Statewide Hazard Assessment

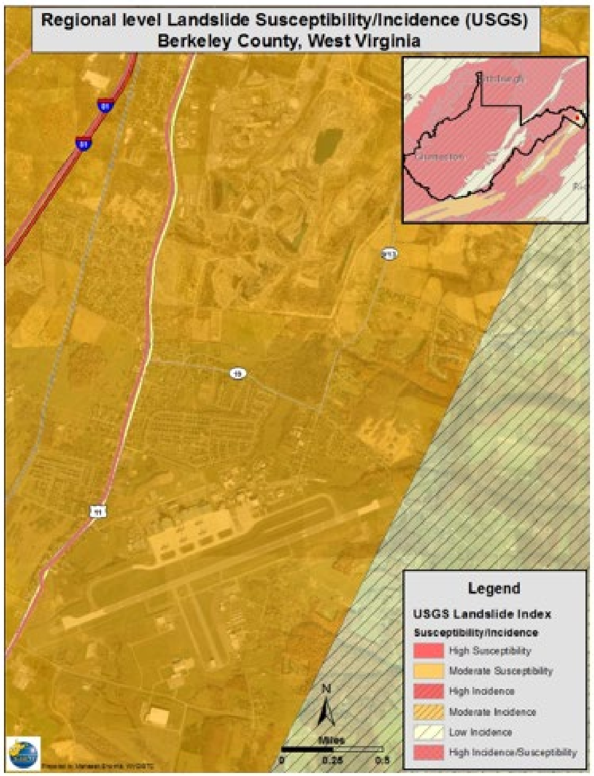
Landslide Risk Assessment

Landslide Maps – Old versus New

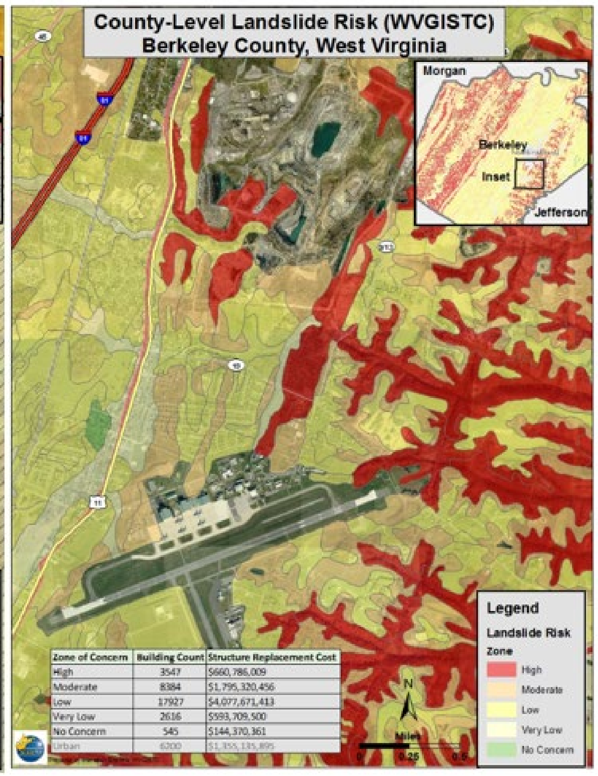
Old Way - Very Generalized

New Way – More Detailed

REGIONAL LANDSLIDE MAP (USGS)



COUNTY LANDSLIDE MAP (WVGISTC)



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

HMGP Landslide Tasks

Five Major Landslide Goals and Deliverables

LANDSLIDE RISK ASSESSMENT
TASK L1: [Landslide Inventory] From eight sources of various published landslide studies, reports, and maps for West Virginia, created an initial geodatabase of historical landslide incidents from the year 1973 to present. The Center has compiled or digitized more than 76,000 landslide features. Purchased a Cannon 9000F MKII Photo, Film and Negative scanner to create a geodatabase of landslide pictures.
TASK L2: [Landslide Method Development] Knowledge experts employed at West Virginia University were identified and hired to include Dr. Steve Kite (Geomorphologist), Dr. James Thompson (Soil Scientist), Dr. Aaron Maxwell (Geologist/Modeler), and Dr. Maneesh Sharma (Geologist/GIS). A statistical model is being developed to evaluate various spatial inputs that have a high correlation to mapped landslide incidents: geology, soils, topography (slope, aspect, etc.), proximity to roads and streams. An information exchange meeting occurred with the Oregon Geological Survey (William Burns) regarding landslides.
TASK L3: [County-Level Landslide Map and Report Generation] Initiated a landslide susceptibility pilot for Monongalia County using a machine learning technique called Maximum Entropy Modeling. Professor Aaron Maxwell is conducting the modeling.

HMGP Landslide Tasks (Cont.)

Five Major Landslide Goals and Deliverables

TASK L4: [Publish landslide risk data and products to WV Landslide Tool] Started publishing landslide information to the WV Landslide Tool (www.mapwv.gov/landslide). Landslide information includes Historical Landslide Incidences (with pictures), Mapped Landslides, Landslide Susceptibility Model, Landslide Model Inputs, and Reference Layers. An online Story Map is being developed for the landslide risk assessment published in 1976 by the WV Geological and Economic Survey that was funded by the Appalachian Regional Commission. A Story Map will also be created for the statewide landslide risk assessment funded by this project. Started development of a mobile web application for reporting landslides in West Virginia.
TASK L5: [Update State Plan] Contributed preliminary information about the landslide risk assessment project for the 2018 State Hazard Mitigation Plan update. A deliverable of this project is to update the Landslide Hazard Section of the 2023 State Plan update.

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

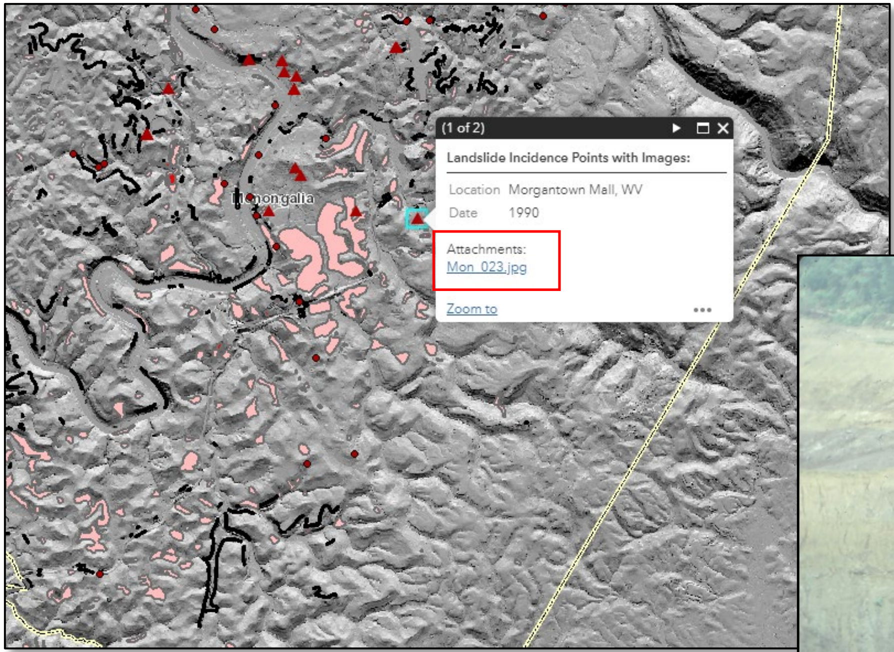
Landslide Incident Inventory

#	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 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	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	17,970

