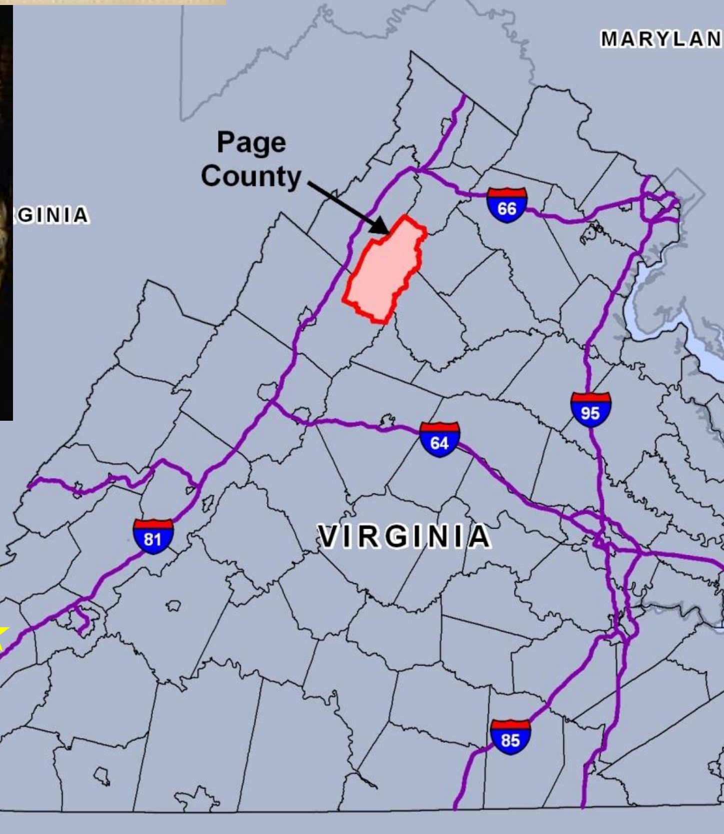
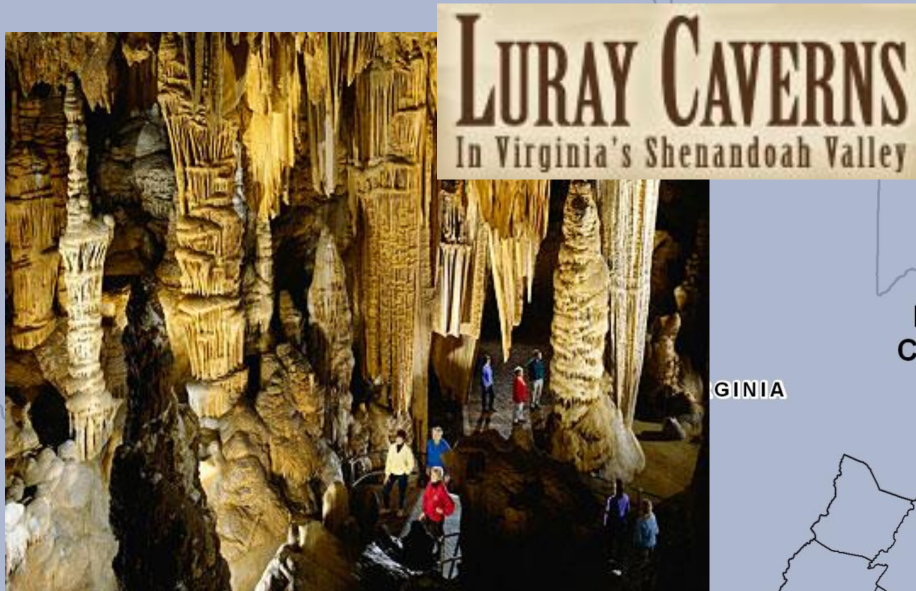
Landslide Hazard Mapping in Page County, Virginia: Processes, Results and Lessons Learned

Anne Carter Witt
Matt Heller

Division of Geology and Mineral Resources, Virginia Department of Mines, Minerals and Energy, 900 Natural Resources Drive, Suite 500, Charlottesville, VA 22903
anne.witt@dmme.virginia.gov



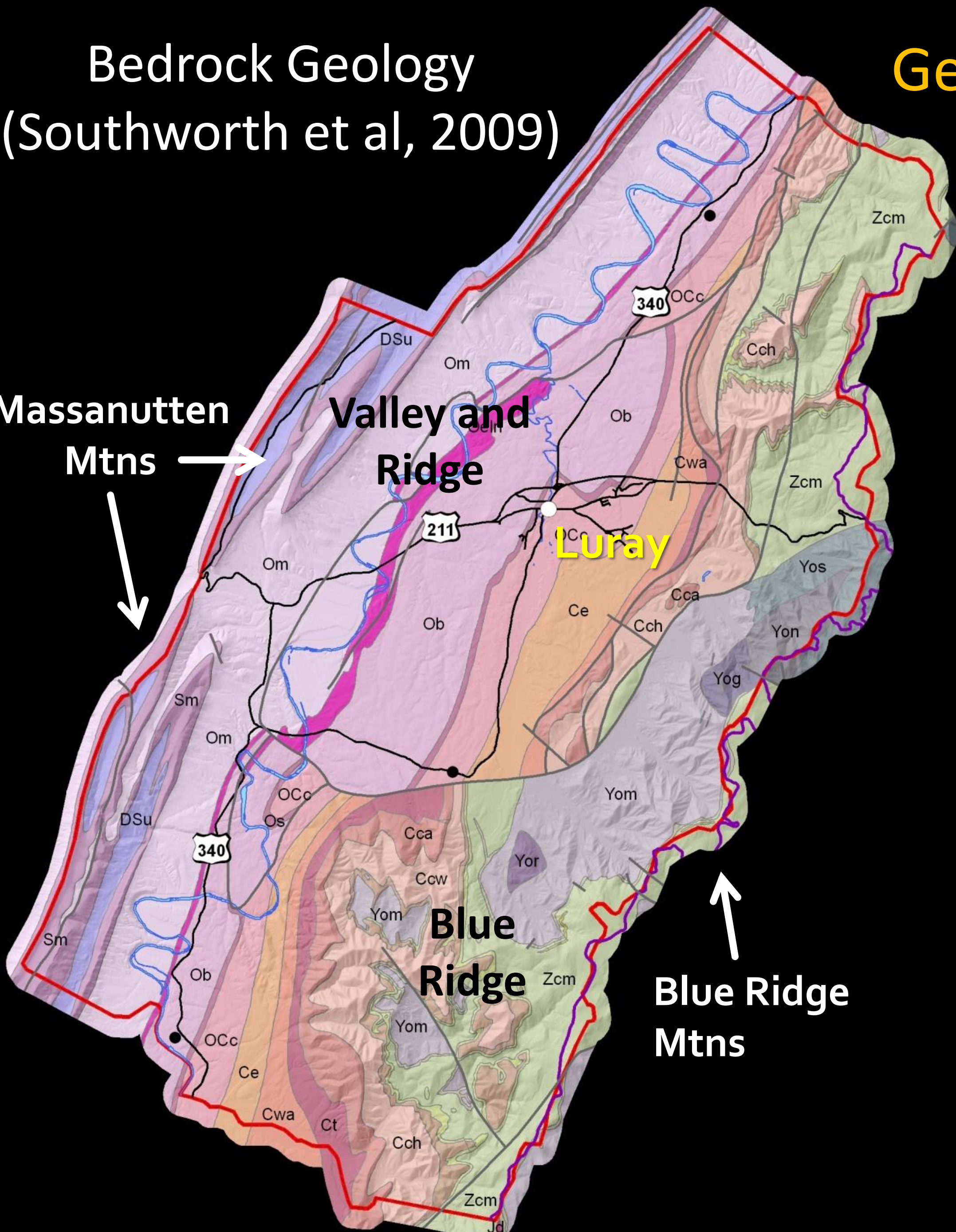


- Project funded by FEMA through a VDEM managed hazard mitigation grant (HMGP-DR-1874-00-002)

