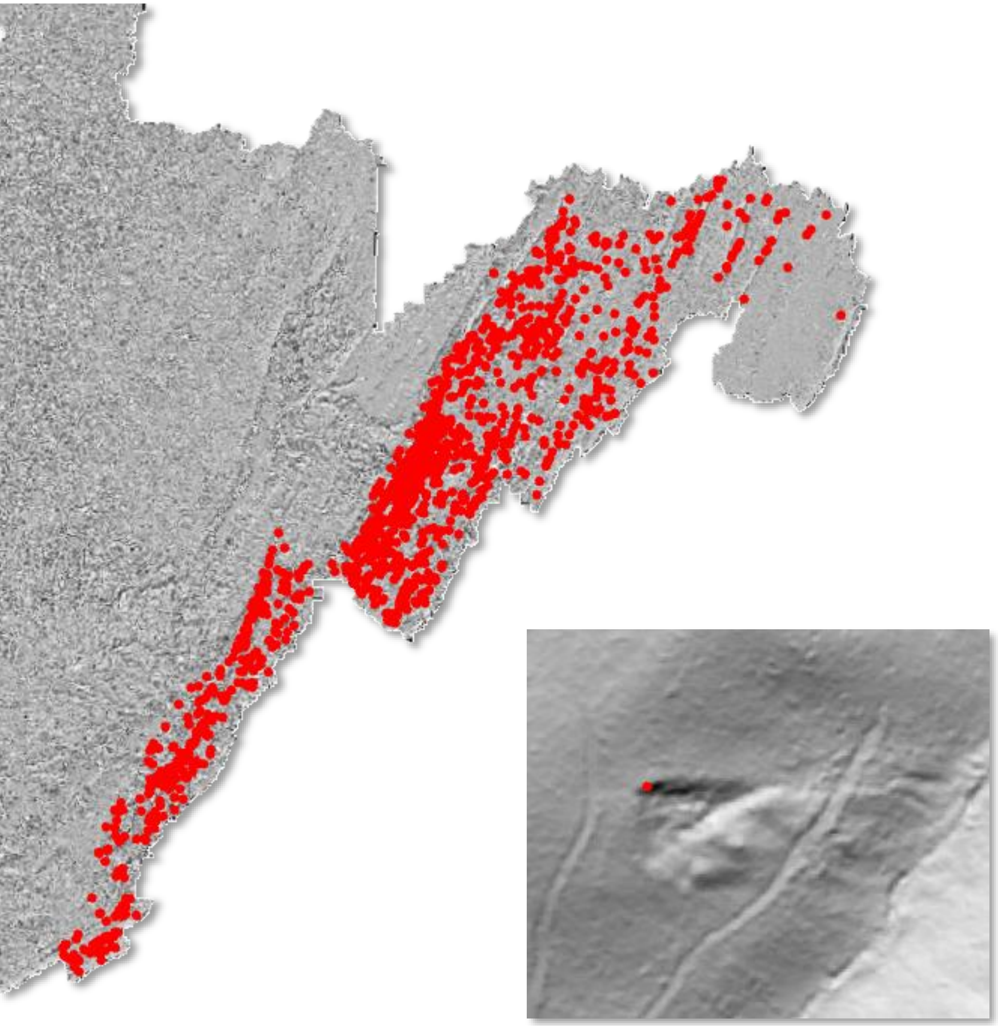


Landslide Method Development



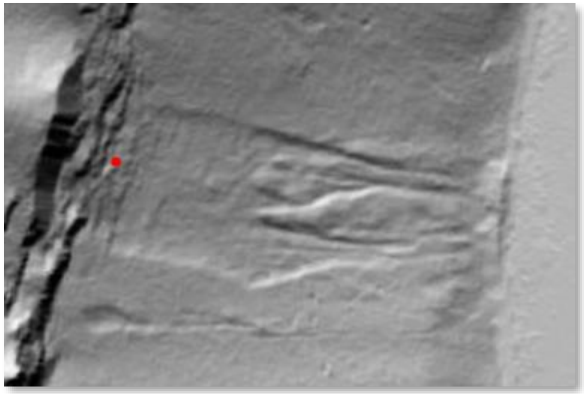
Machine Learning = Learning from Examples

Landslide Method Development



Training the Model

- Based on visual interpretation of terrain data
- 1,799 examples



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)