111,061 landslide features

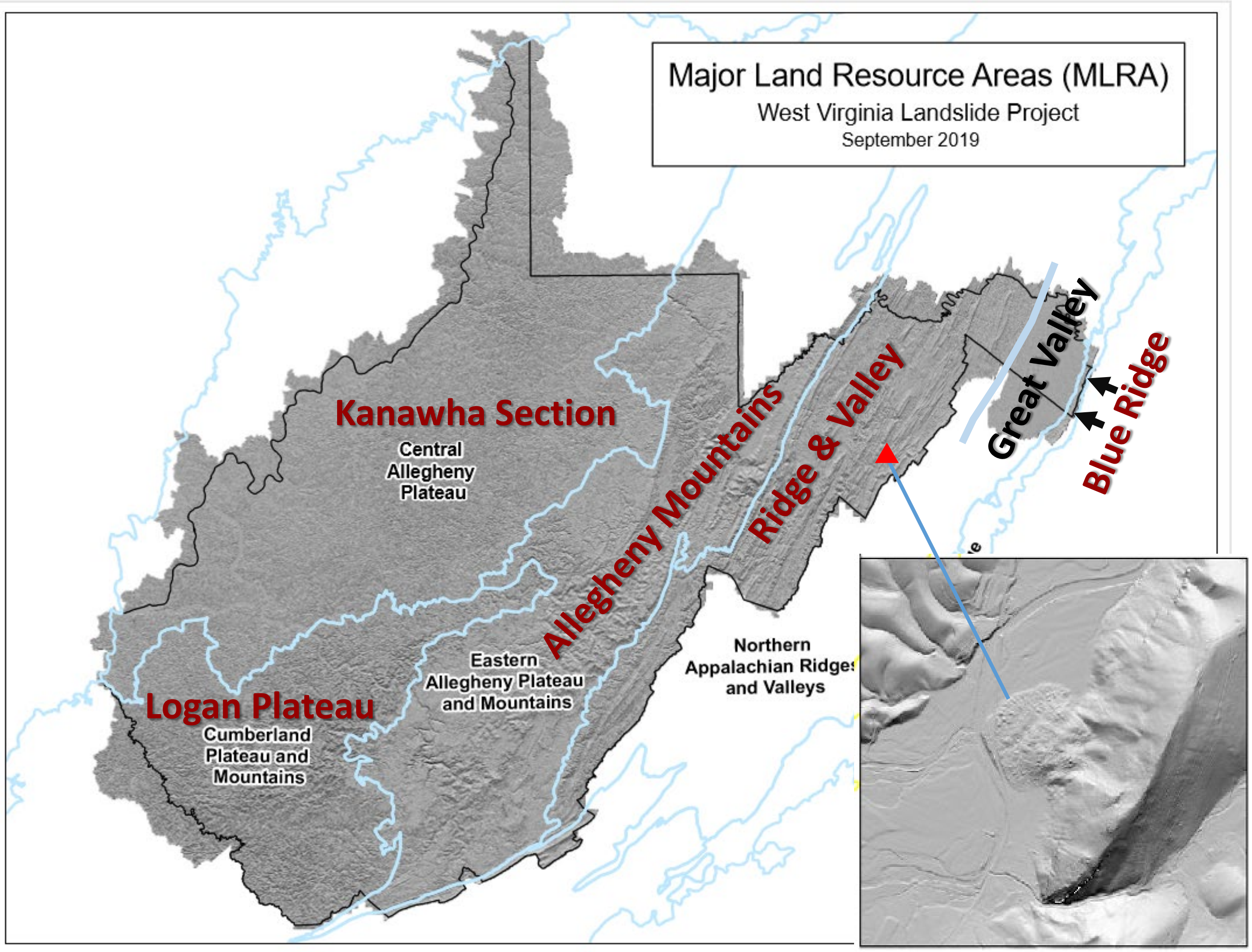
Landslide Incident Inventory

- 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

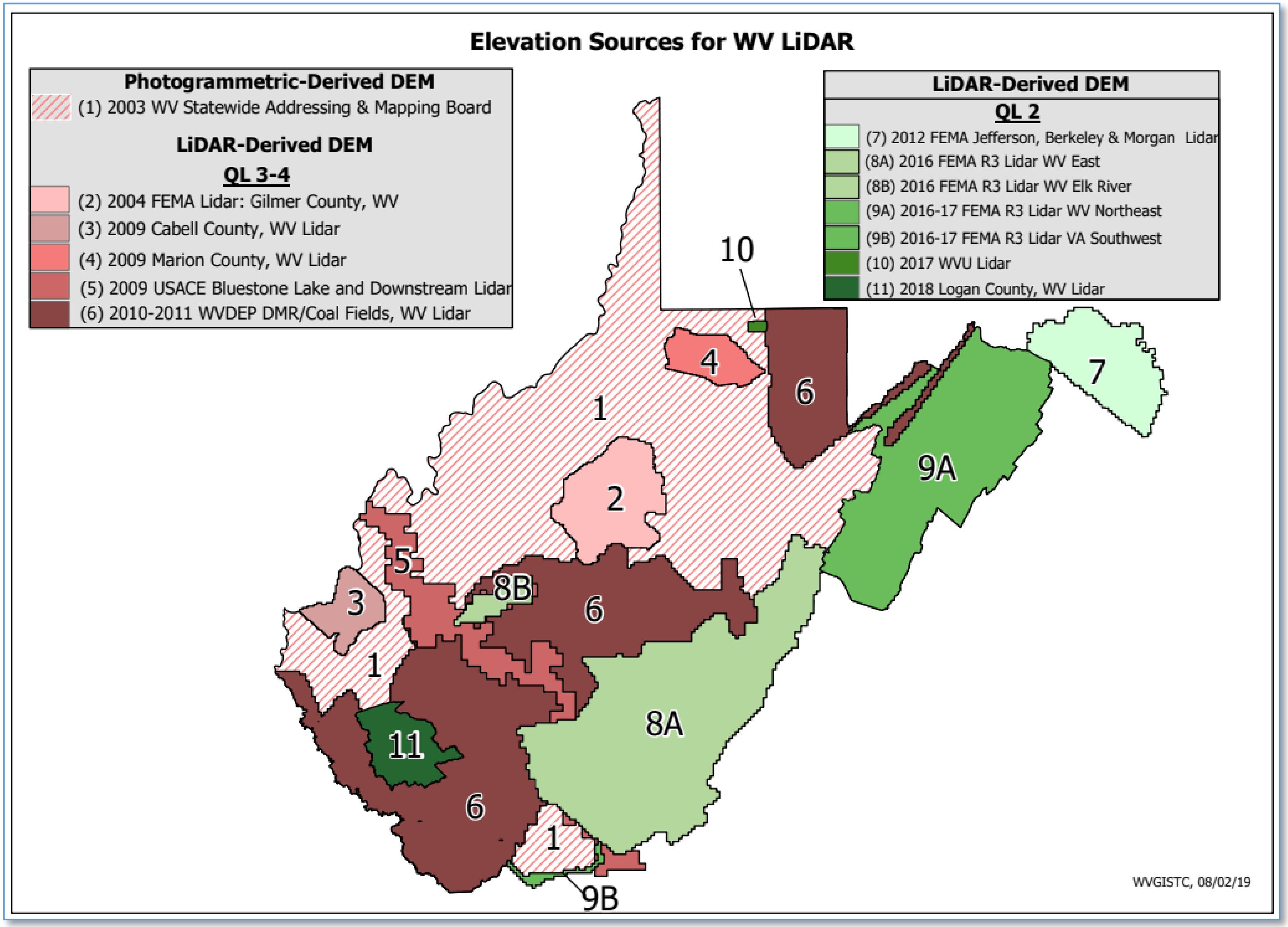


Mapping Landslides from new DEM

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



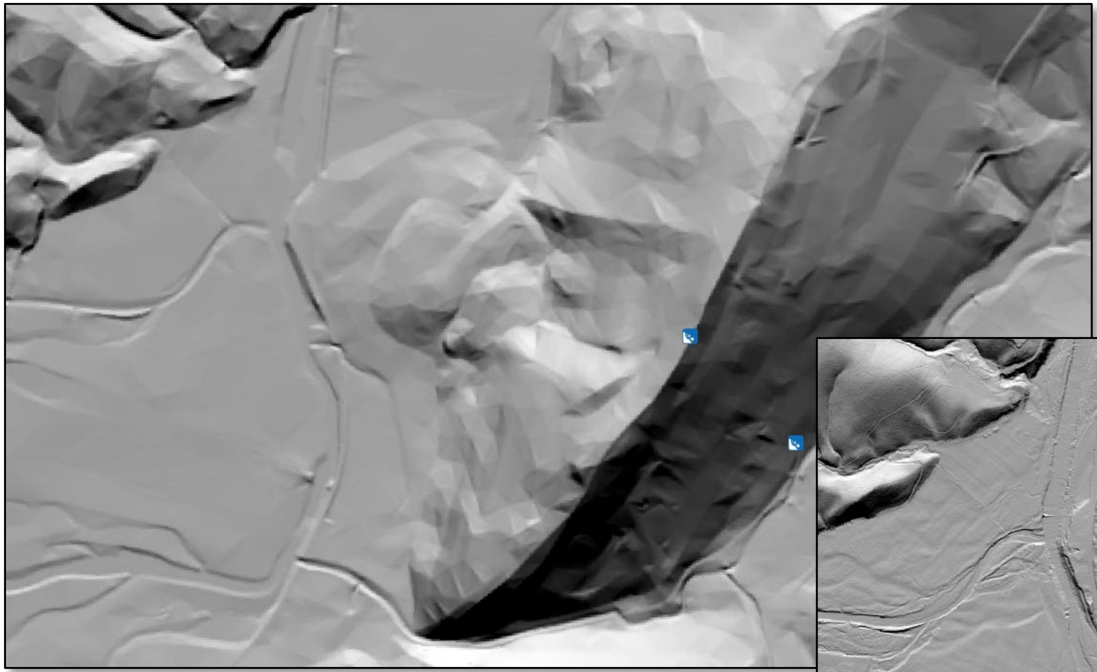
Mapping Landslides from new DEM



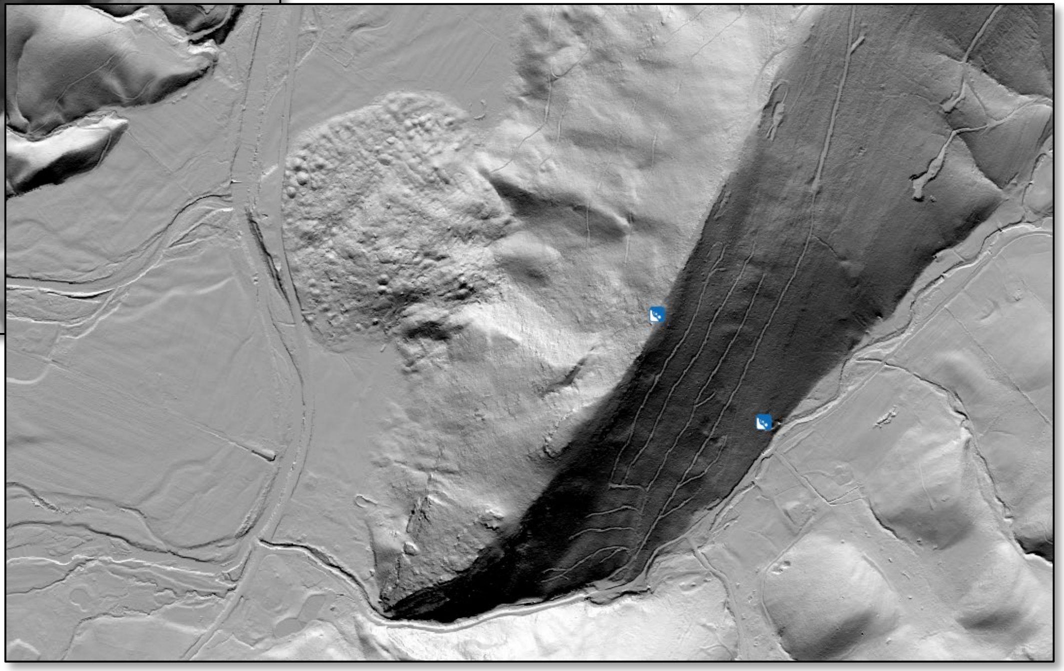
Best-Available Elevation Sources for West Virginia: [*https://www.mapwv.gov/floodtest/docs/WV_FloodTool_ElevationSource_Metadata.pdf*](https://www.mapwv.gov/floodtest/docs/WV_FloodTool_ElevationSource_Metadata.pdf)

Mapping Landslides from new DEM

Old DEM



New DEM



Comparison of Old and New 1 meter DEM

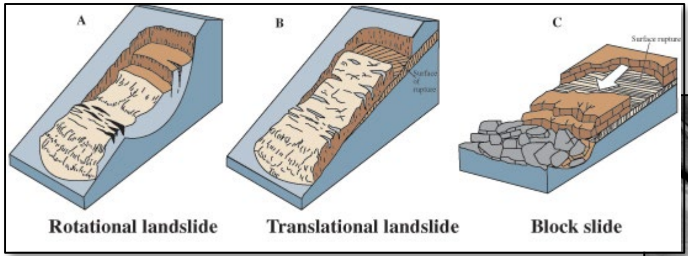
Landslide Incident Inventory

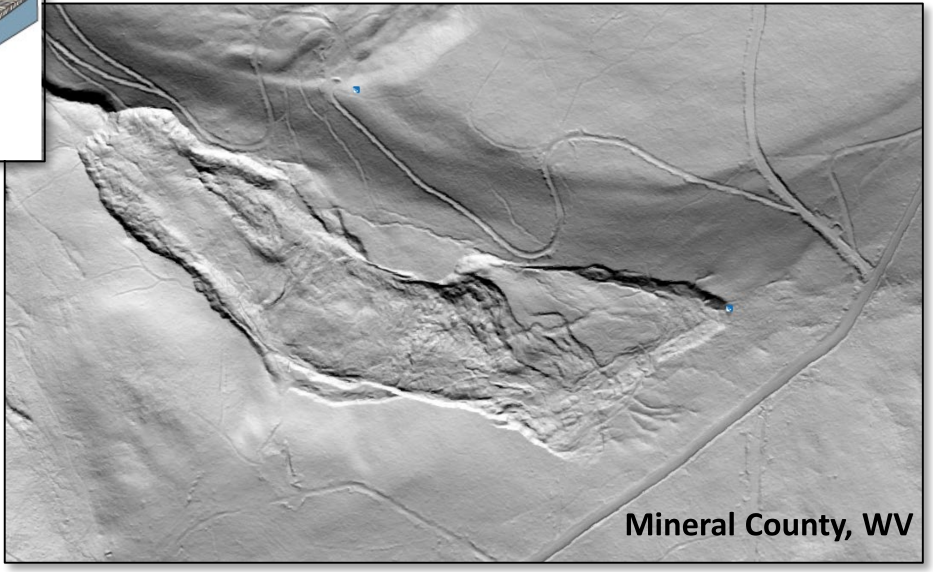
Landslide mapping from new LiDAR-derived DEM

- 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

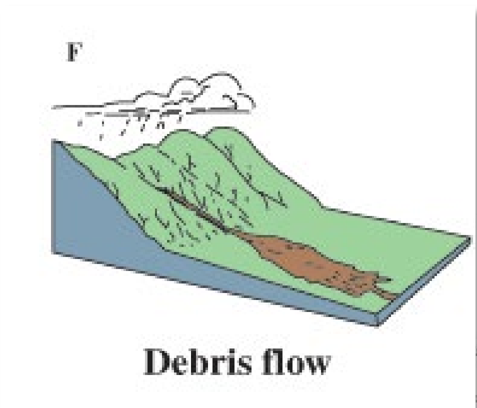


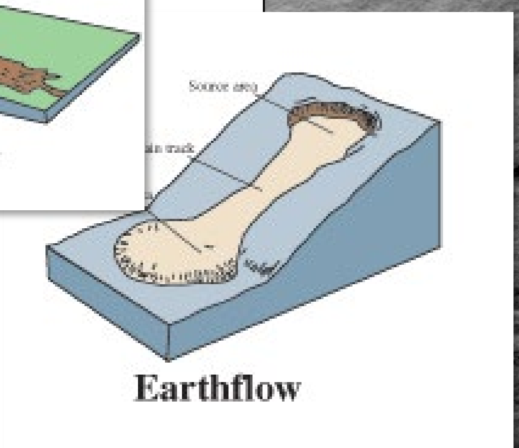


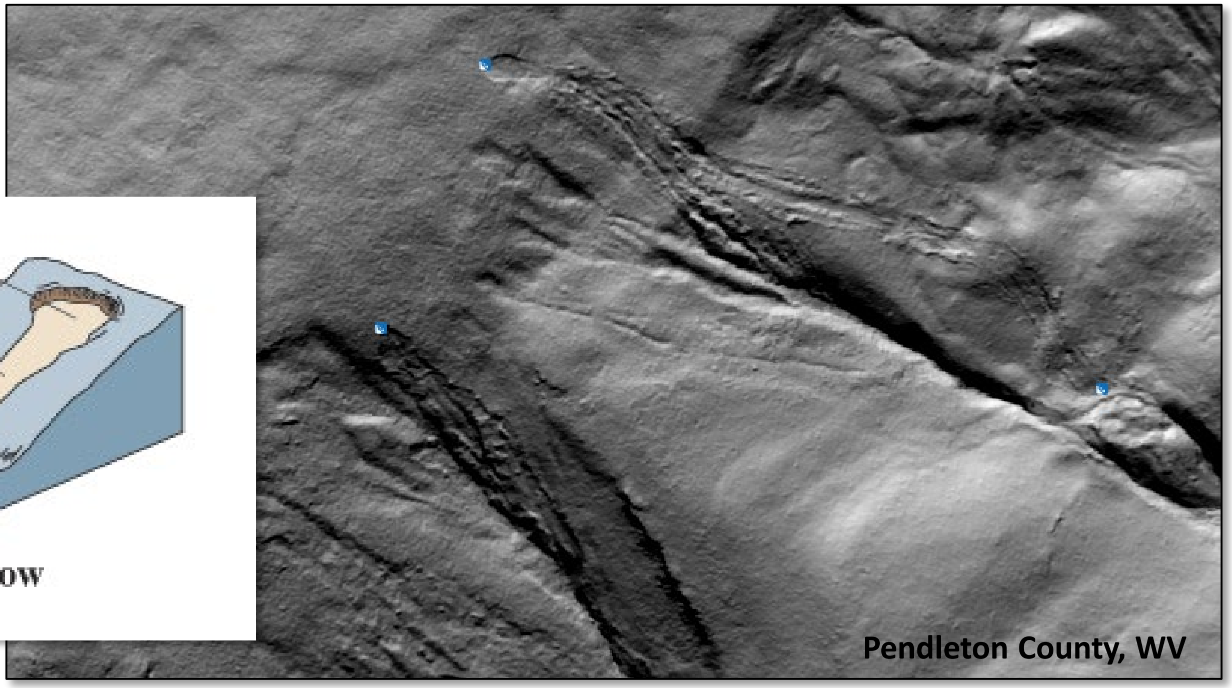
*Description from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html
Images from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