- Part of this funding also supported research and field work by JMU faculty and students to estimate volume in colluvial hollows

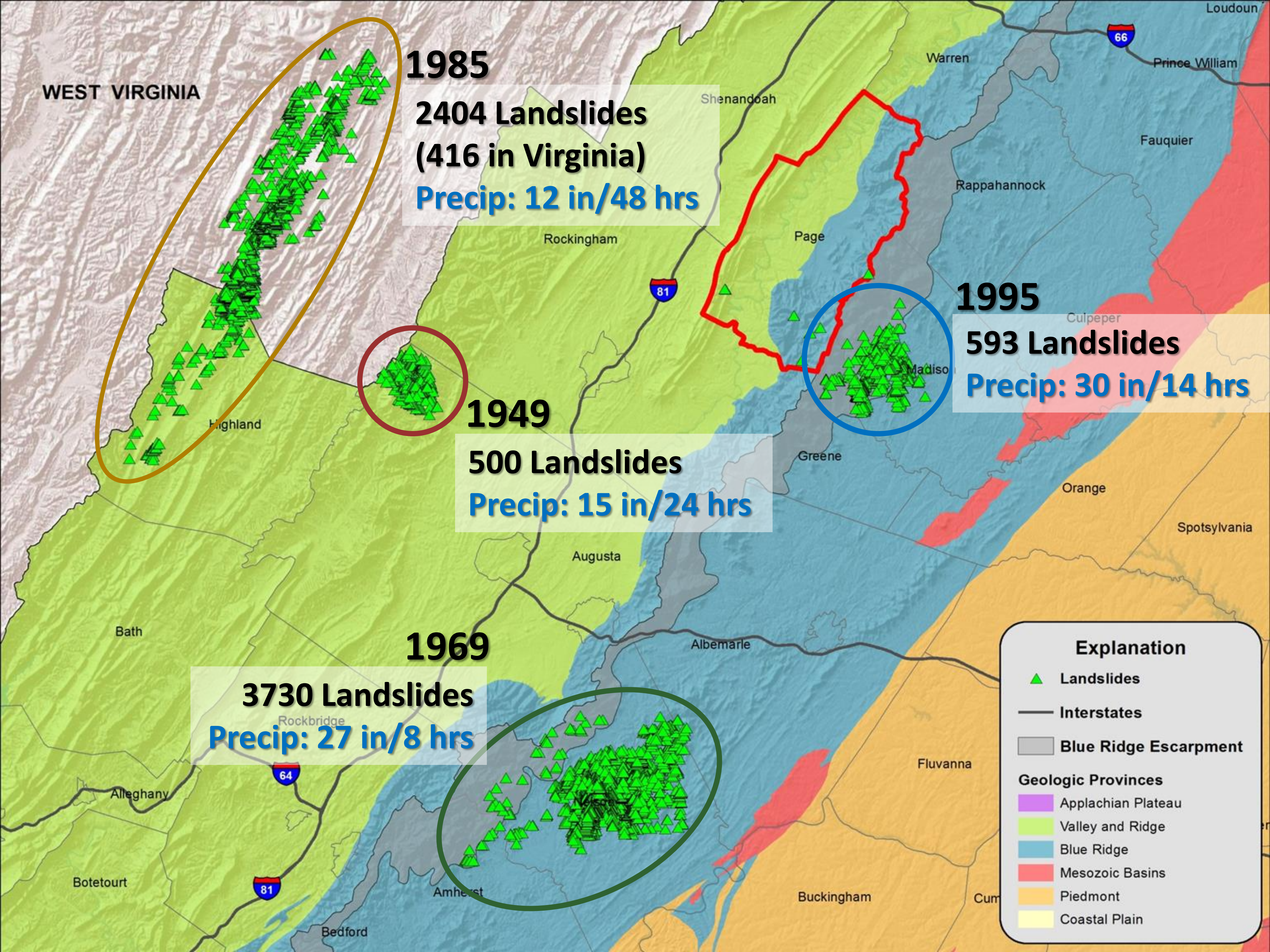
General Page County Stats

Bedrock Geology
(Southworth et al, 2009)



*No known or recorded modern landslides before completion of the project *

- Elevation: Max: 4032 ft
  Min: 560.6 ft
- Slope: Maximum: 85.6°
  Mean: 12.6 °
  SD: 9.4 °
- Size of County: 314 mi^2
- Population: 24,042
- Within the Blue Ridge & Valley and Ridge Geologic Provinces – primarily Precambrian to Devonian aged rock


1985
2404 Landslides
(416 in Virginia)
Precip: 12 in/48 hrs
1949
500 Landslides
Precip: 15 in/24 hrs
1995
593 Landslides
Precip: 30 in/14 hrs
1969
3730 Landslides
Precip: 27 in/8 hrs
WEST VIRGINIA
Loudoun
Warren
Prince William
Shenandoah
Fauquier
Rappahannock
Page
Rockingham
Culpeper
Madison
Highland
Greene
Orange
Spotsylvania
Augusta
Bath
Albemarle
Rockbridge
Alleghany
Fluvanna
Botetourt
Amherst
Buckingham
Bedford
66
81
64
Explanation
Landslides
Interstates
Blue Ridge Escarpment
Geologic Provinces
Applachian Plateau
Valley and Ridge
Blue Ridge
Mesozoic Basins
Piedmont
Coastal Plain