    - Dr. Kite's Comments (Categorical)
  - Soils
    - DPSM (Categorical)
    - Drainage Class (Categorical)

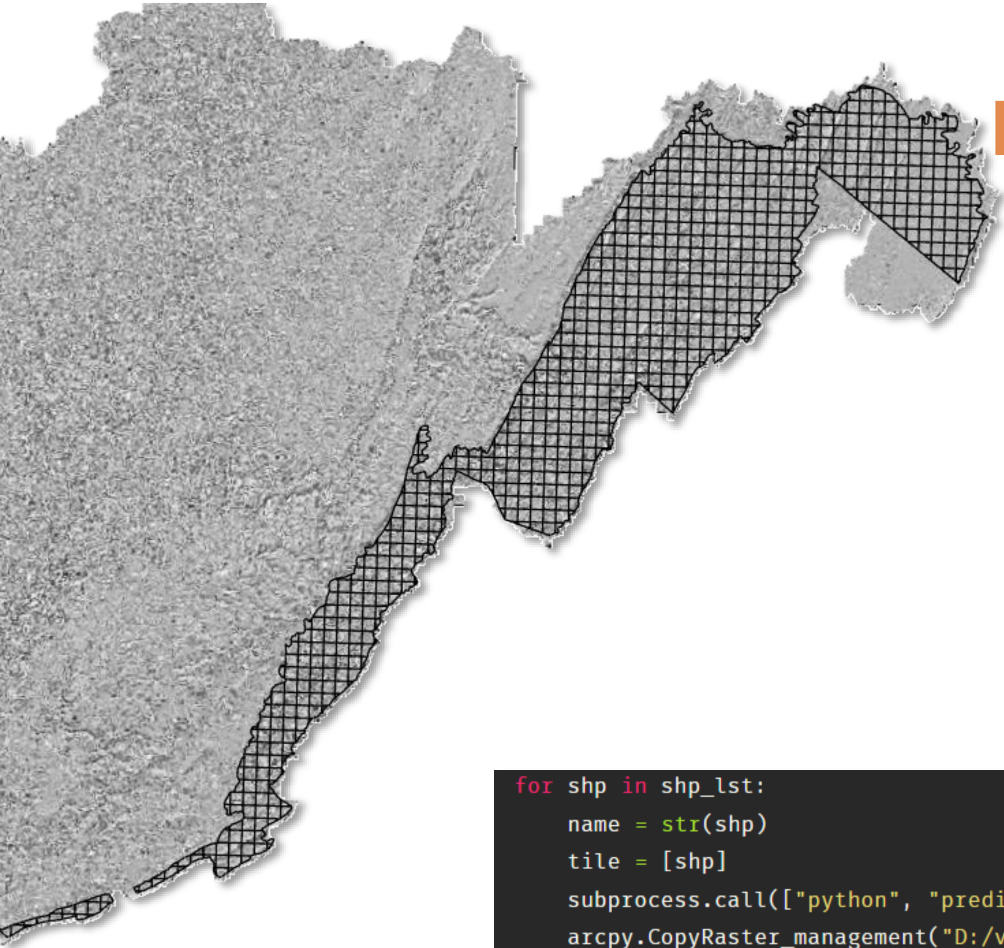
Landslide Method Development

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

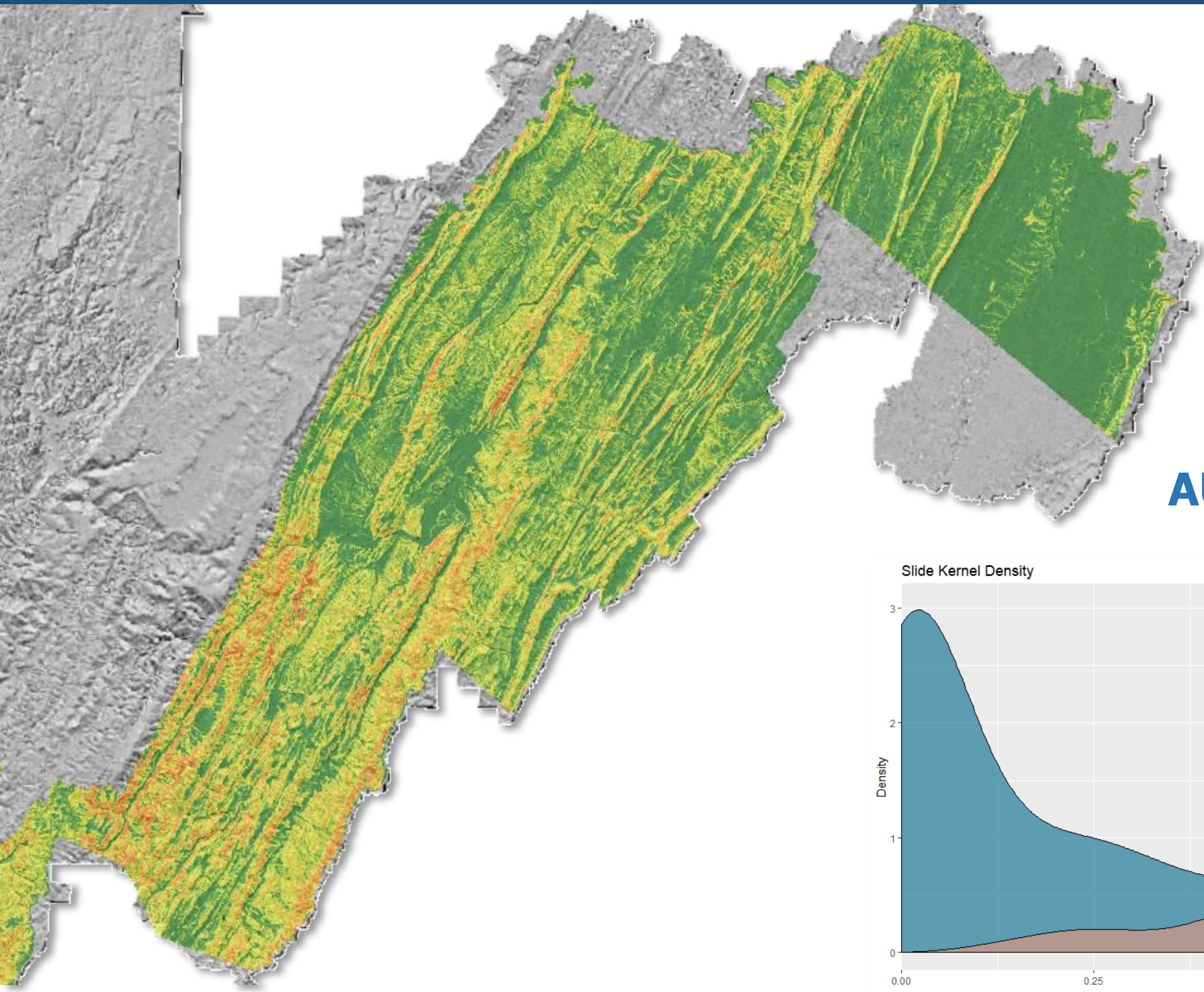


Predict to Entire Extent

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