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



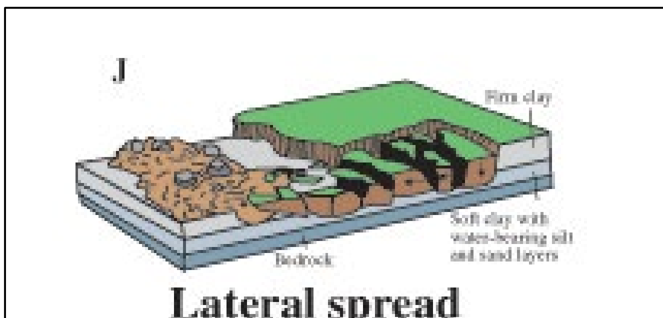


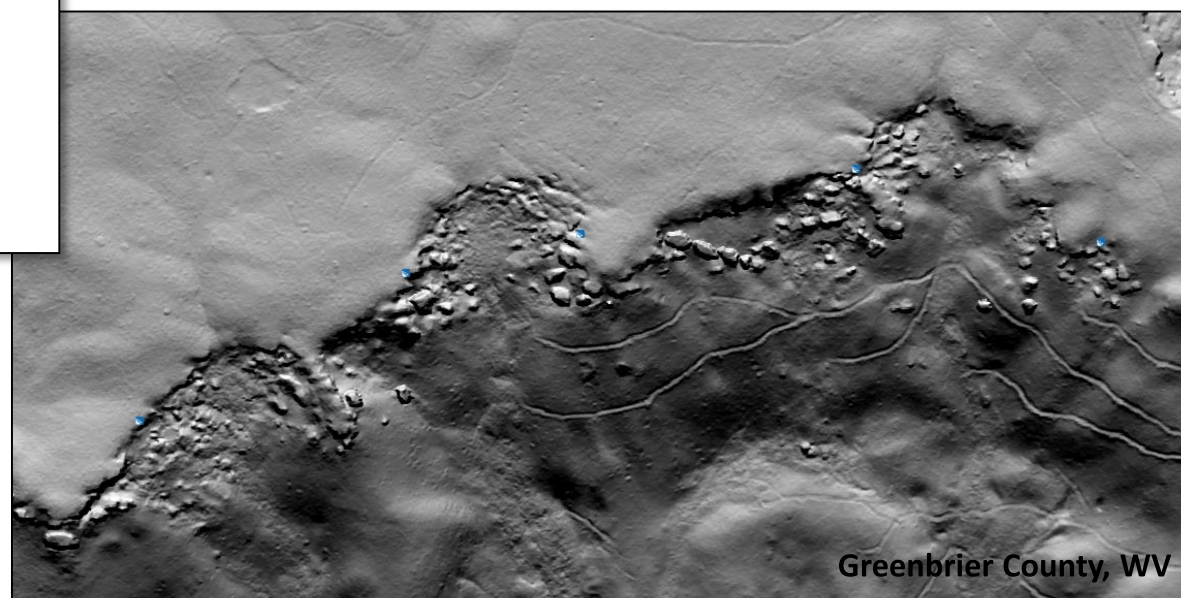


*Description from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html
Images from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

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

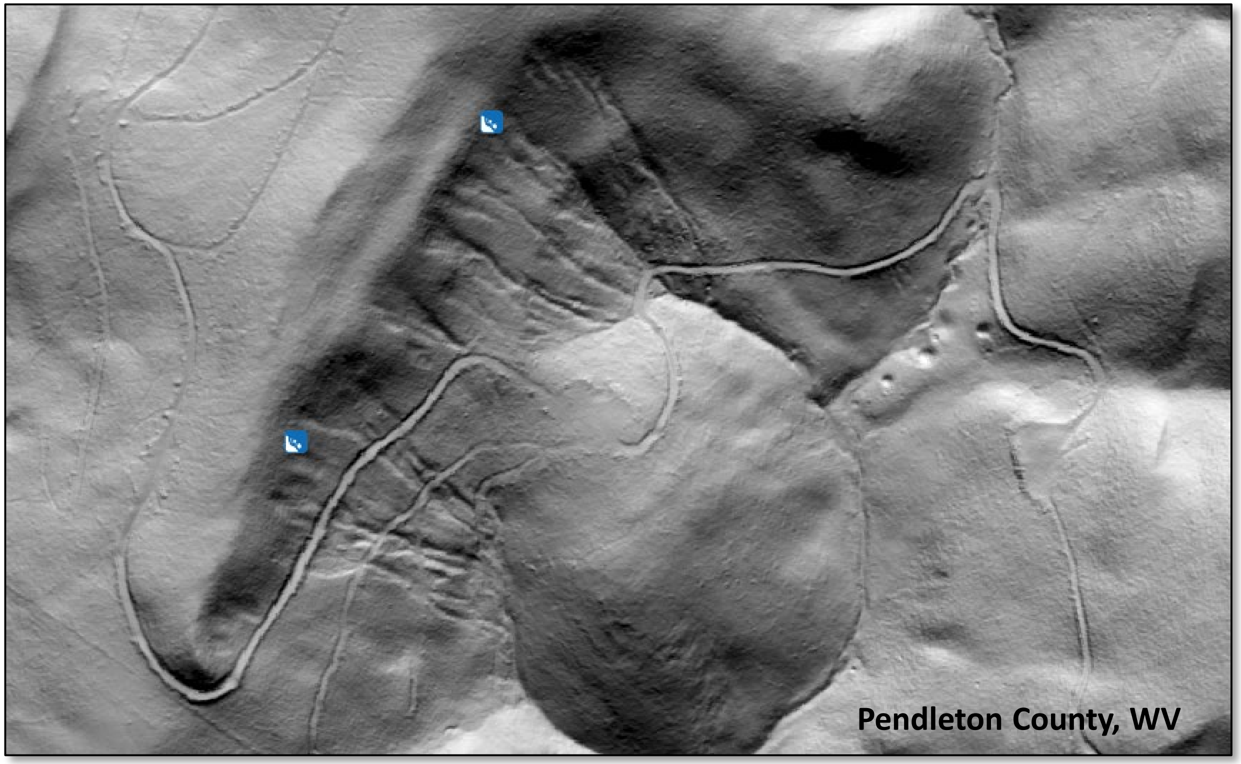




*Description from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html
Images from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

Landslide Incident Inventory

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



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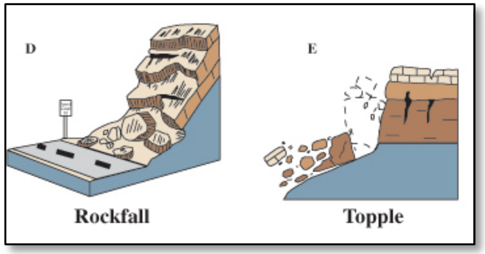
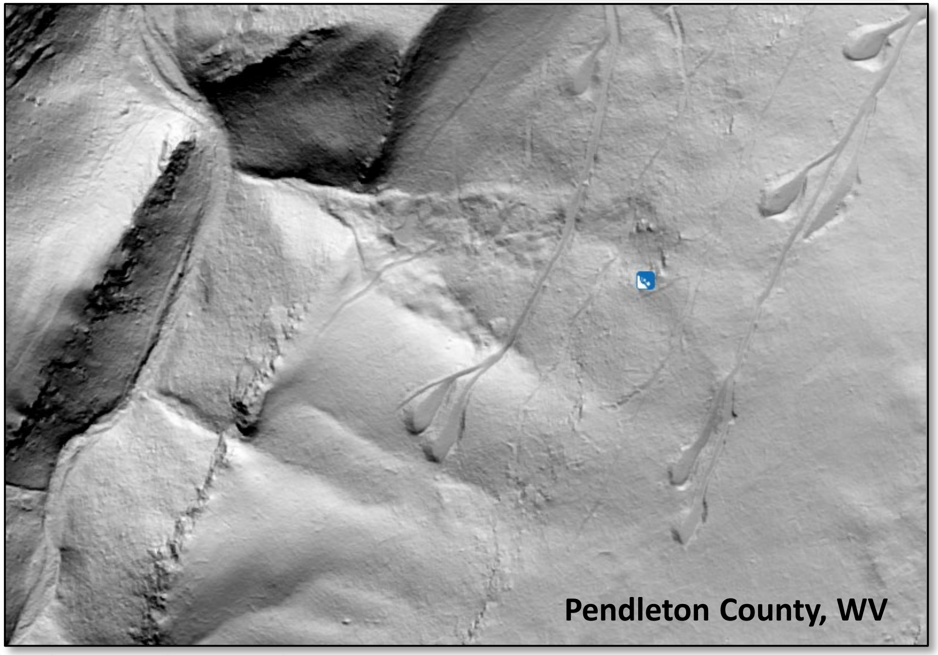
Images from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

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

WV GIS TC
Landslide Mapping
March-September 2019

WV GIS TC Mapping on LiDAR-Based DEMs

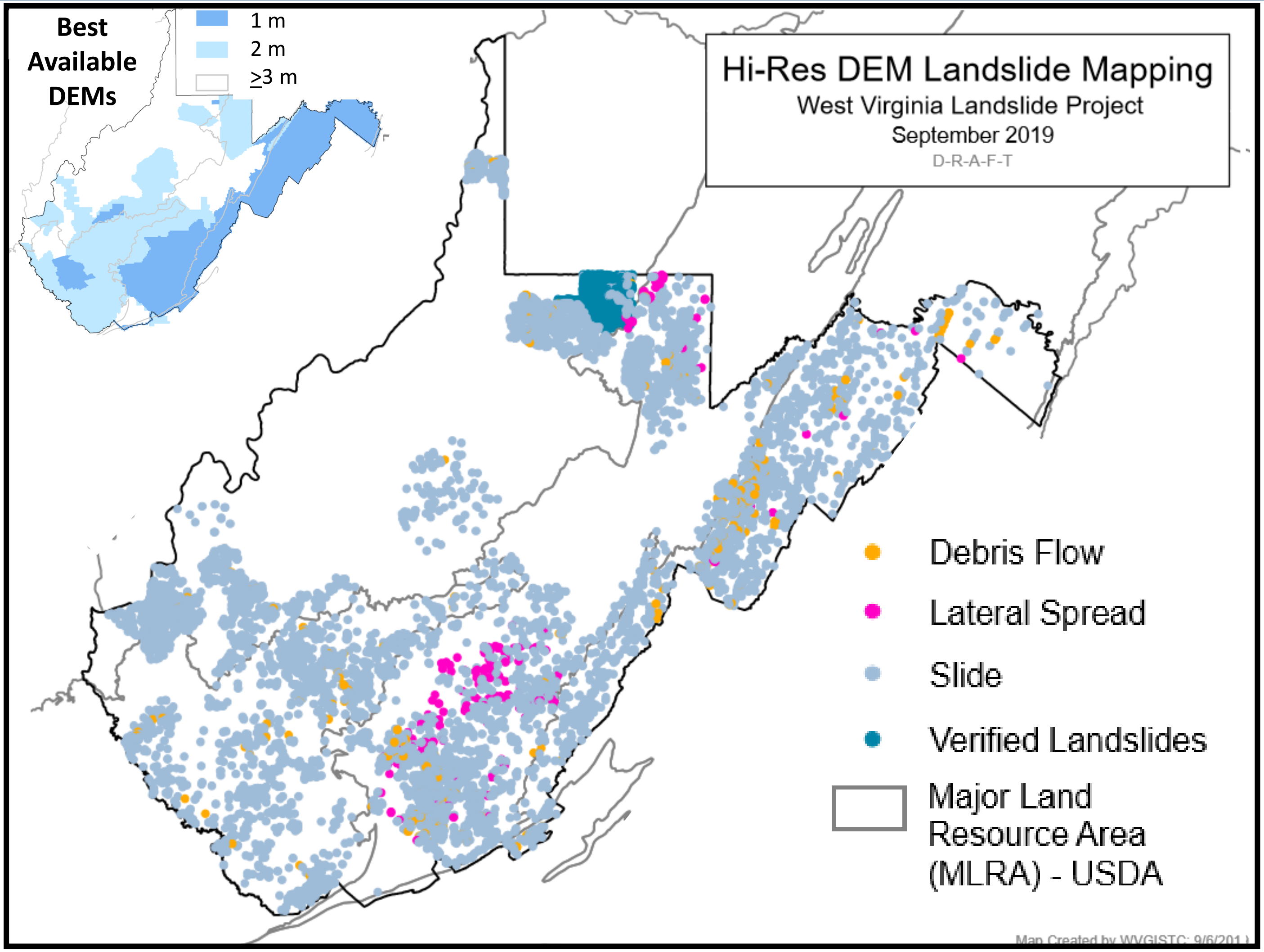
8,991 Failures *(≥10 m wide)*
Most from 1 m DEMs