Page County Landslide Hazard Mapping - Deliverables

Maps and Data Delivered to VDEM August 31, 2013

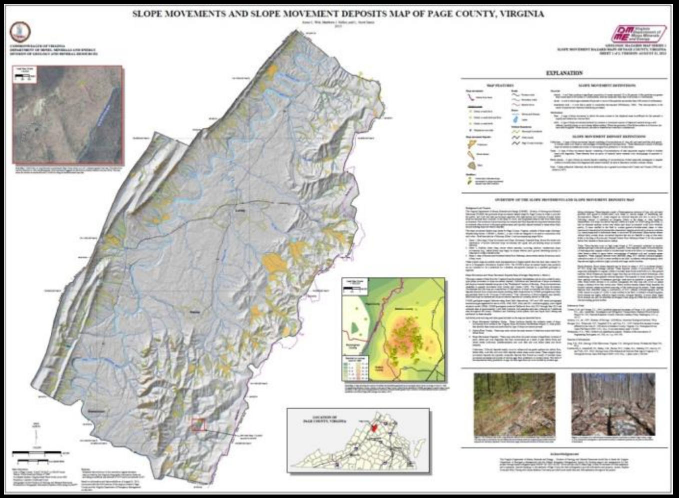
Contents | Preview | Description

Name	Type
Air_Photo_Points	File Geodatabase Feature Class
Deposit_Polygons	File Geodatabase Feature Class
External_Data_Table	File Geodatabase Table
Feature_Deposit_To_External_Data	File Geodatabase Relationship Class
Feature_Deposit_To_FieldNotes	File Geodatabase Relationship Class
Feature_Deposit_To_Picture	File Geodatabase Relationship Class
Feature_Deposit_To_Soil	File Geodatabase Relationship Class
Feature_Ground_Ruptures_To_FieldNotes	File Geodatabase Relationship Class
Feature_Ground_Ruptures_To_Picture	File Geodatabase Relationship Class
Feature_Process_To_External_Data	File Geodatabase Relationship Class
Feature_Process_To_FieldNote	File Geodatabase Relationship Class
Feature_Process_To_Ground_Ruptures	File Geodatabase Relationship Class
Feature_Process_To_Picture	File Geodatabase Relationship Class
Feature_Process_To_Rock	File Geodatabase Relationship Class
Feature_Process_To_SM_Outlines	File Geodatabase Relationship Class
Feature_Process_To_Soil	File Geodatabase Relationship Class
Feature_Process_To_Structure	File Geodatabase Relationship Class
Feature_SM_Outline_To_FieldNotes	File Geodatabase Relationship Class
Feature_SM_Outline_To_Picture	File Geodatabase Relationship Class
Field_Check	File Geodatabase Feature Class
Field_Note_Points	File Geodatabase Feature Class
Ground_Rupture_Lines	File Geodatabase Feature Class
Picture_Table	File Geodatabase Table
Point_FieldNote_To_External_Data	File Geodatabase Relationship Class
Point_FieldNote_To_Picture	File Geodatabase Relationship Class
Point_FieldNote_To_Rock	File Geodatabase Relationship Class
Point_FieldNote_To_Soil	File Geodatabase Relationship Class
Point_FieldNote_To_Structure	File Geodatabase Relationship Class
Point_Process_To_External_Data	File Geodatabase Relationship Class
Point_Process_To_Picture	File Geodatabase Relationship Class
Point_Process_To_Rock	File Geodatabase Relationship Class
Point_Process_To_Soil	File Geodatabase Relationship Class
Point_Process_To_Structure	File Geodatabase Relationship Class
Process_Points	File Geodatabase Feature Class
Process_Points_Project_SP	File Geodatabase Feature Class
Rock_Table	File Geodatabase Table
Slope_Movement_Outlines	File Geodatabase Feature Class
Soil_Table	File Geodatabase Table
Structure_Table	File Geodatabase Table
Traverses	File Geodatabase Feature Class

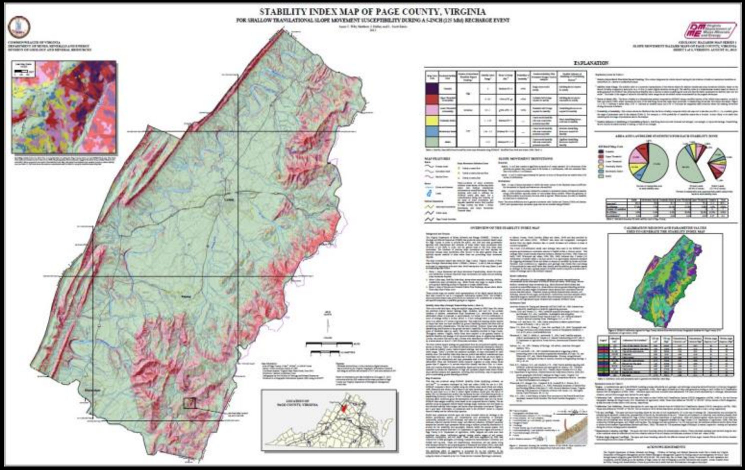
ArcGIS File Geodatabase of VA Slope Movement Inventory

(Current entries: 5252)

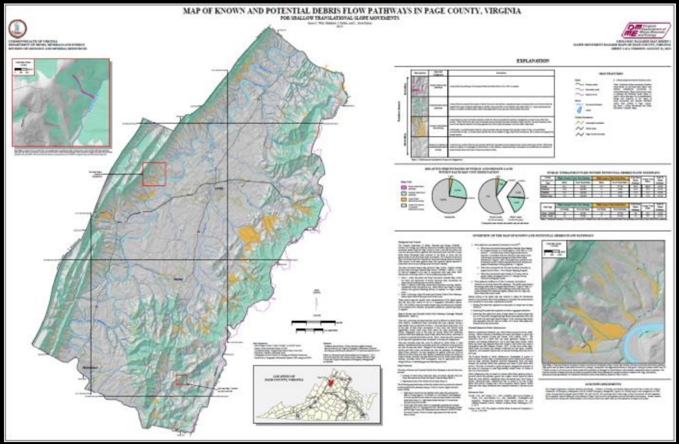
MAP 1: Slope Movements and Slope Movements Deposits



MAP 2: Stability Index (Where landslides may start)



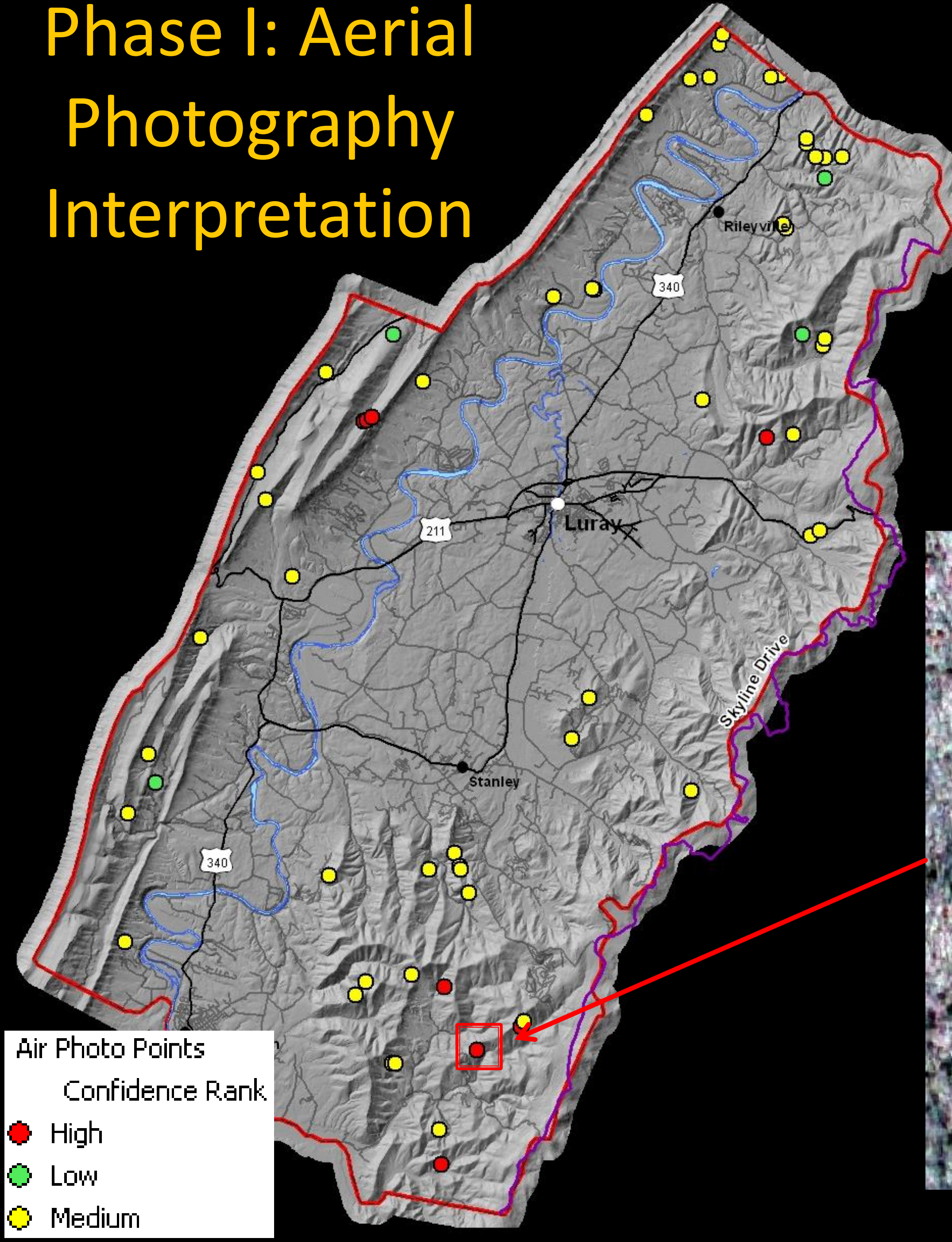
MAP 3: Debris Flow Pathways (Where landslides may go)