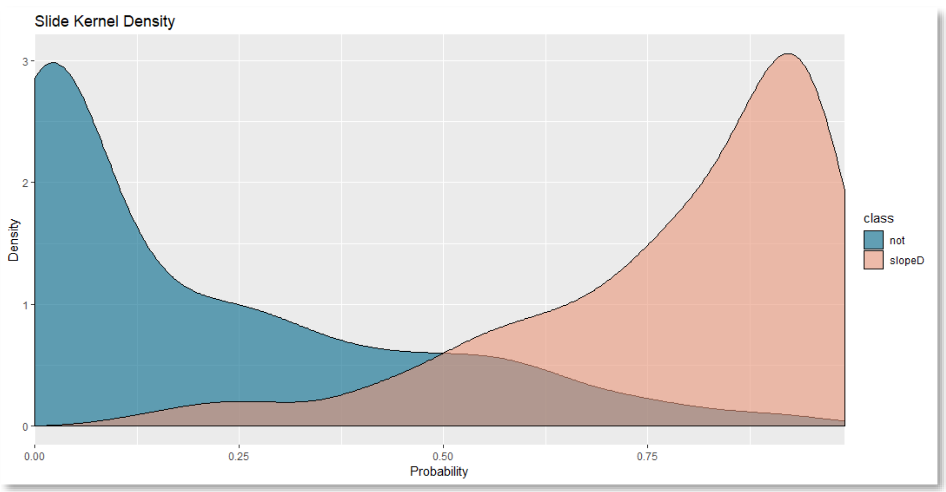
```
for shp in shp_lst:
    name = str(shp)
    tile = [shp]
    subprocess.call(["python", "predict_to_grid_subscript3.py"] + tile, shell=True)
    arcpy.CopyRaster_management("D:/v_r_landslide/stack/pred_out.tif", "D:/v_r_landslide/pred_out/"
                                + str(os.path.splitext(shp)[0])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

Landslide Method Development



Results

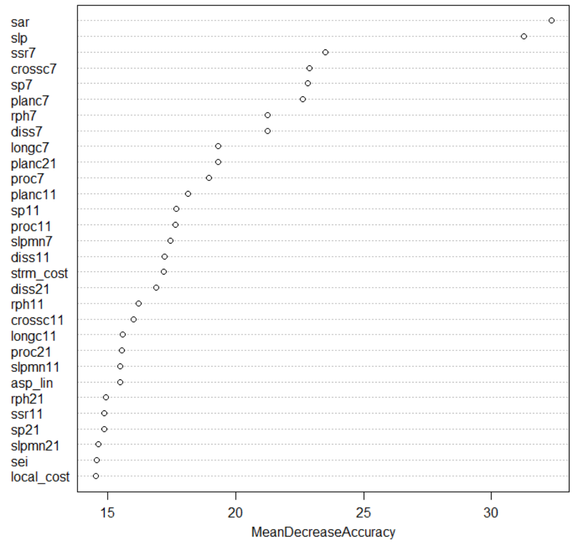
AUC – 0.94

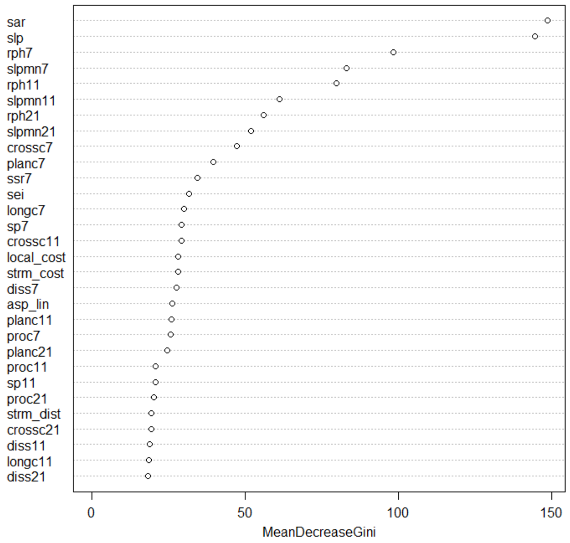


Landslide Method Development

Important Variables

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

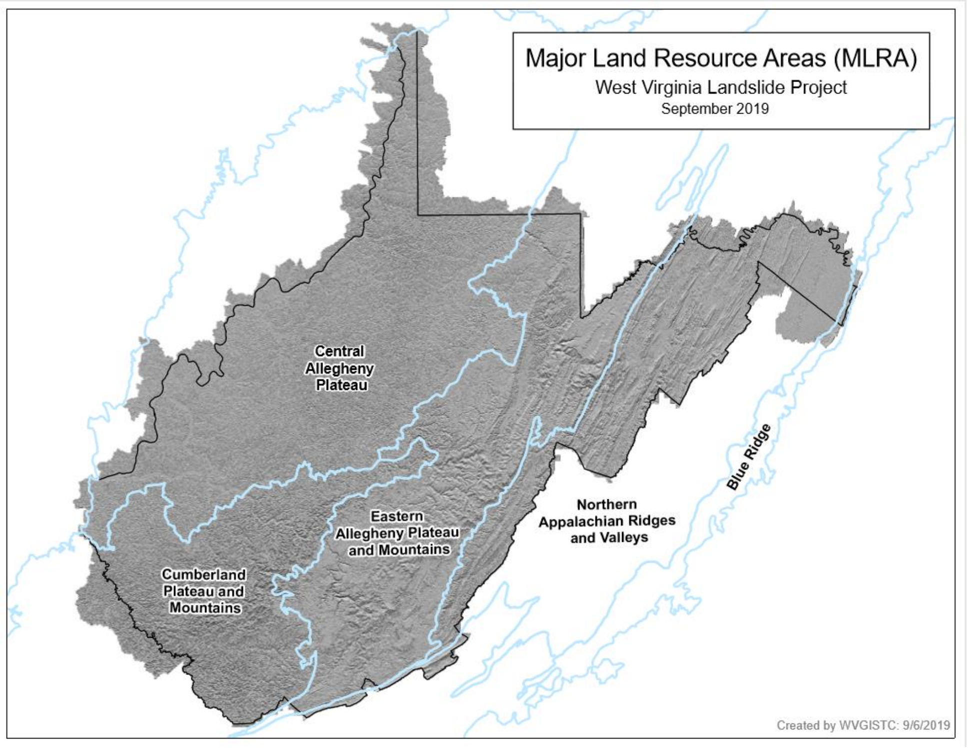