- **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**

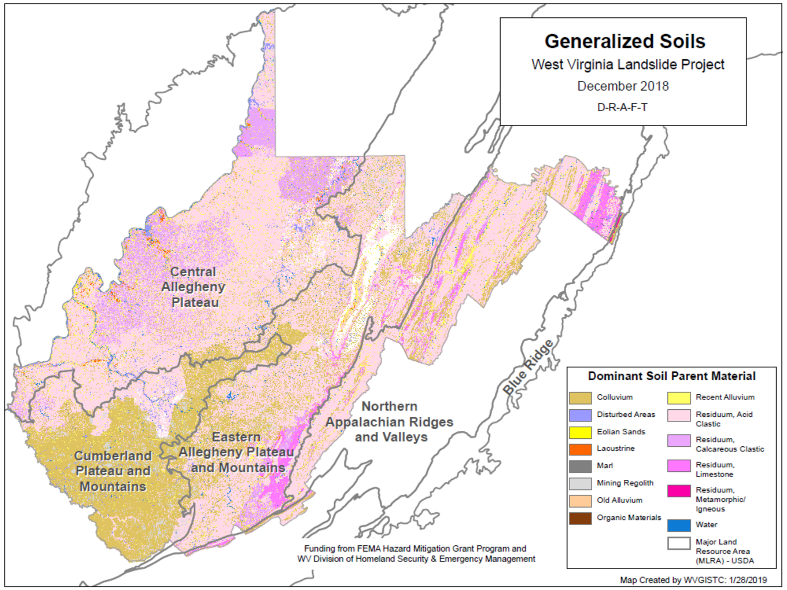


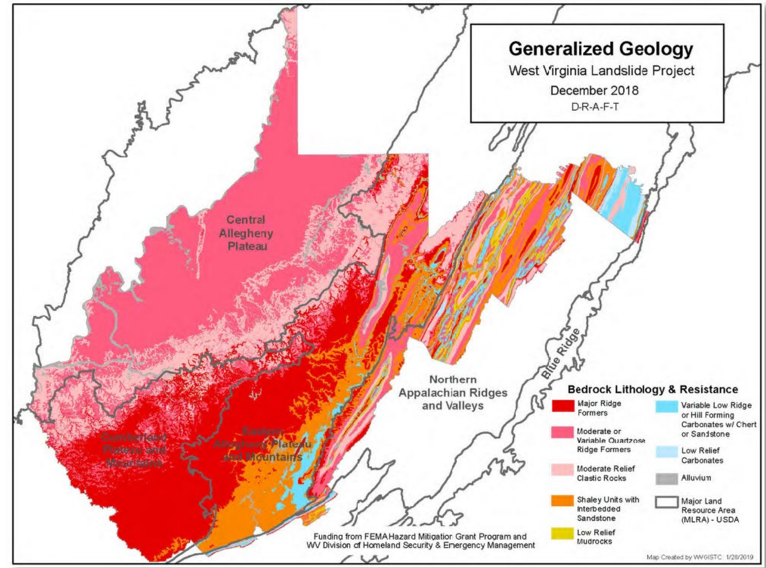
Landslide Incident Inventory

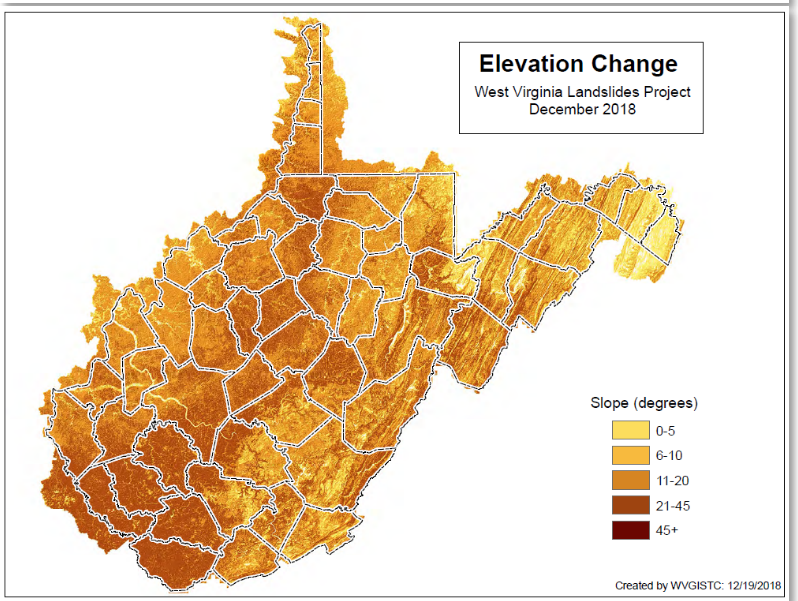
Type of Movement	Number of user identified points	Percentage of user identified points	Description
Slide	8232	92.2	A zone of weakness separates the slide from the underlying material; can be translational or rotational
Fall	5	0	Rocks or other geologic materials dislocate from steep slopes
Debris Flow	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