Map Production

- Phase I: Field Work Preparation
  - Aerial Photography Interpretation
  - DTM LS Deposit Interpretation
- Phase II: Field Reconnaissance
  - Adjust Interpreted Data
- Phase III: Slope Stability Modeling
  - SINMAP – Where landslides may start
- Phase IV: Hydrologic (Runout) Routing
  - Debris Flow Pathways – Where landslides may go
  - Identification of infrastructure in hazard zones
- Phase V: Finalized GIS Map Deliverables

Phase I: Aerial Photography Interpretation



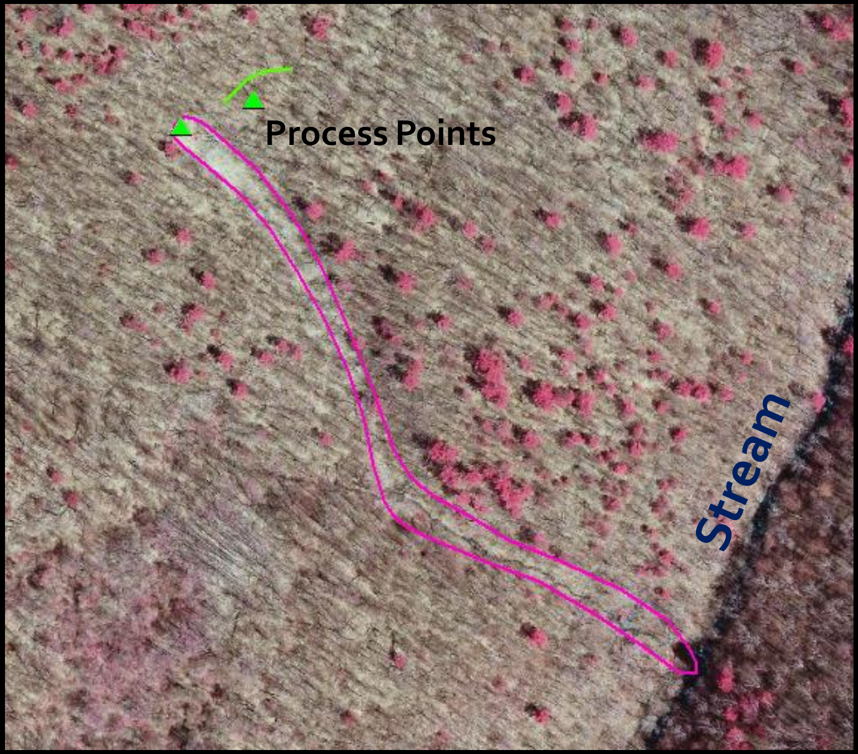
- 60 Potential landslides identified for further field investigation
- 42 visited; 4 were landslides
- Interpretation done at 1:6,000
- Air Photo Vintages: 1958, 1963-1964, 1972, 1998, 2002, 2006, 2011

1998 Infrared DOQQ

Sometimes aerial photography interpretation worked great!

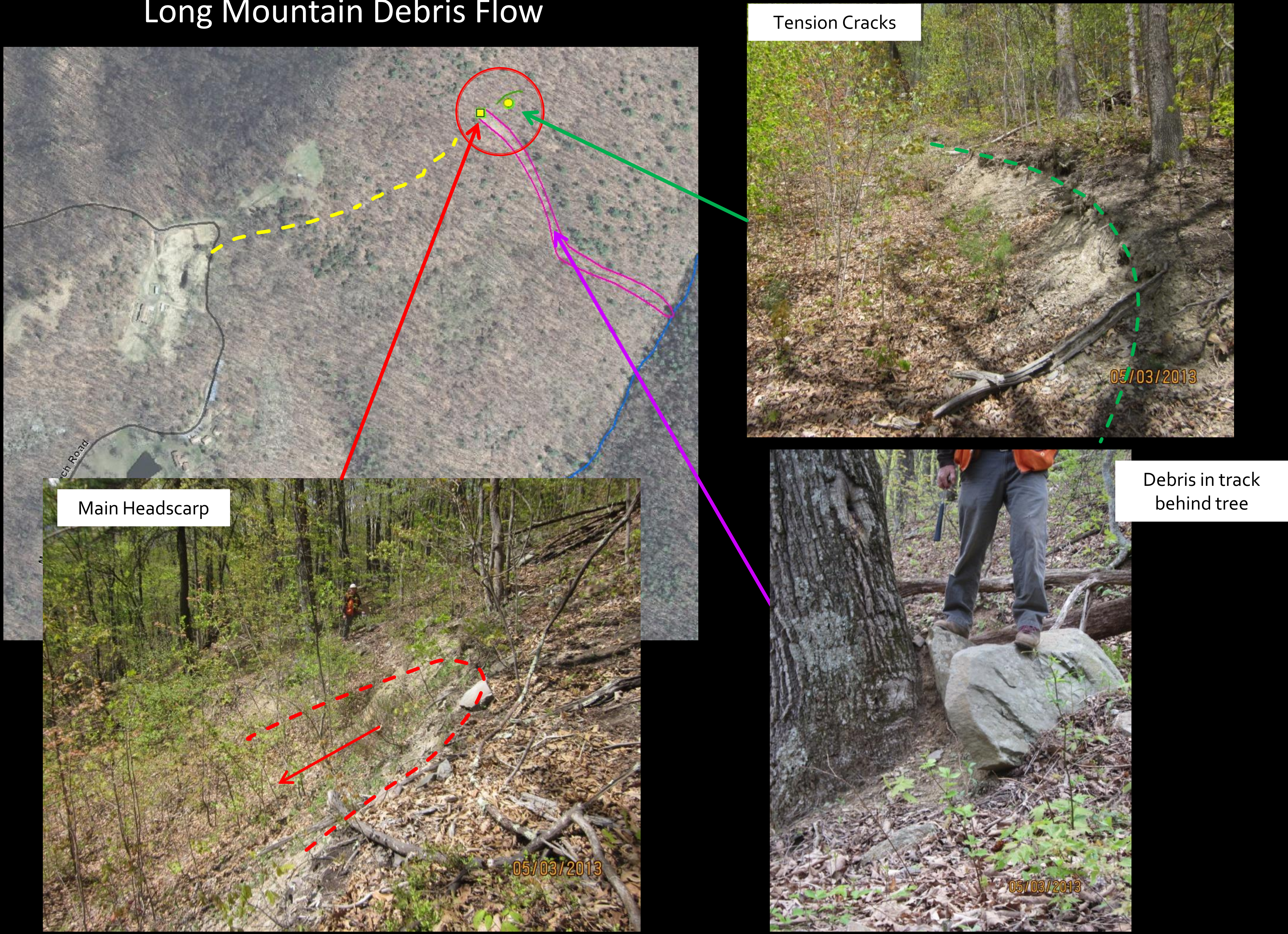
Long Mountain Debris Flow

1998 Infrared DOQQ



2011 Infrared DOQQ

Long Mountain Debris Flow



Geologic units where aerial photography was unsuccessful

Massanutten:

- Martinsburg Shale (Om) - 40%
- Devonian/Silurian shale, mudstone, siltstone (DSu) - 16%

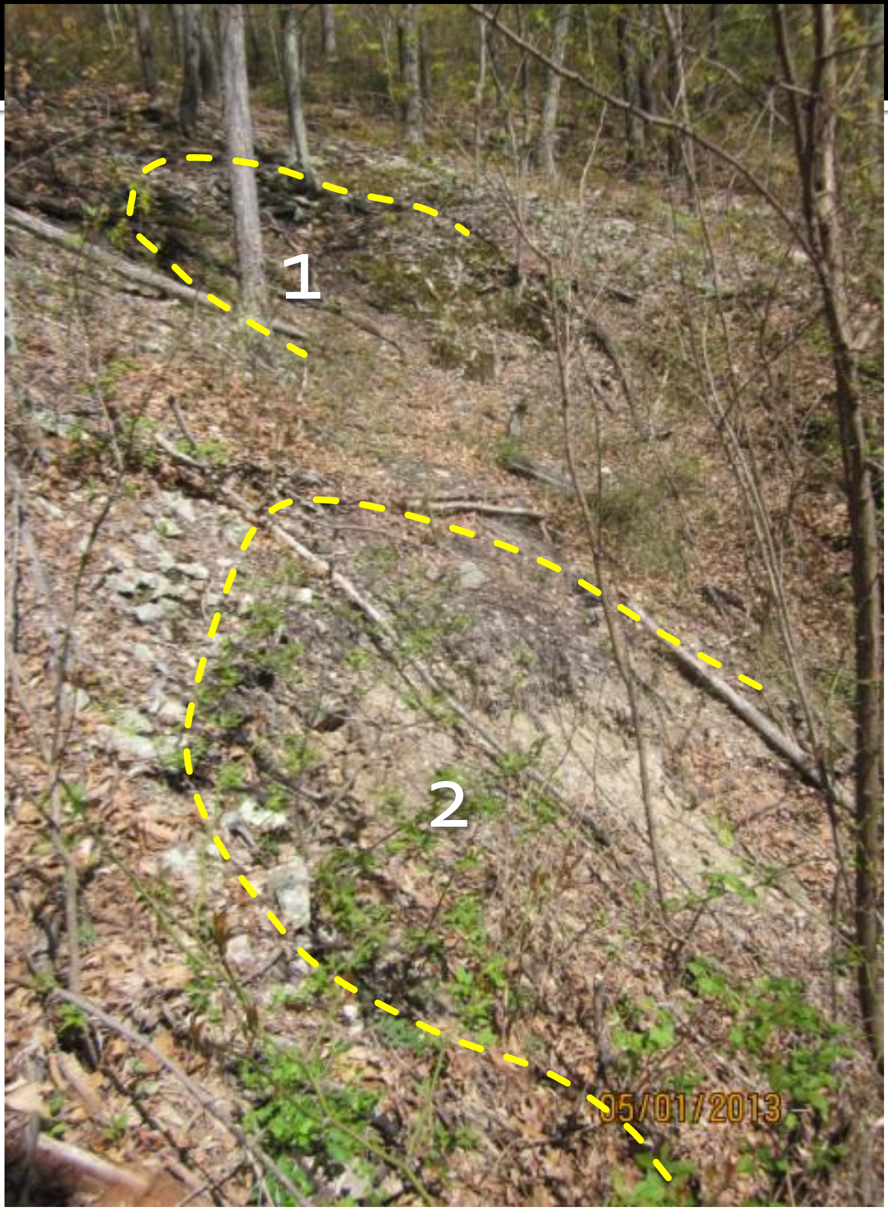
Blue Ridge :

- Harpers Fm (Cch) – 18%

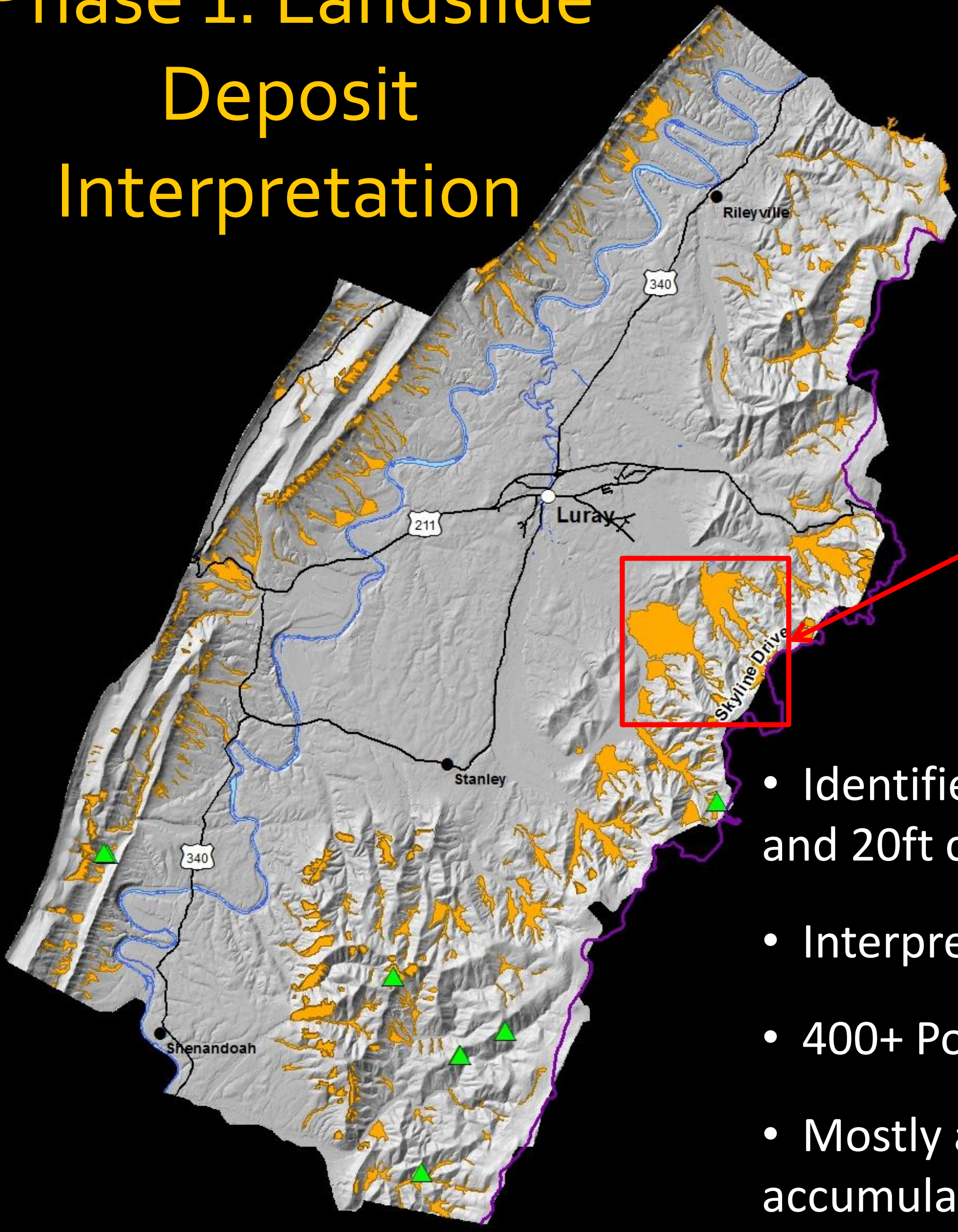
Looking downhill from interpreted "headscarp" in the Martinsburg Fm (Om)