Landslide Method Development

Moving Forward

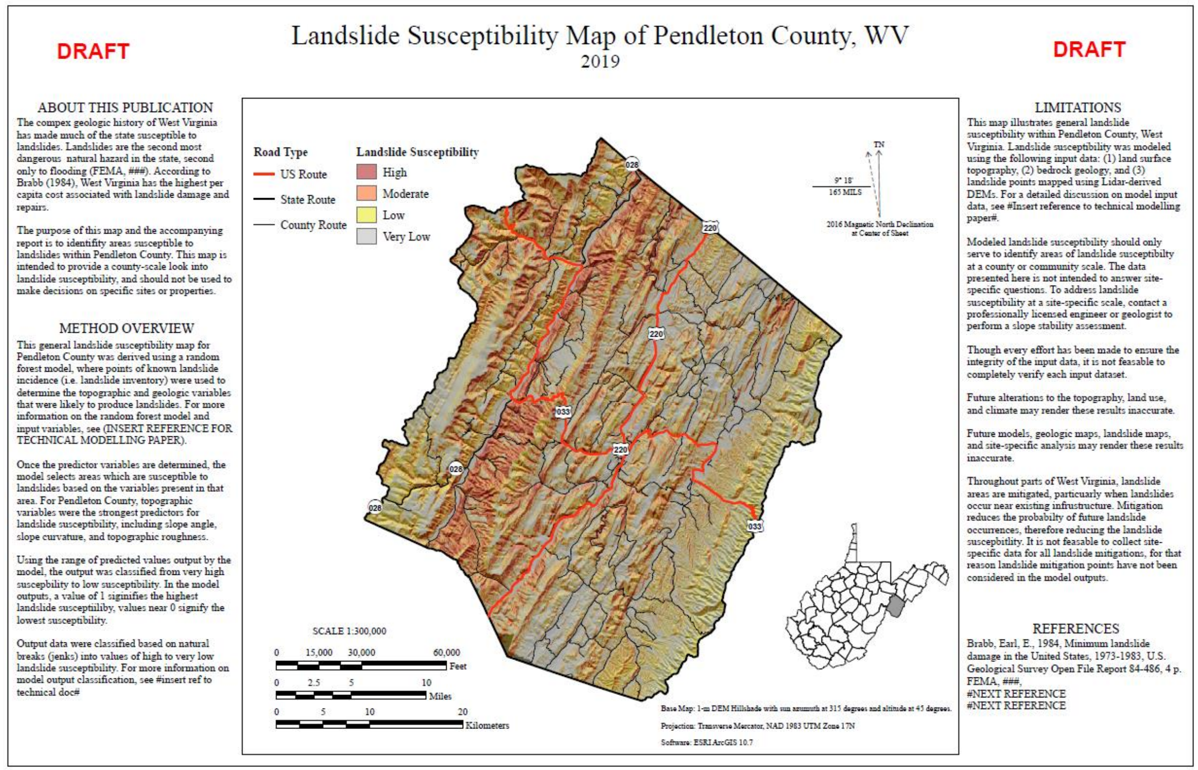
- Semi-automate with scripting
- Develop models for different physiographic regions
- Predict entire state
- Further validate results



Landslide Susceptibility Prediction

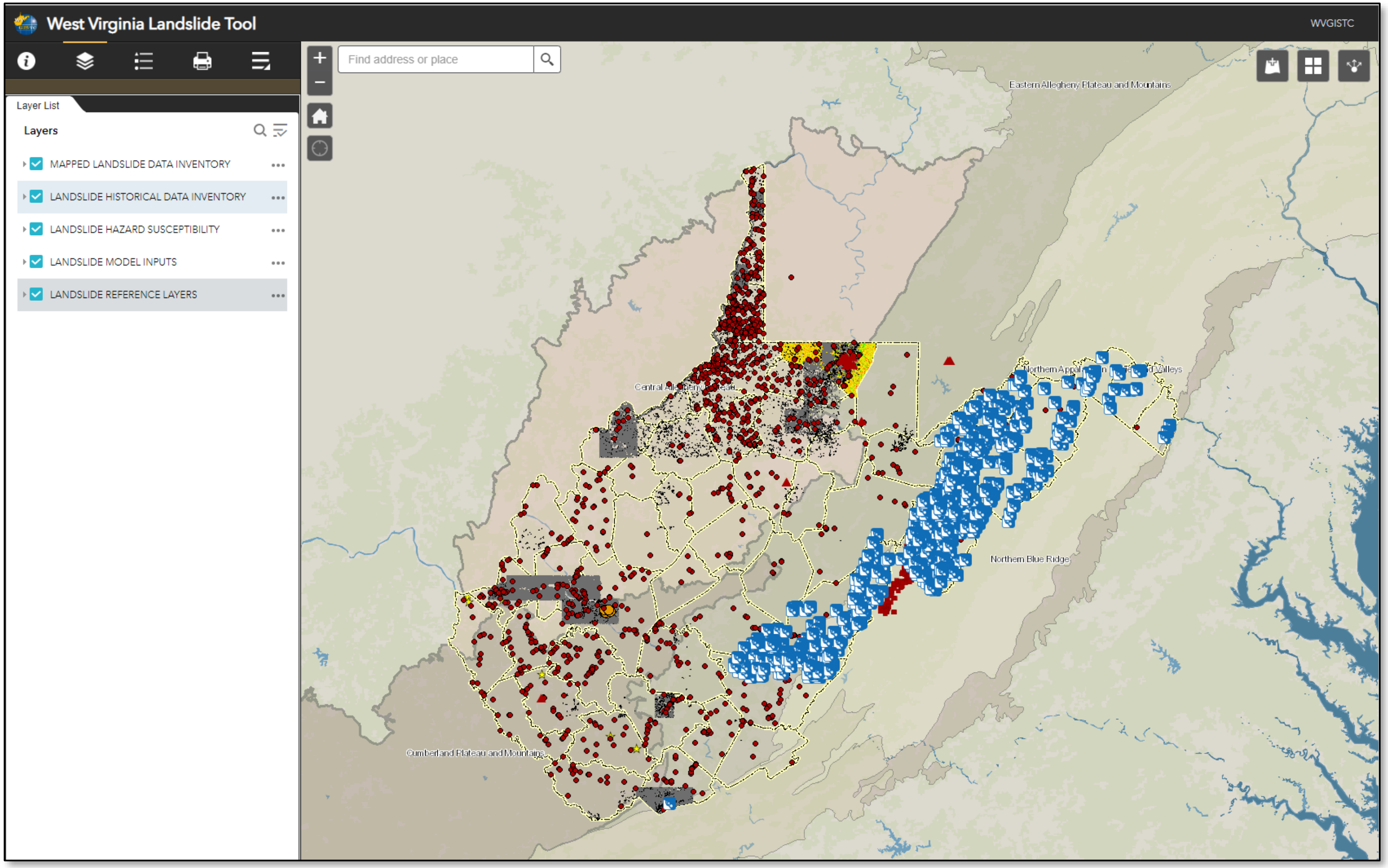
Susceptibility and Hazard Assessment