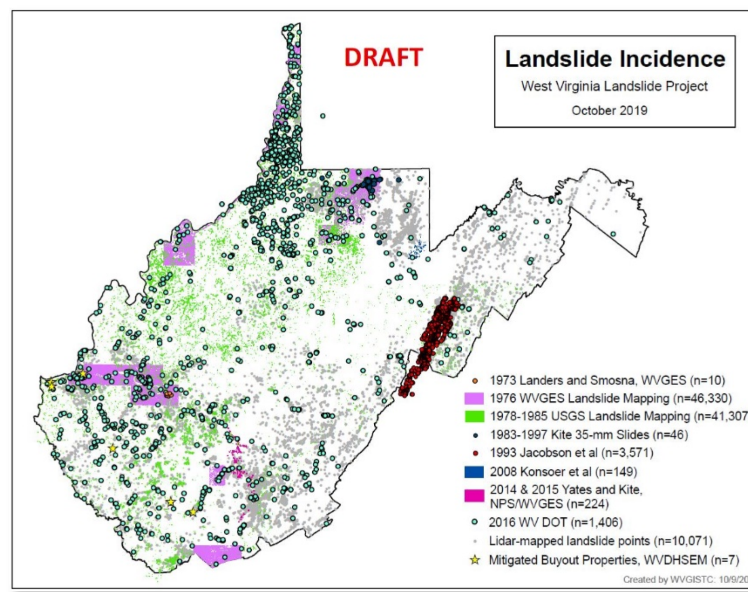
Landslide Method Development

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

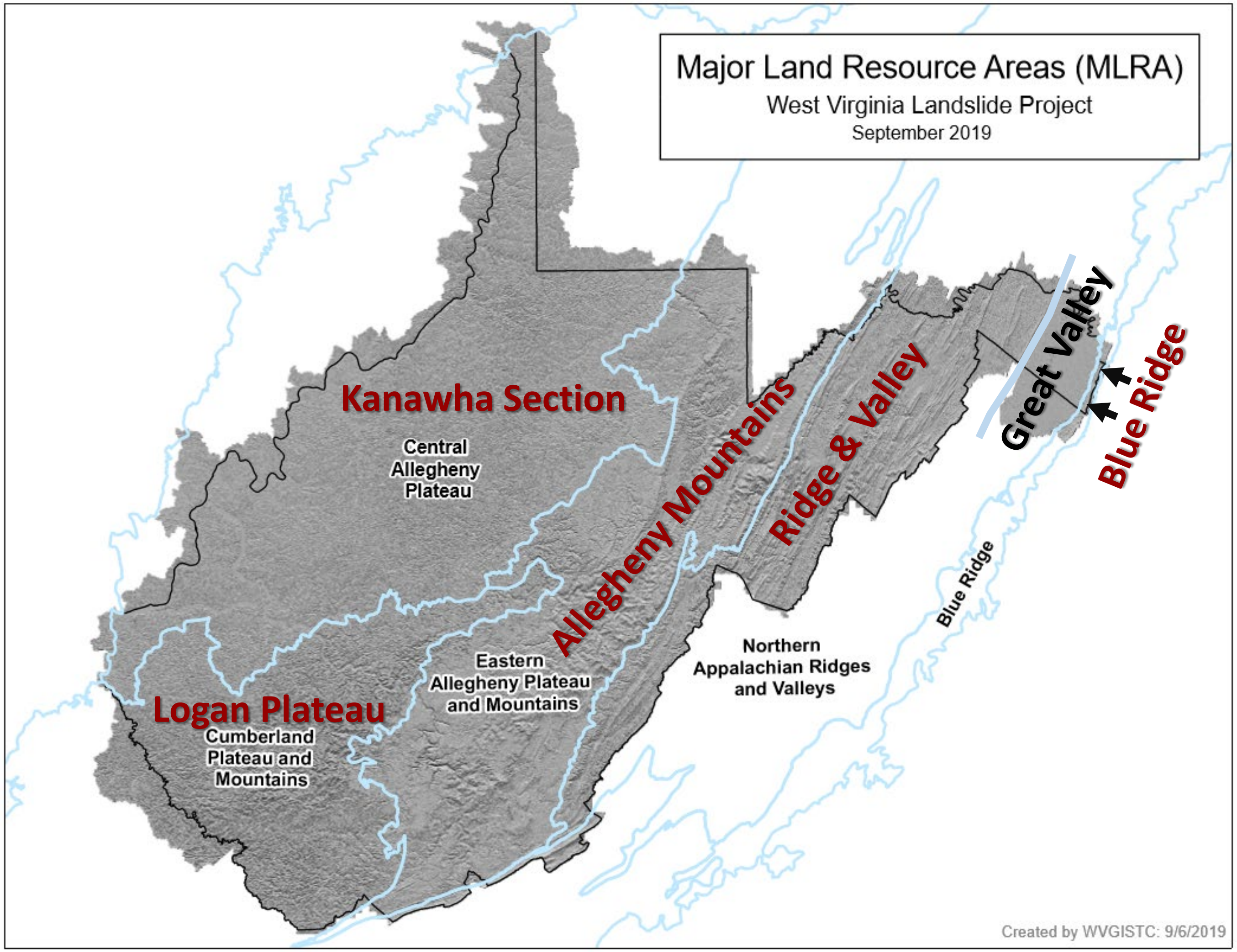
<u>Provinces & Subdivisions</u>

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

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

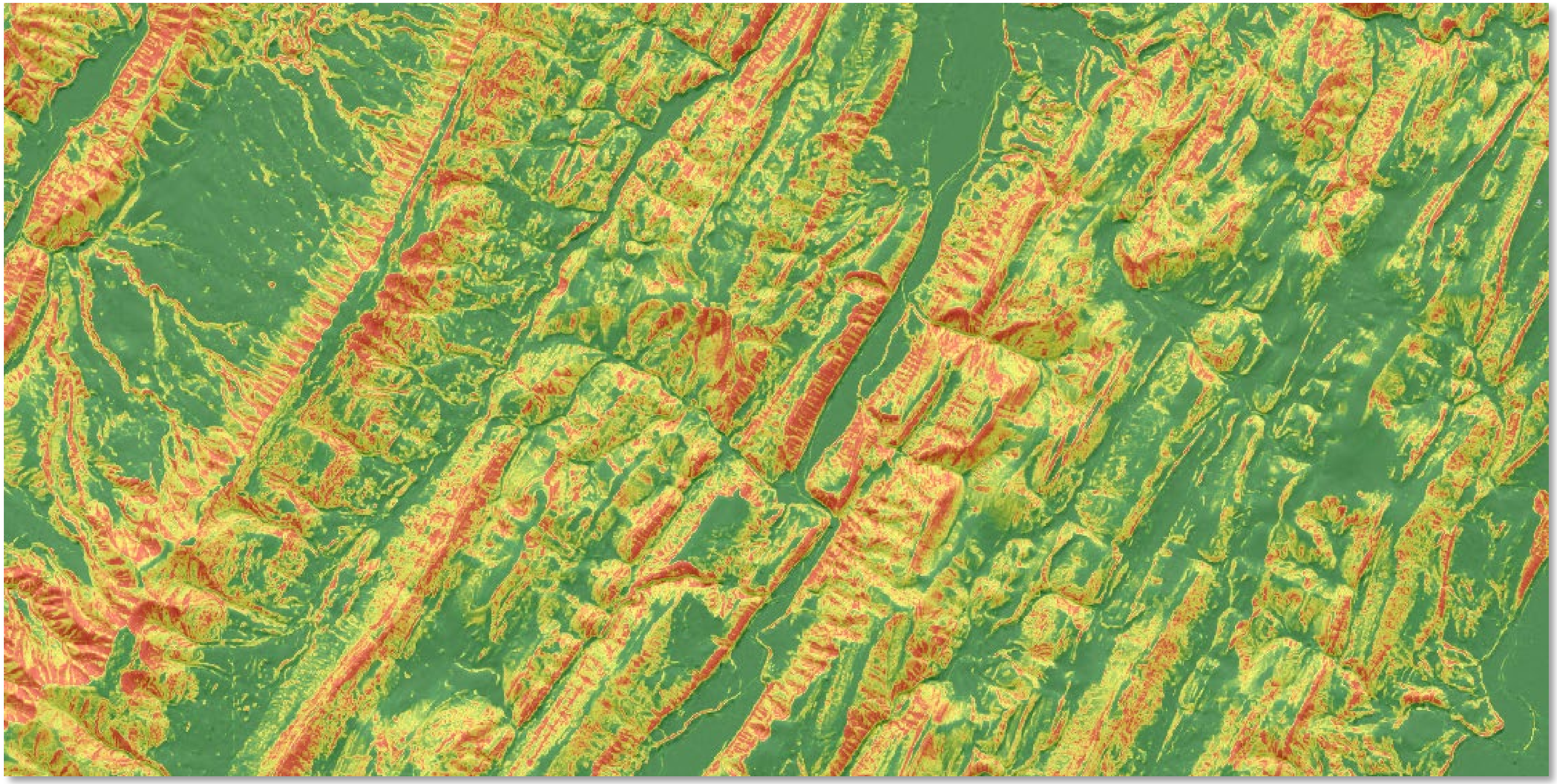
Blue Ridge

Red = Landslide-Prone

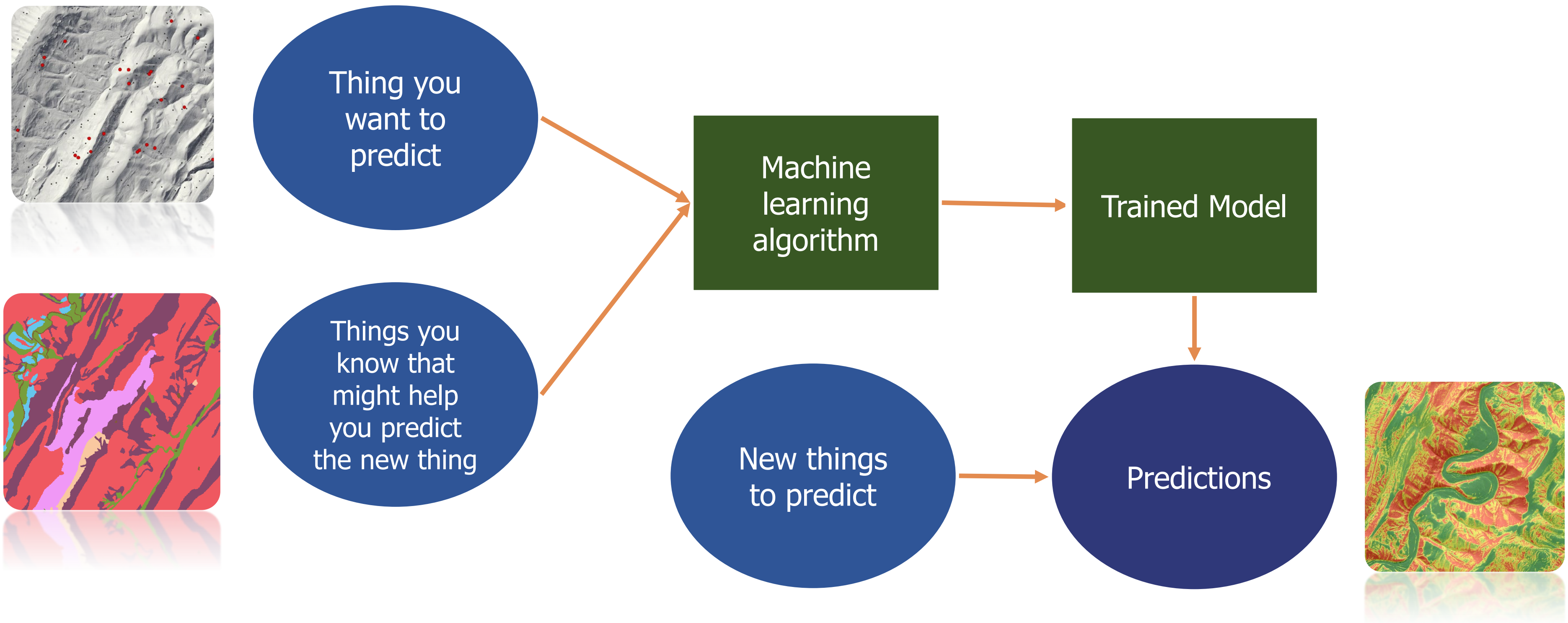


Landslide Method Development

Goal: Generate predictive models of slope failure probability/occurrence

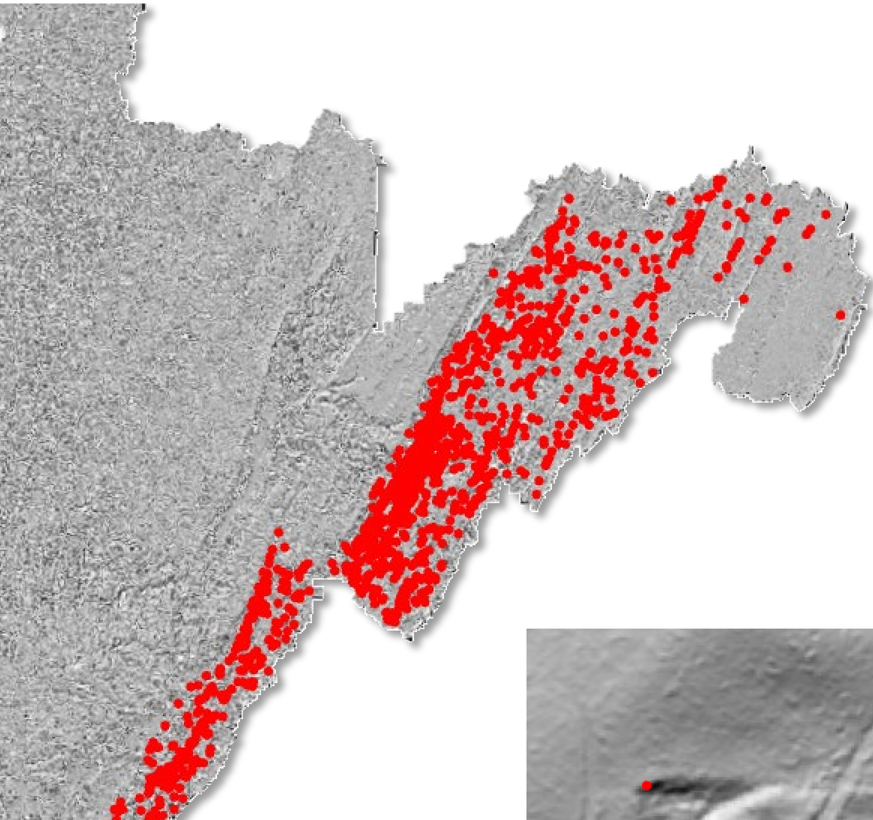


Landslide Method Development



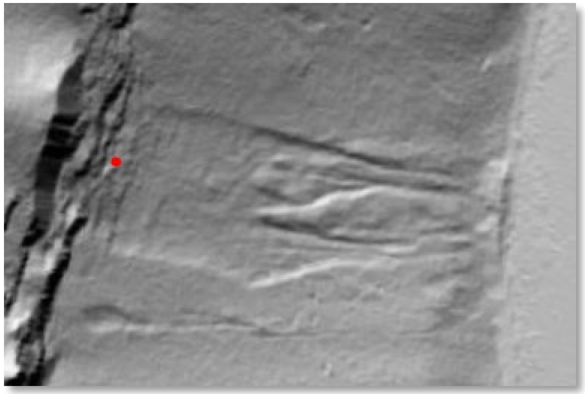
Machine Learning = Learning from Examples

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)
    - 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)
```

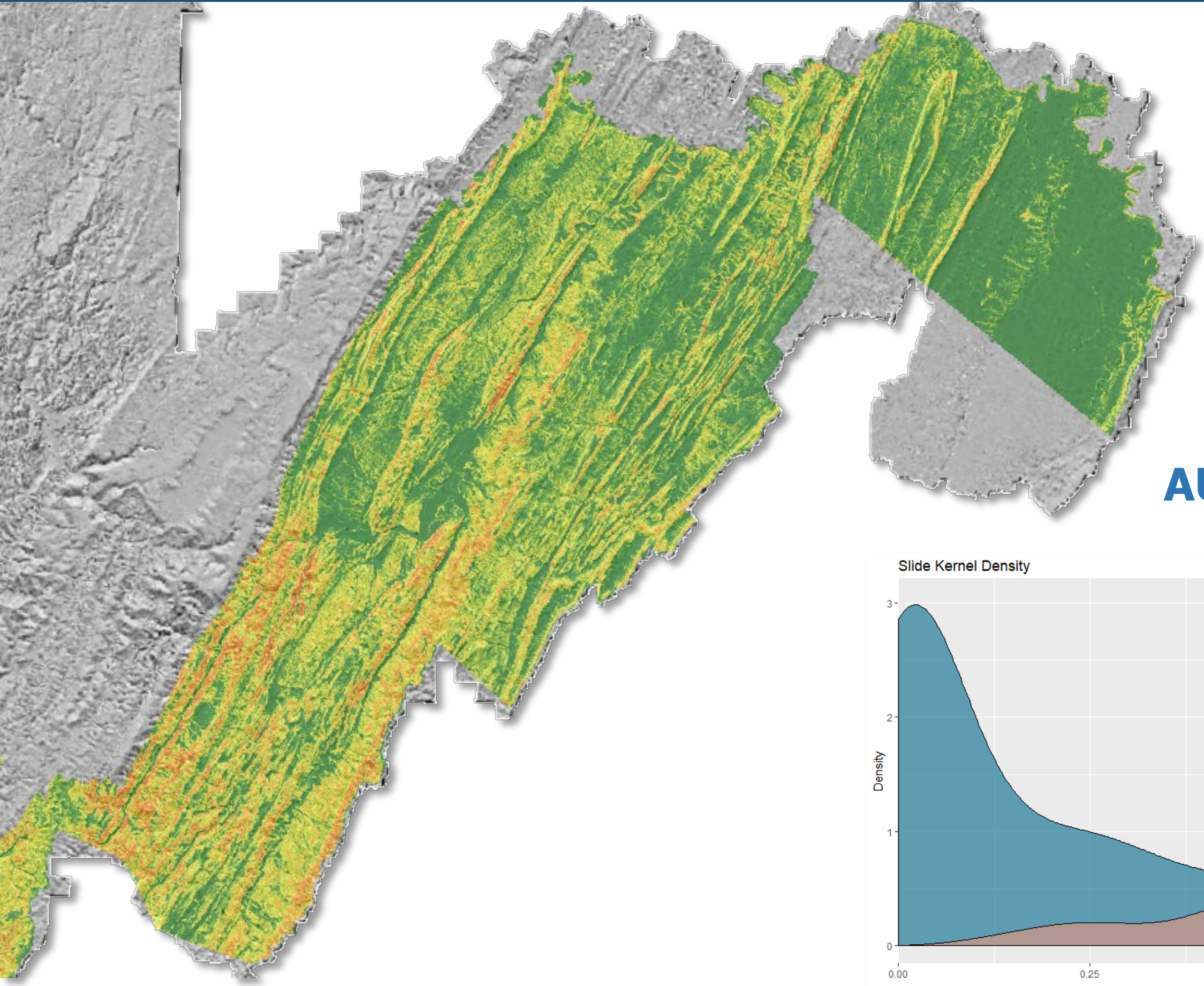
Landslide Method Development

Predict to Entire Extent

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

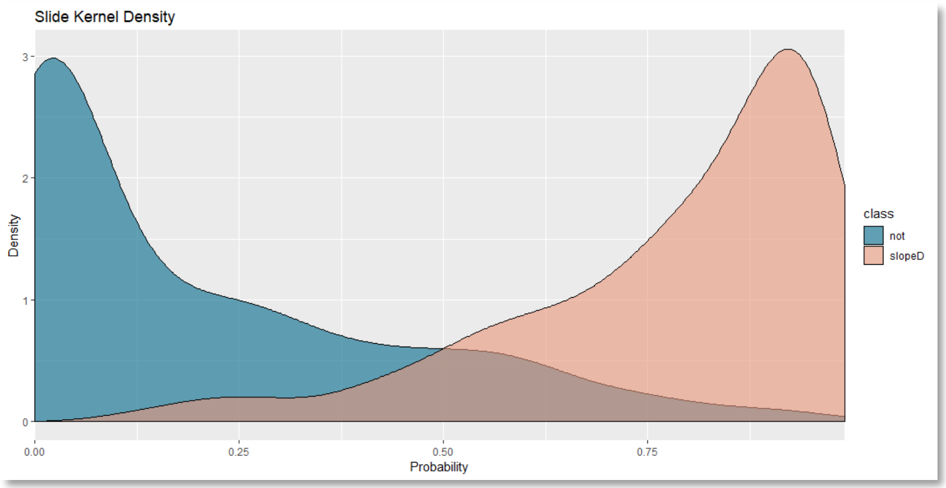
```
for shp in shp_lst:
    name = str(shp)
    tile = [shp]
    subprocess.call(["python", "predict_to_grid_subscript3.py"] + tile, shell=True)
    arcpy.CopyRaster_management("D:/v_r_landslide/stack/pred_out.tif", "D:/v_r_landslide/pred_out/"
                                + str(os.path.splitext(shp)[0])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