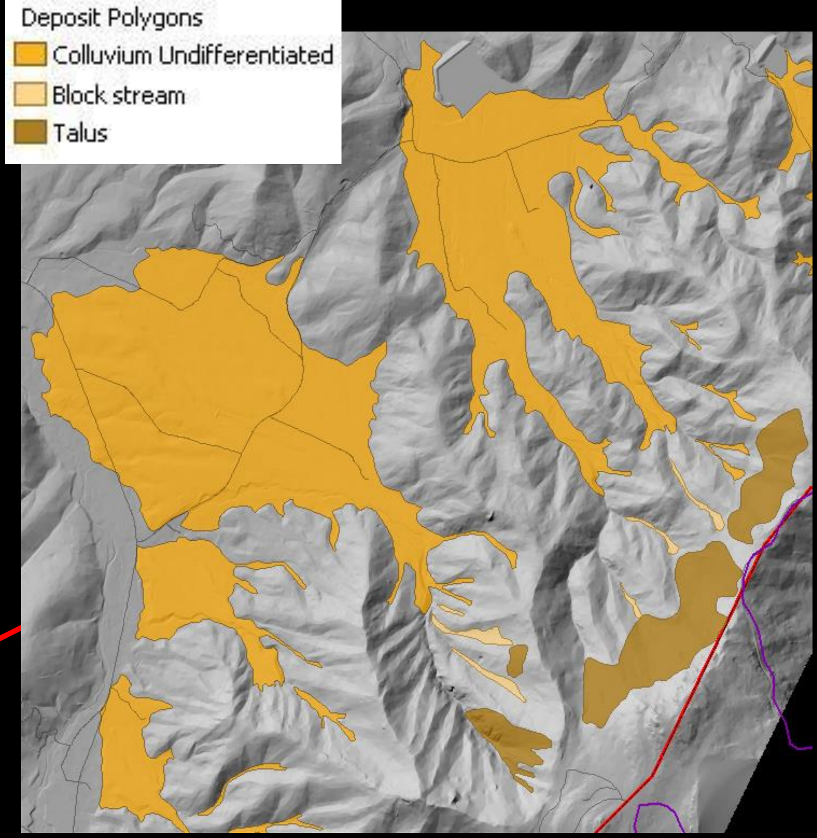
9 Modern Landslides in Page County

- Type: Weathered Rx Slides; Debris Flows; Debris Slides
- Slope: Min – 15°
  Max – 80°
  *Mean - 32°
- All on "natural" slopes
- 7 of 9 occurred in Blue Ridge
- 6 initiated at the base of geologic contacts



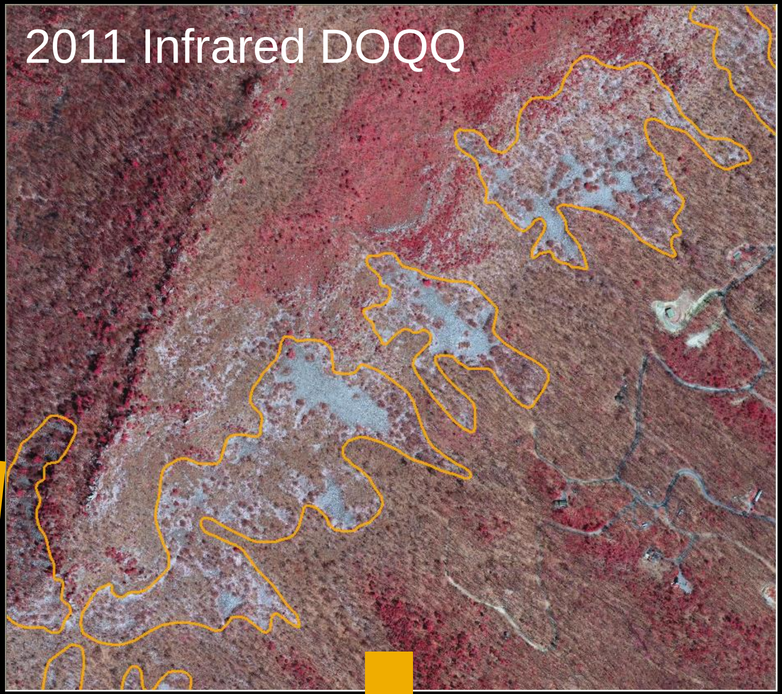
Phase 1: Landslide Deposit Interpretation

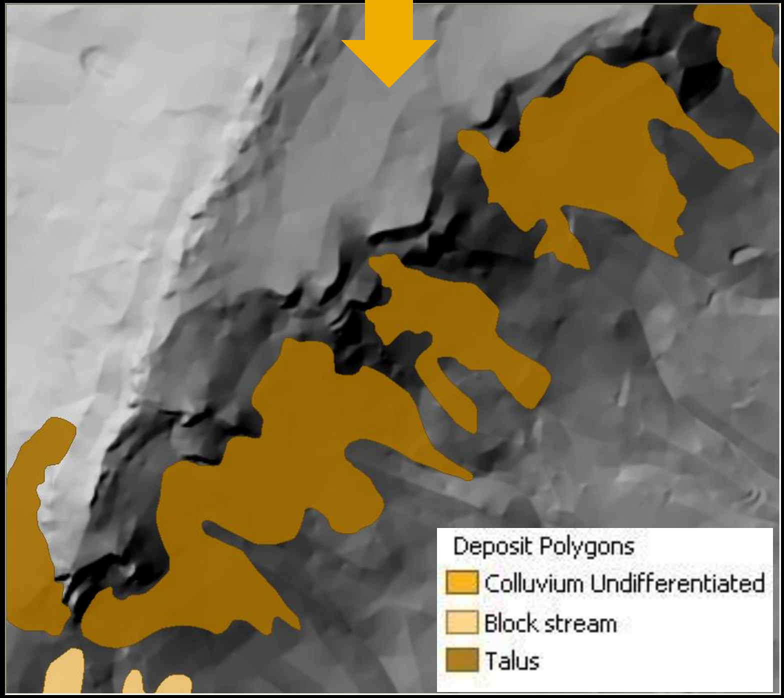




- Identified using DTM data (10 ft resolution) and 20ft contours
- Interpretation done at 1:6,000
- 400+ Polygons in Database – 6% of county
- Mostly ancient debris fan deposits – accumulations of coarse boulder-to-sand sized colluvial particles