- Produce landslide susceptibility map by county
- Calculate at risk properties for each county



Landslide Incident Inventory

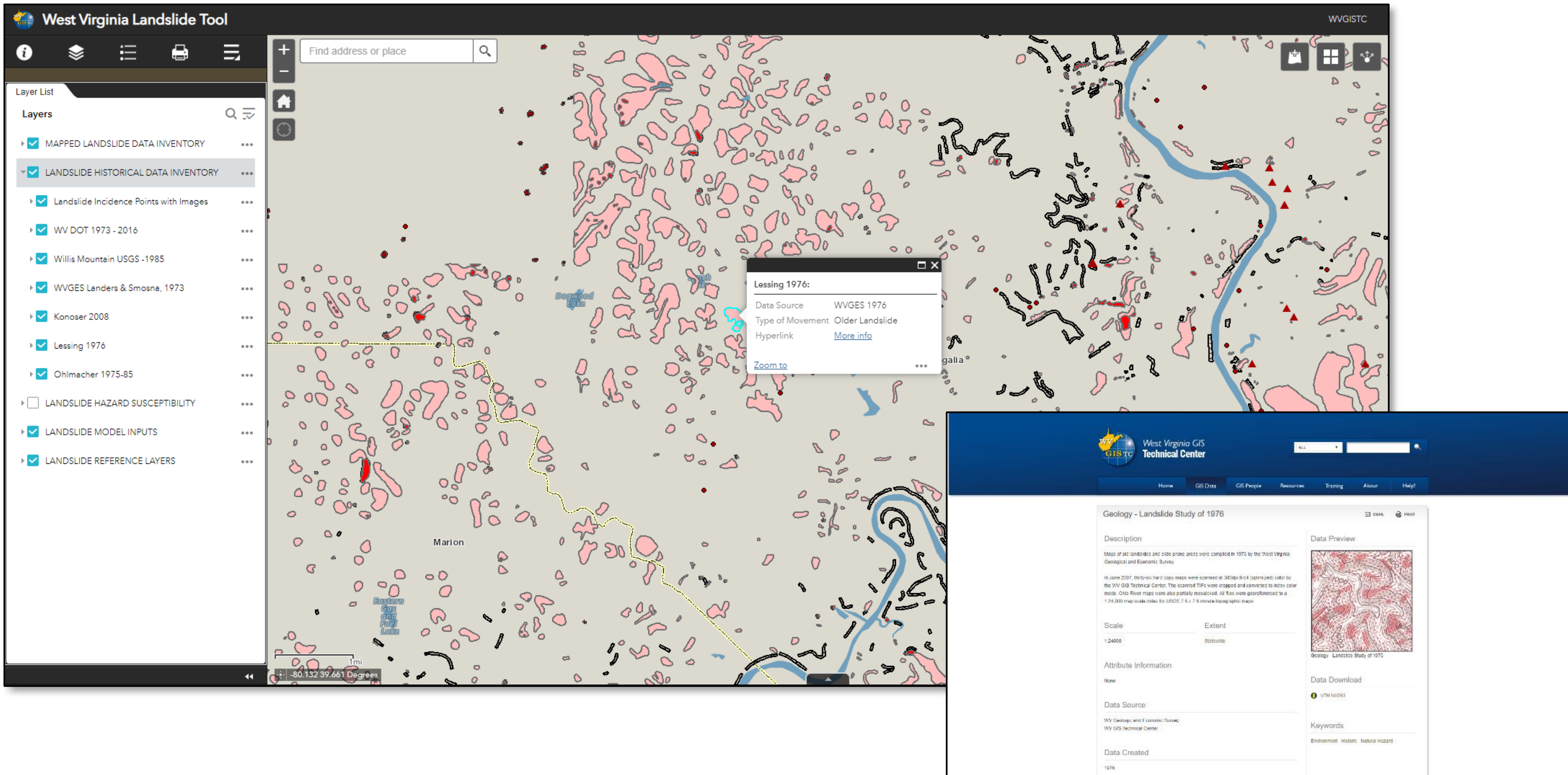
www.mapWV.gov/Landslide (in development)



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

Landslide Incident Inventory

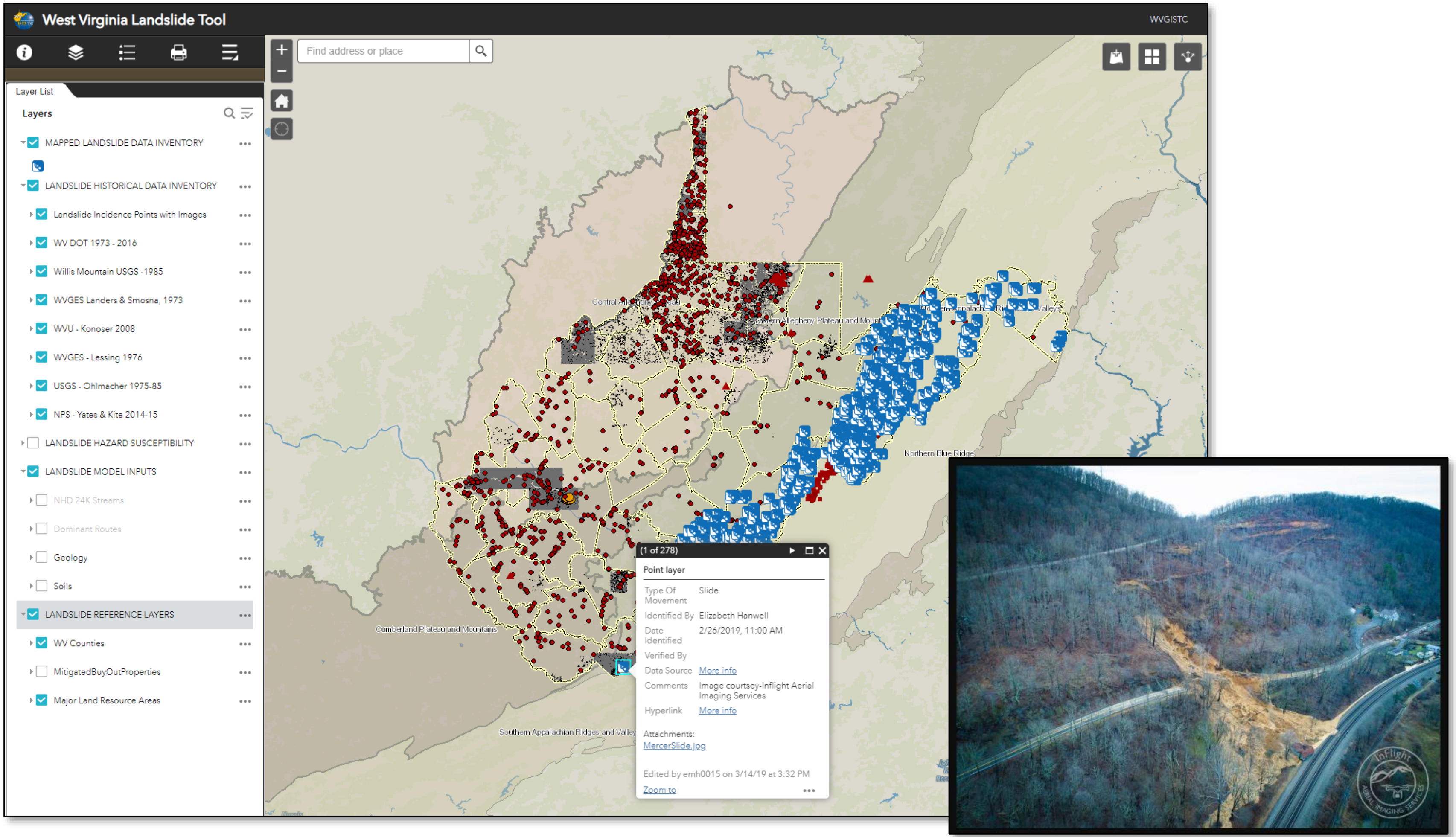