Landslide Method Development



Results

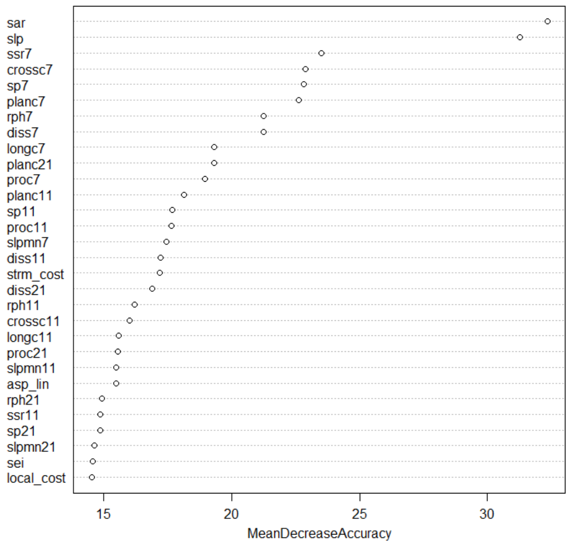
AUC – 0.94

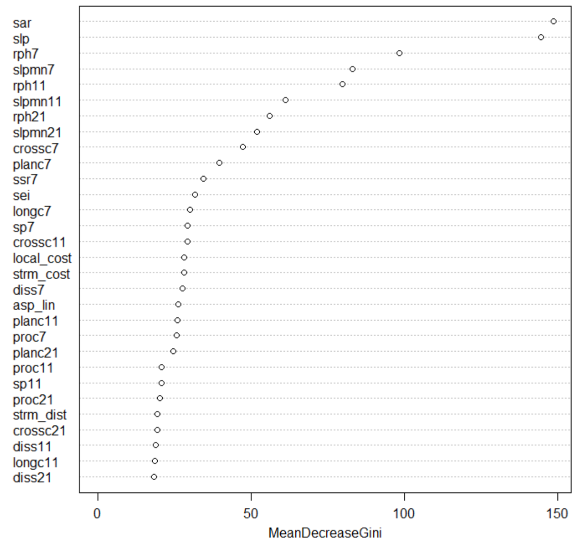


Landslide Method Development

Important Variables

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

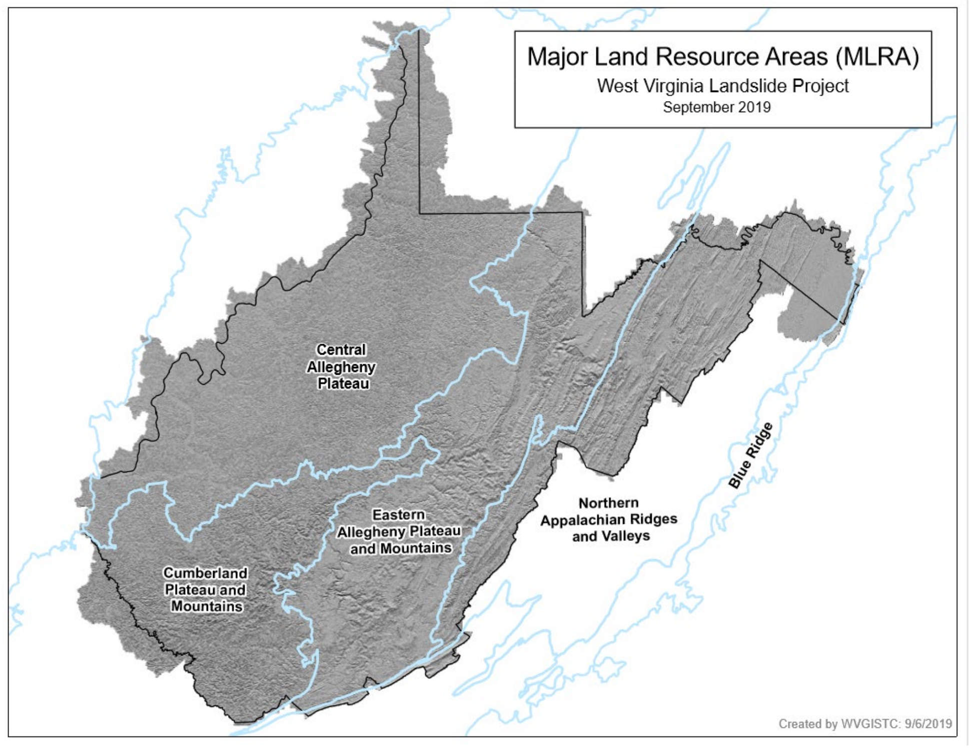




Landslide Method Development

Moving Forward

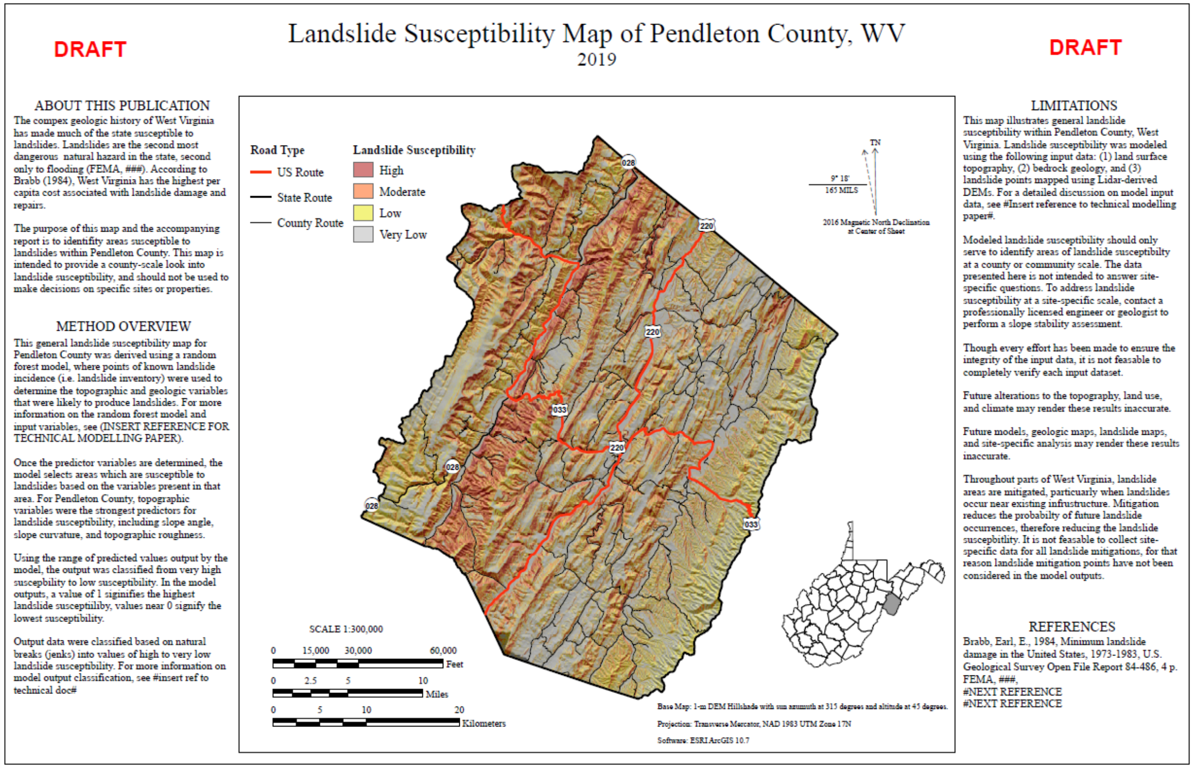
- Semi-automate with scripting
- Develop models for different physiographic regions
- Predict entire state
- Further validate results