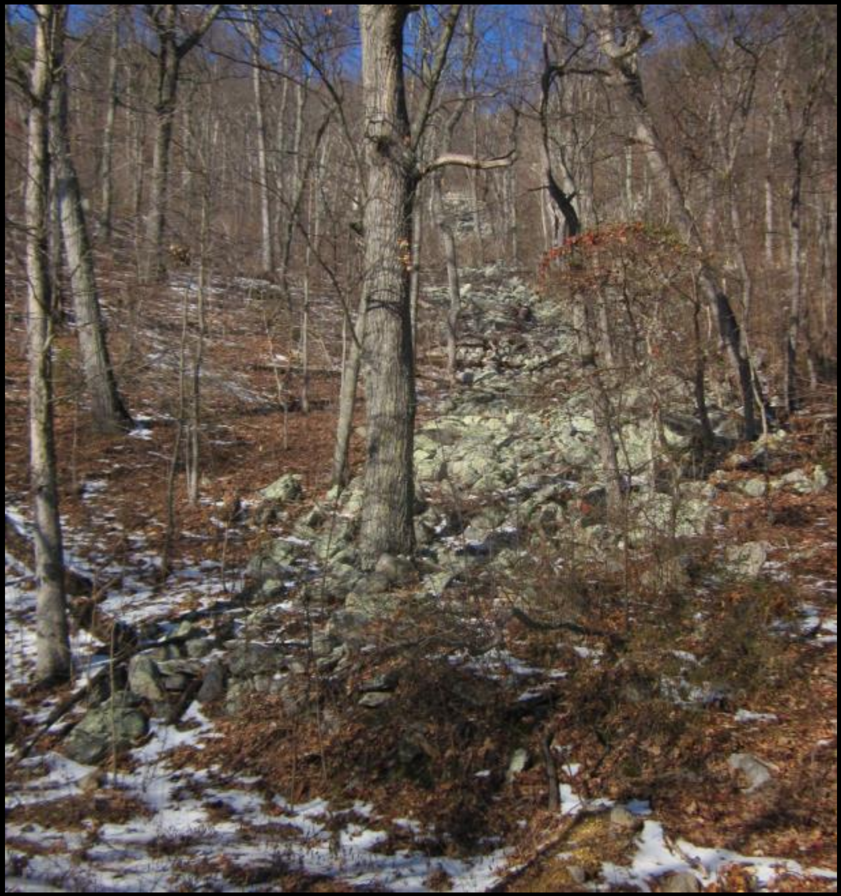
3 Types of Deposits
Talus

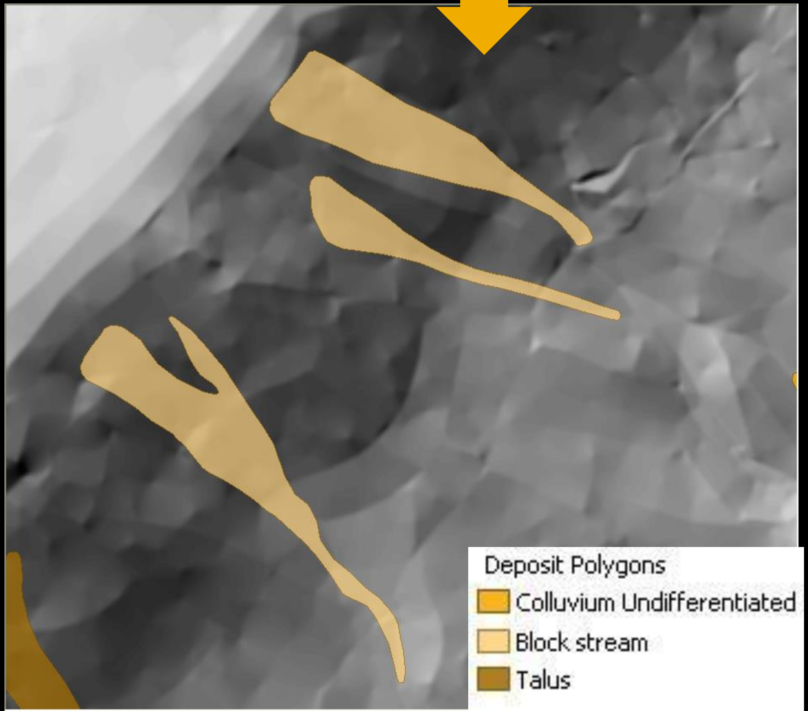




- Identified using only aerial photography
- Must be able to see patches of bare rock at 1:6,000
- Primarily a maintenance/construction hazard

3 Types of Deposits - Block Streams



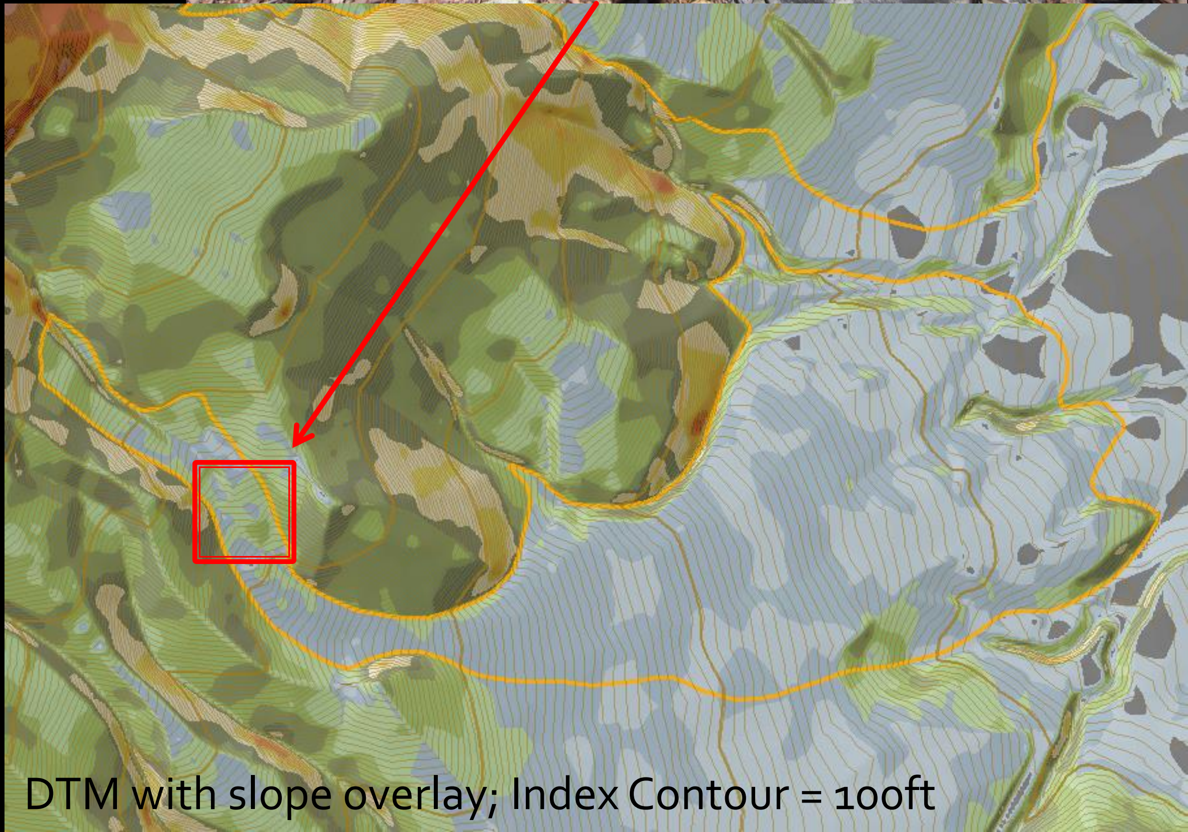


- Identified using a combination of aerial photography and DTM
- Some are highly dissected by modern stream channels
- Moderate hazard if remobilized