www.mapWV.gov/Landslide *(in development)*



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

Landslide Incident Inventory

www.mapWV.gov/Landslide *(in development)*



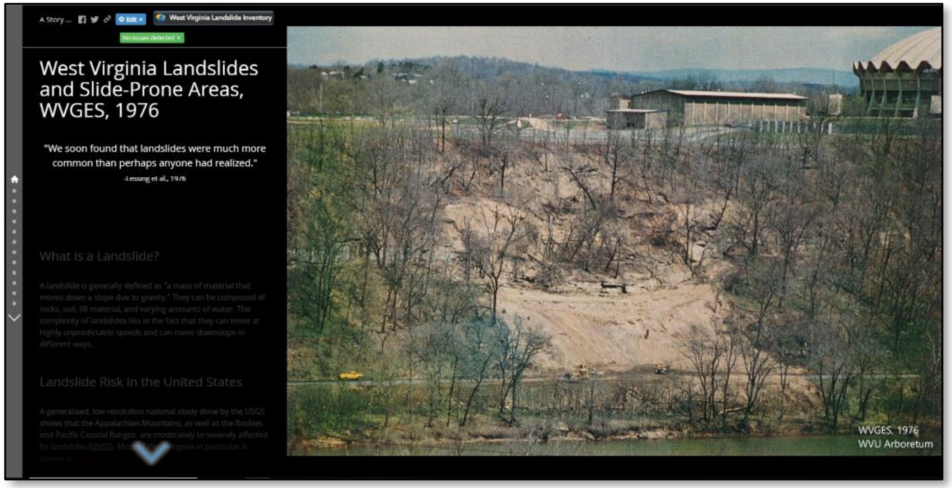
According to Dr. Kite "*Looks to be in the 5000-8000 square meter range in total. One of the biggest observed slides I know about in the state*". Feb 25, 2019