Landslide Susceptibility Prediction

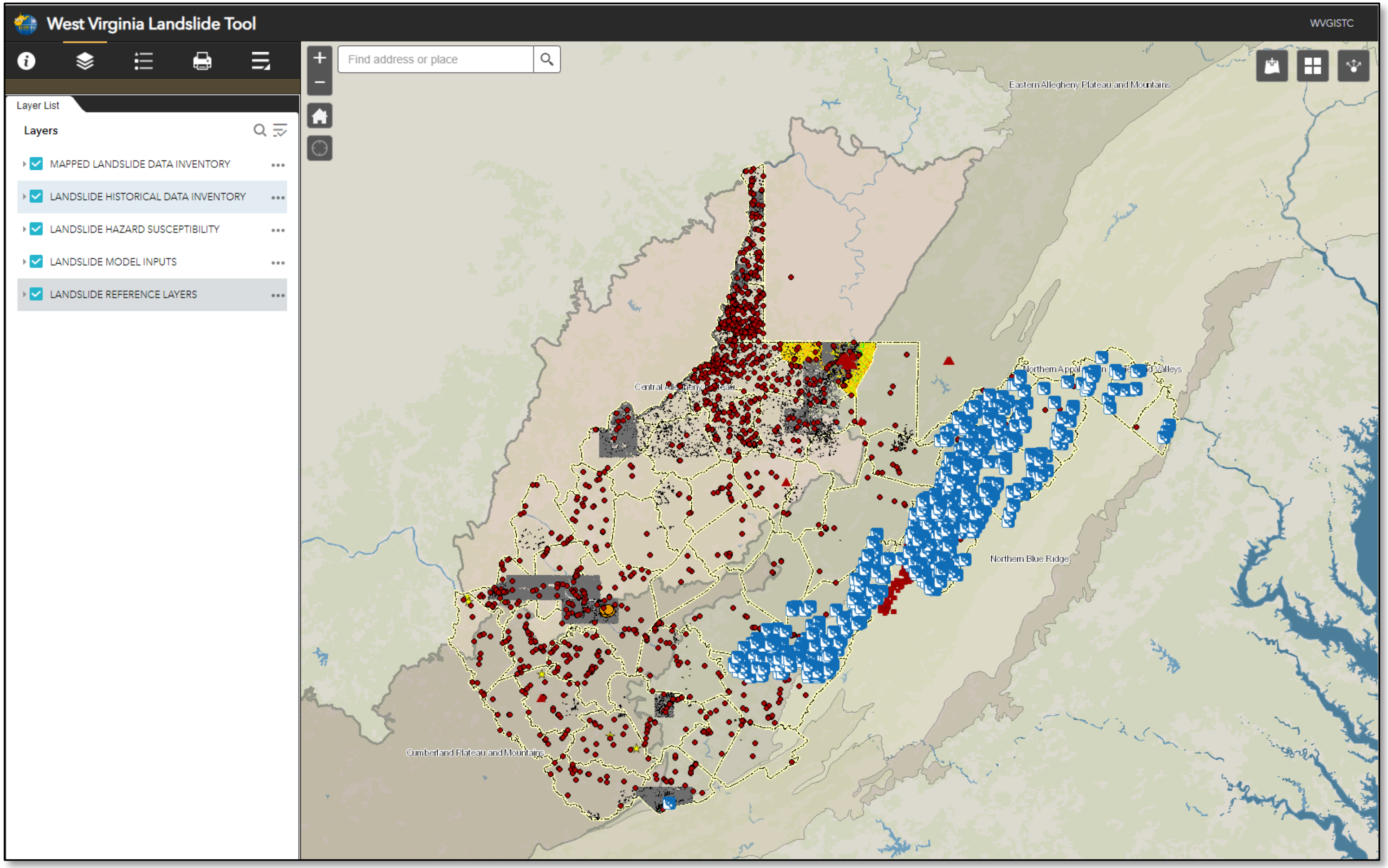
Susceptibility and Hazard Assessment

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



Landslide Incident Inventory

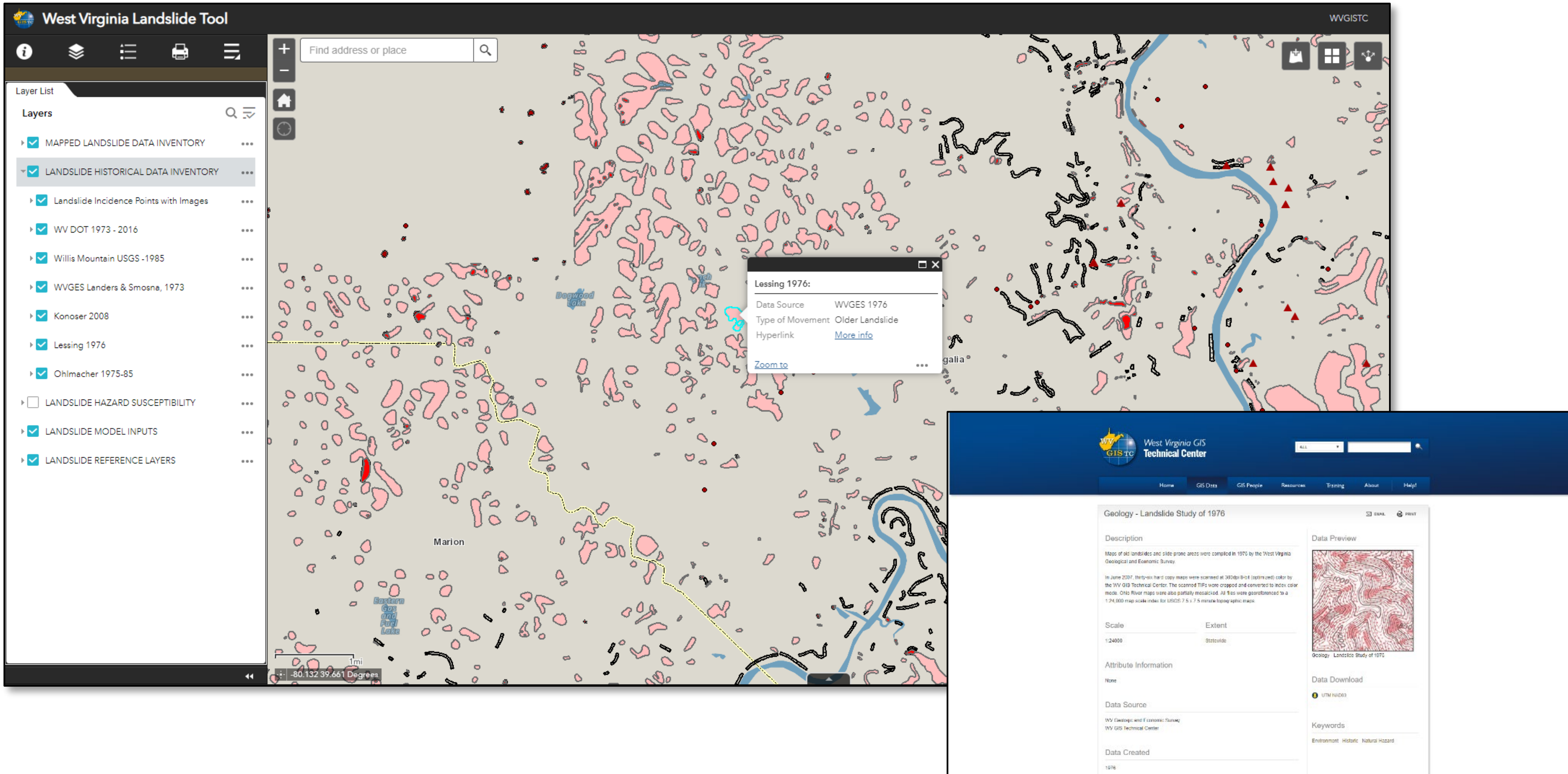
www.mapWV.gov/Landslide *(in development)*



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

Landslide Incident Inventory

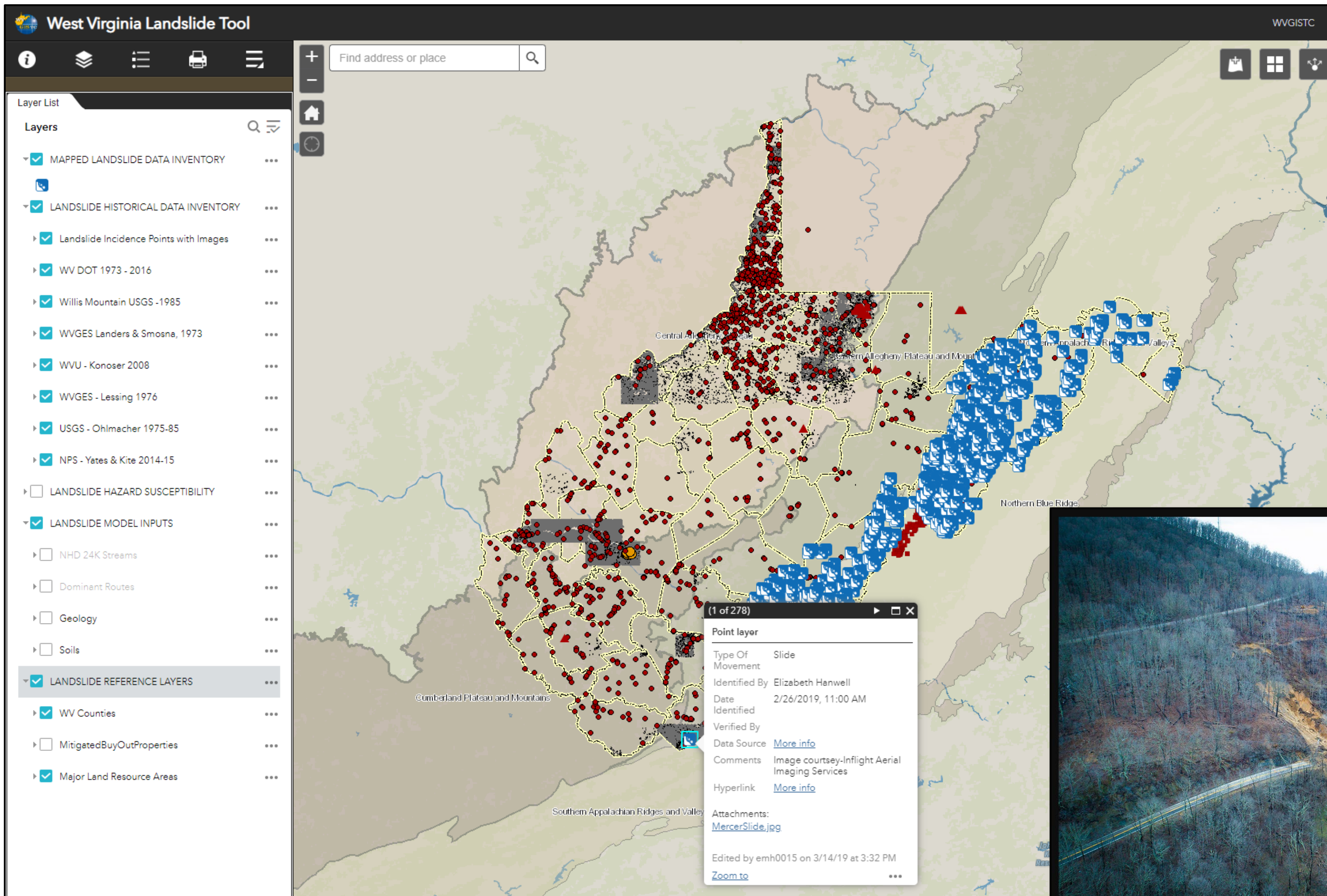
www.mapWV.gov/Landslide (in development)

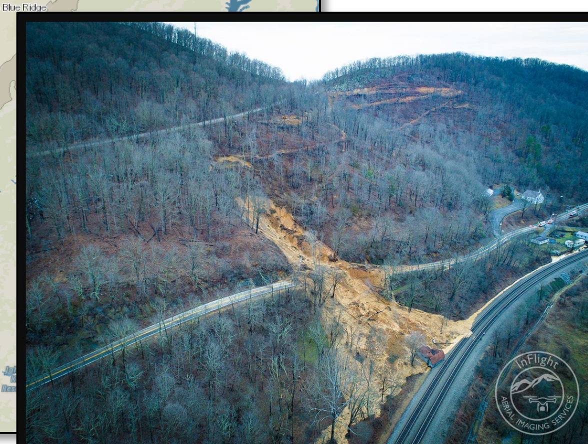


Over 100,000 landslide incident point and polygon features have been inventories into a digital geodatabase

Landslide Incident Inventory

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



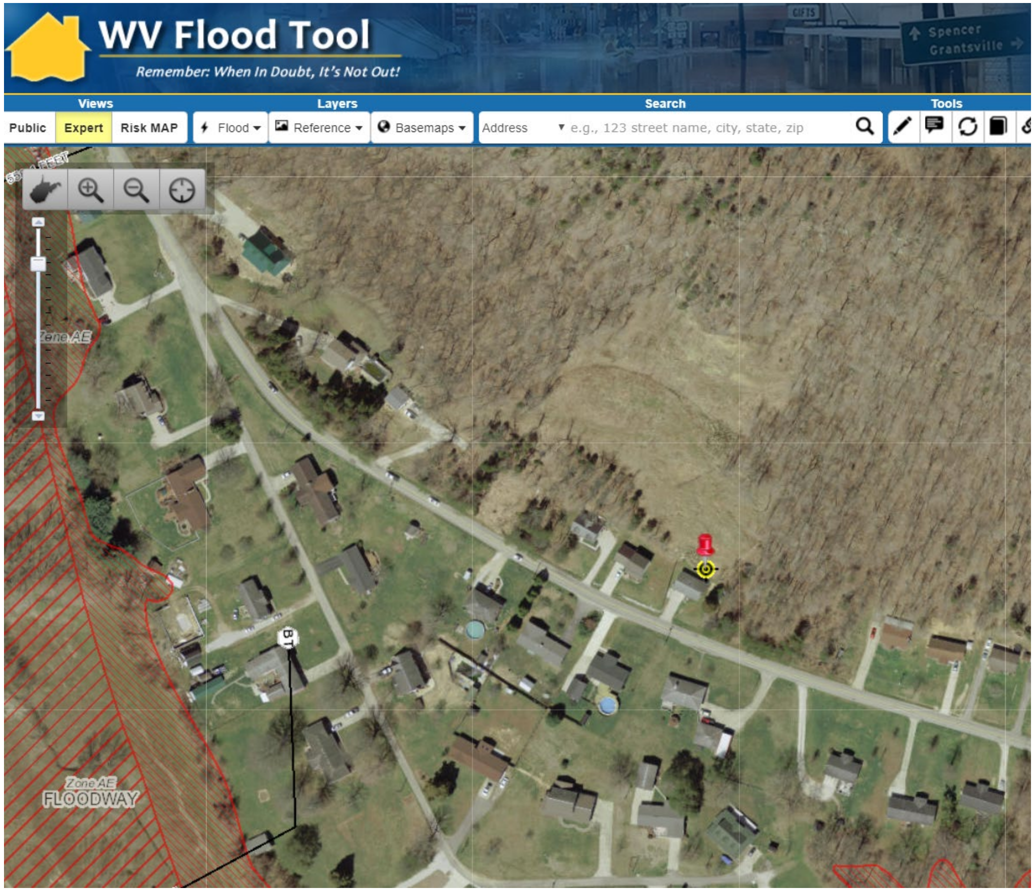


5000-8000 square meter range in total. One of the biggest observed in the state. Feb 25, 2019