Landslide Outreach Material

Two StoryMaps In Development

West Virginia Landslides and Slide-Prone Areas, WVGES 1976

https://arcg.is/1KDnvq



Causes of Landslides in Mountain State, West Virginia

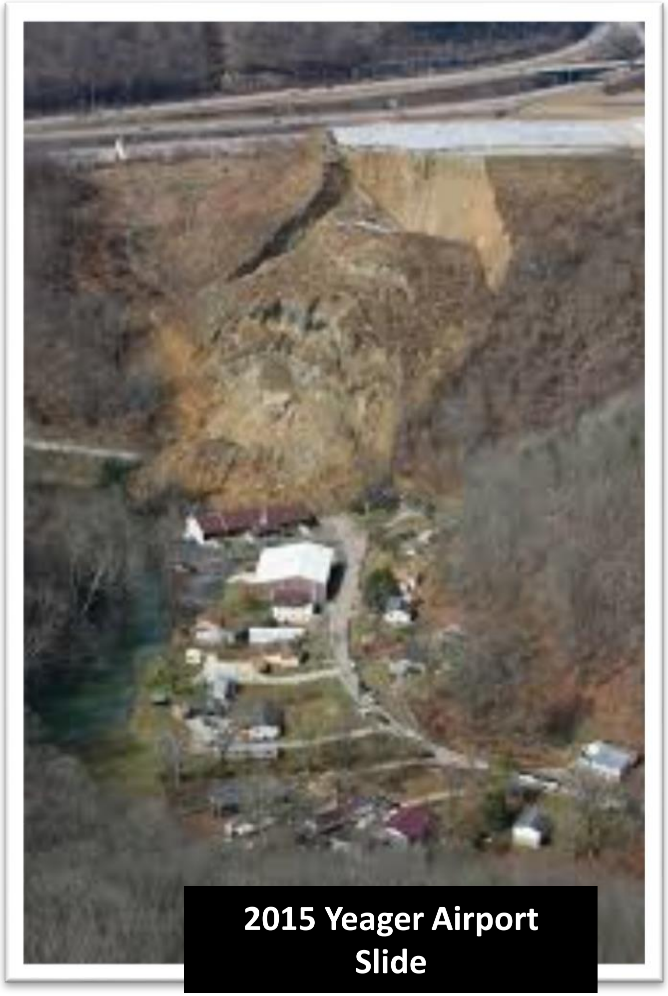
https://arcg.is/1SW0Sn

Landslide 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