Landslide Buyout properties

Cabell County buyout properties

- 06-08-004A-0049-0004 - https://www.mapwv.gov/flood/map/?wkid=102100&x=-9159293&y=4632966&l=11&v=1
- 06-08-004A-0049-0007 - https://www.mapwv.gov/flood/map/?wkid=102100&x=-9159328&y=4632979&l=11&v=1
- 06-08-004A-0049-0005 - https://www.mapwv.gov/flood/map/?wkid=102100&x=-9159374&y=4633002&l=11&v=1



https://arcg.is/1SW0Sn

Landslide Buyout properties

Cabell County buyout properties

- 06-08-004A-0049-0004 - https://www.mapwv.gov/flood/map/?wkid=102100&x=-9159293&y=4632966&l=11&v=1
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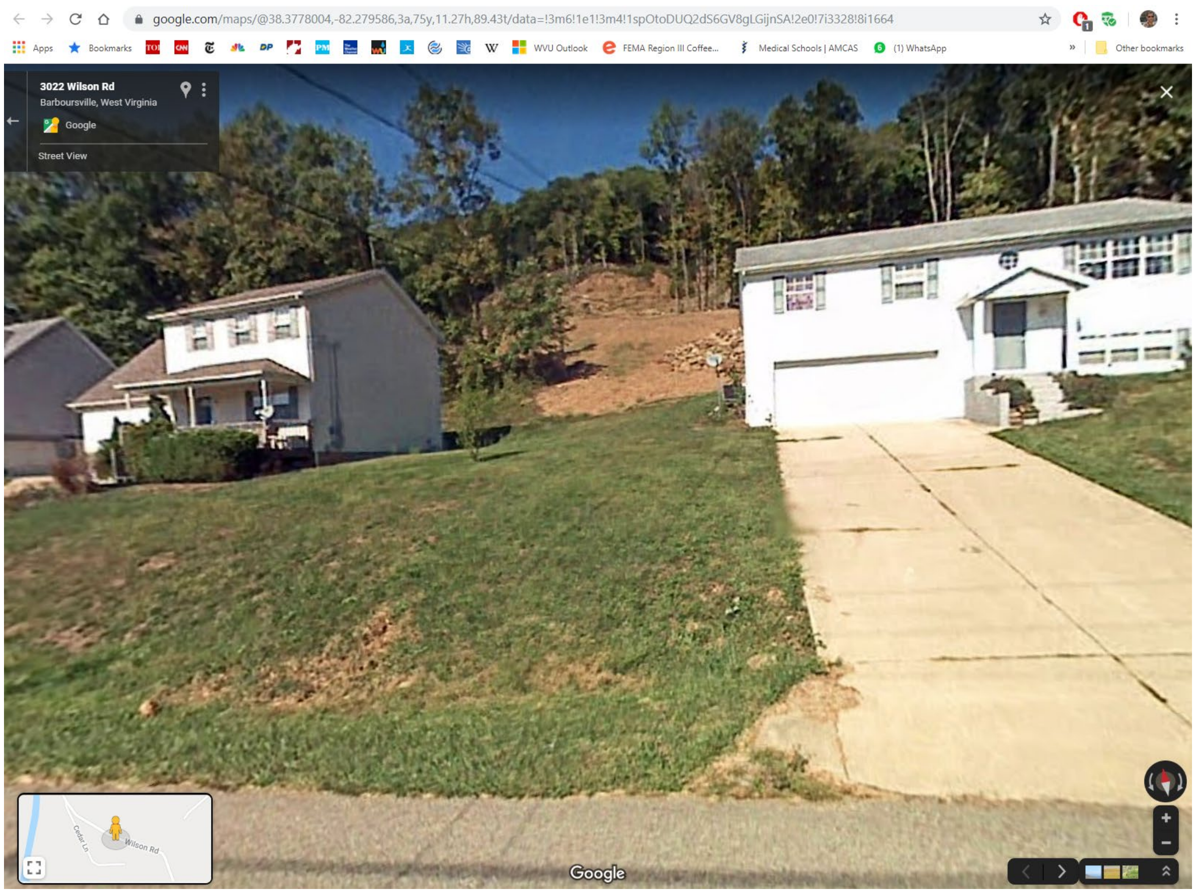
- 06-08-004A-0049-0005 - https://www.mapwv.gov/flood/map/?wkid=102100&x=-9159374&y=4633002&l=11&v=1

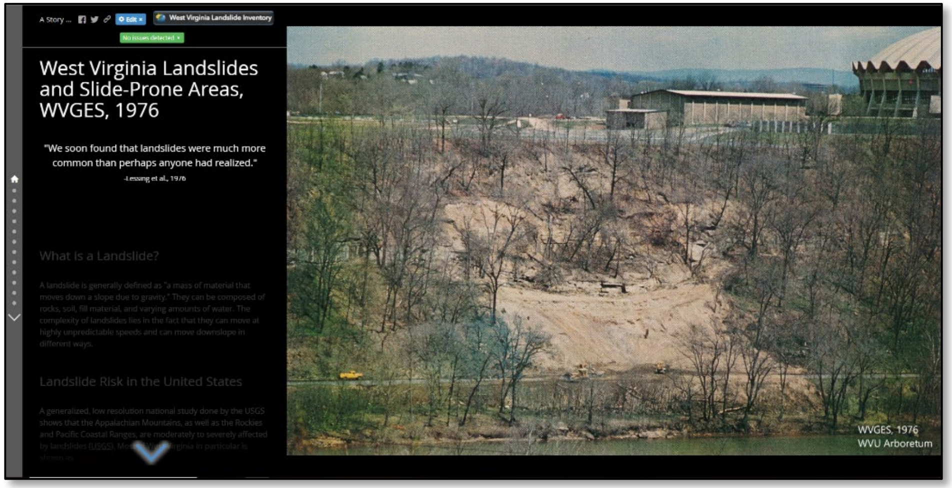
https://www.google.com/maps/@38.3778004,-82.279586,3a,75y,11.27h,89.43t/data=!3m6!1e1!3m4!1spOtoDUQ2dS6GV8gLGijnSA!2e0!7i3328!8i1664



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

Mitigation Approaches

- Landslide is classed as sever hazard
- **Two mitigation approaches**
  1. **Emergency Management and Response**
     1. Emergency Management
        1. Anticipation
        2. Prediction
        3. Issuance of warnings of impending occurrence of life- and property-threatening landslides
     2. Response
        1. Identification of landslide-prone areas
        2. Planning, training and other preparatory measures to ensure effective warning and response

  2. **Long Term Hazard Reduction**
     1. Focus on reducing frequency of landslides
     2. Reducing the likelihood of slide causing damage
     3. Minimizing damage when slides do occur

https://www.fema.gov/media-library/assets/documents/7251

Mitigation Approaches

- **Landslide losses can be reduced** in two ways
  1. **Reduce the occurrence** by requiring
     1. Excavation, grading, landscaping and construction do NOT contribute to slope instability
  2. **Minimize damage** when landslide do occur by
     1. Restricting development in landslide prone terrain
     2. By protecting building and other structure from landslide damage

Outreach: Landslide Remediation

Prevention and Protection Projects (1)

Landslide prevention and protection are possible in some cases; however they are typically very expensive. Less expensive methods involve slope stabilization using native vegetation and drainage improvements. In many cases the most effective methods will involve relocation of utilities and critical facilities, realignment of roadways, and acquisition and demolition of high-risk structures. Some examples of stabilization techniques include:

- Vegetation placement and management;
- Implementing drainage improvements (drainage pipes, ditches, berms, and catchment basins);
- Dewatering or installing impermeable membranes on existing slide areas to prevent oversaturation;
- Debris removal;
- Grading to lessen slope; and
- Constructing rock buttresses and retaining walls.

(2)

	Classification	Component of risk addressed	Brief description	Notes and other terms used
STRUCTURAL	Stabilization	Hazard (H)	Engineering works to reduce the landslide probability of occurrence	Preventive, remedial, hard, soft, active stabilization.
STRUCTURAL	Control	Vulnerability (V) (consequence)	Engineering works to protect, reinforce, isolate the elements at risk from the landslide zone of influence	Preventive, hard, soft, passive stabilization.
NON STRUCTURAL	Avoidance	Elements (E) (consequence)	Temporary and/or permanent reduction of exposure through: warning systems, emergency evacuation, safe sheltering, land-use planning and/or relocation of existing facilities	Reduction of the exposure of the elements at risk. Monitoring, early warning systems and civil protection procedures, often described as reducing vulnerability, are essentially temporary, selective avoidance measures.
NON STRUCTURAL	Tolerance	Elements (E) (consequence)	Awareness, acceptance and/or sharing of risk	Indirect reduction of the exposure of the elements at risk.

Table 2. Techniques for reducing landslide hazards (Kockelman, 1986). (3)

Discouraging new developments in hazardous areas by:
- Disclosing the hazard to real-estate buyers
- Posting warnings of potential hazards
- Adopting utility and public-facility service-area policies
- Informing and educating the public
- Making a public record of hazards

LT-LS#2: Limit activities in identified landslide hazard areas through regulation and public outreach. (4)

Possible Actions

- Use the hazard identification and mapping processes to determine where to regulate.
- Coordinate with property owners to reduce risk in landslide hazard areas;
- Provide information on hazard location to future residents; and
- Show hazard susceptibility on deeds.

(1) https://files.dnr.state.mn.us/waters/watermgmt_section/shoreland/landslide-mitigation.pdf
(2) SafeLand Grant Agreement No.: 226479 (2011); Toolbox of landslide mitigation measures
(3) https://www.fema.gov/media-library-data/20130726-1440-20490-1637/fema_182.pdf
(4) https://www.beavertonoregon.gov/DocumentCenter/View/4662/NHMP-Chapter-9-Landslide

Outreach: For Homeowners

10 **Reduce Your Risk** (1)

THERE ARE ACTIONS YOU CAN TAKE AS A HOMEOWNER TO REDUCE THE CHANCES OF A LANDSLIDE AFFECTING YOUR PROPERTY:

DO

- Drain water from surface runoff, downspouts, and driveways well away from slopes
- Plant native ground cover on slopes
- Consult with a professional before significantly altering existing slopes uphill or downslope of your home
- If you suspect you are on a landslide, contact a licensed engineering geologist or a geotechnical engineer for an evaluation
- Check online maps, such as SLIDO (Oregon) or the Washington Geologic Information Portal to see if you might live in a landslide area

DO NOT

- Do not add water to steep slopes
- Avoid placing fill soil on or near steep slopes
- Avoid placing yard waste or debris on steep slopes
- Avoid excavating on or at the base of steep slopes

YOU AND YOUR NEIGHBORS SHARE MORE THAN FENCES. YOU ALL SHARE THE RESPONSIBILITY OF KEEPING YOUR SLOPES SAFE.

www.dnr.wa.gov/geology

WHEN YOU BUILD (2)

Buildings should be located away from high risk areas such as steep slopes, rivers and streams (perennial or ephemeral), and fans at the mouth of mountain channels.

Consult a certified or licensed engineering geologist (**CEG** or **LEG**) or a registered/licensed geologist (**RG**) or a professional geotechnical engineer (**PE**) **if** you plan on building on a location that is a **high risk** area.

Purchasing a home (3)

When buying a home, it is important to know if the property is in a landslide hazard area. Here are some things to do and questions to ask:

- Contact your local government and ask if landslide hazard and/or watershed mapping is available for the area, along with slope stability information.
- Complete a home inspection.
- Consider hiring a registered, professional geotechnical engineer or geoscientist to conduct a site assessment.
- Ask the seller for site surveys and engineering reports.
- Be aware of landslide or flood control structures that may be protecting your property. Some of these may not be maintained any longer. If you have any concerns or questions, check with the B.C. Dike Safety Program at ***www.gov.bc.ca/dike-safety***
- Check with the Land Title Office to see if there is a registered covenant regarding potential landslide hazards on the property title.
- Speak with neighbours to learn more about the area's history.

(1) https://www.oregongeology.org/Landslide/ger_homeowners_guide_landslides.pdf
(2) https://www.oregongeology.org/Landslide/homeowners-landslide-guide.pdf
(3) https://www2.gov.bc.ca/assets/gov/public-safety-and-emergency-services/emergency-preparedness-response-recovery/embc/preparedbc/preparedbc-guides/preparedbc_landslide_info_for_homeowners_and_home_buyers_2018.pdf

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