3 Types of Deposits - Block Streams

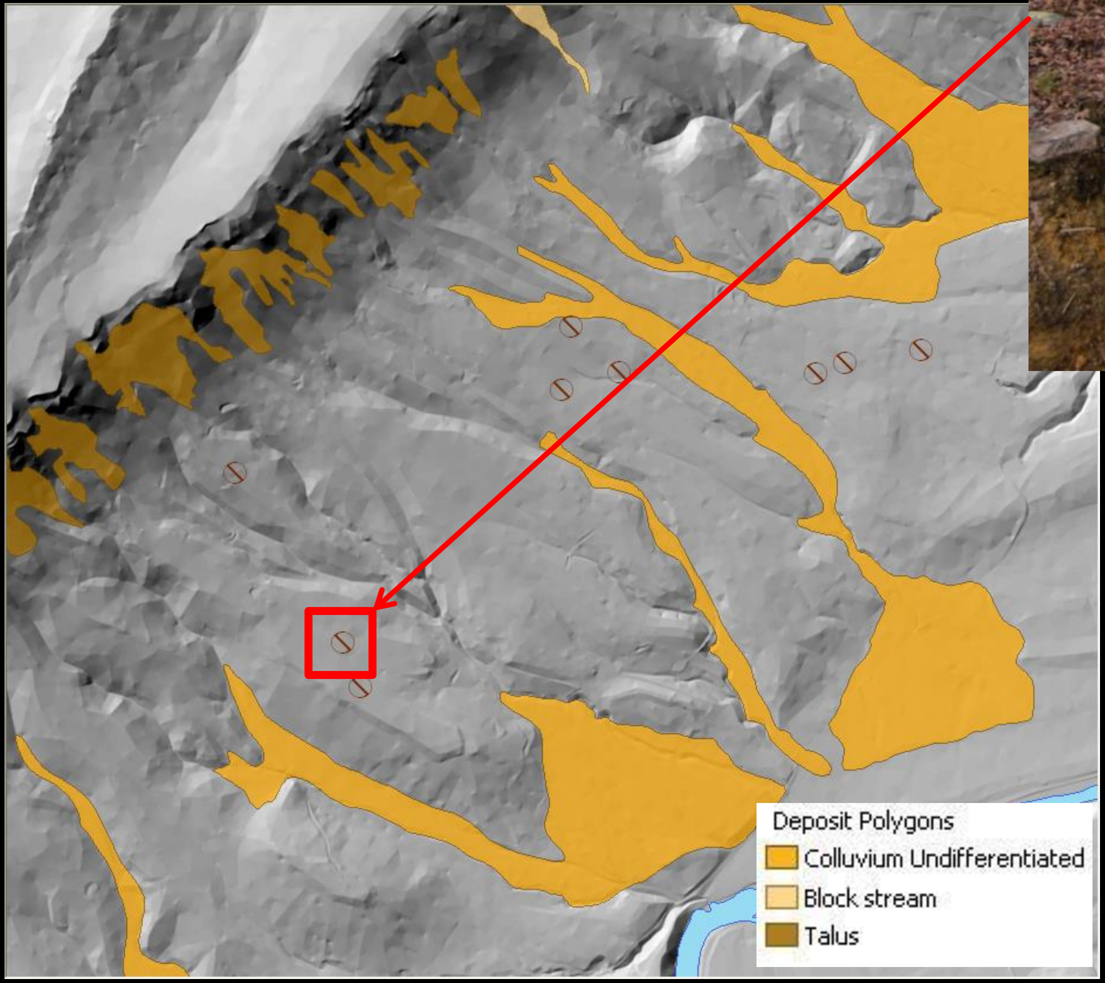
3 Types of Deposits
Colluvium Undifferentiated

- Identified ONLY using DTM and contours
- Accumulations of subangular -to- subrounded boulder-to-cobble size fragments in a finer-grained matrix
- Upper reaches may include boulder streams/talus
- Considered moderate hazard



DTM with slope overlay; Index Contour = 100ft

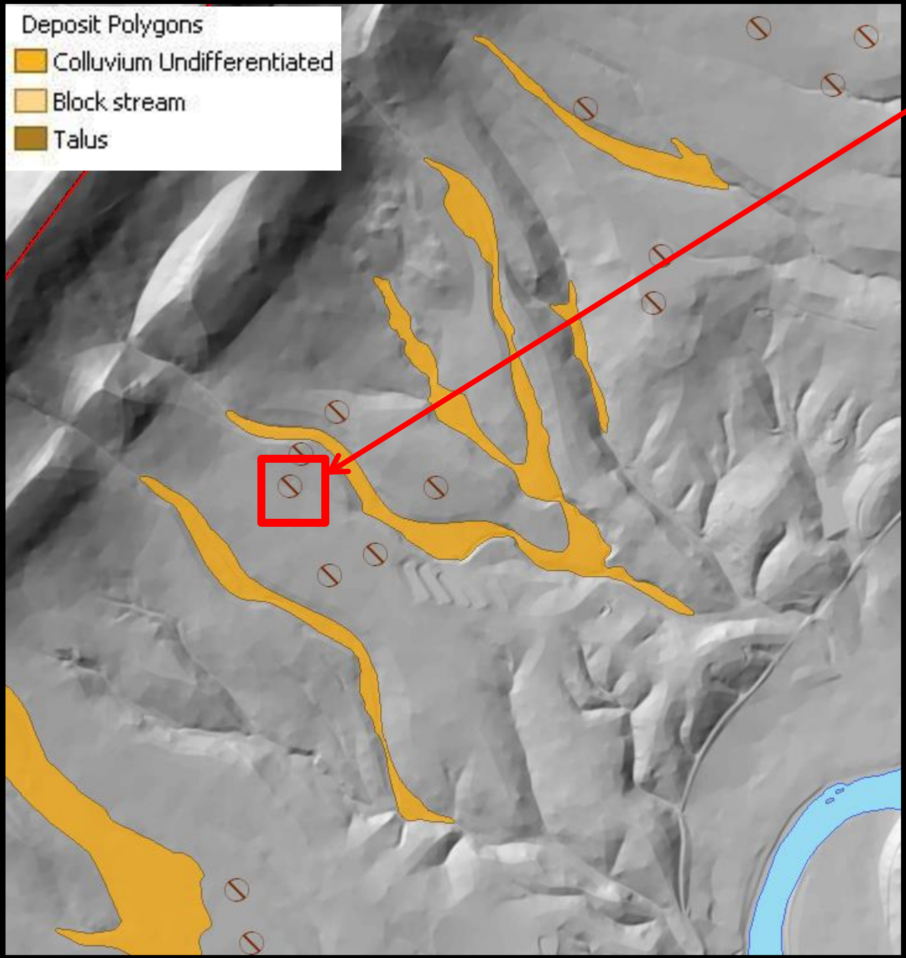
Ancient Deposits (Qd_3 and Qd_4) Not Mapped



- Thin veneer of rounded quartzite cobbles (~1ft)
- Red/brown soils with "ghost clasts"
- Higher clay % than younger deposits

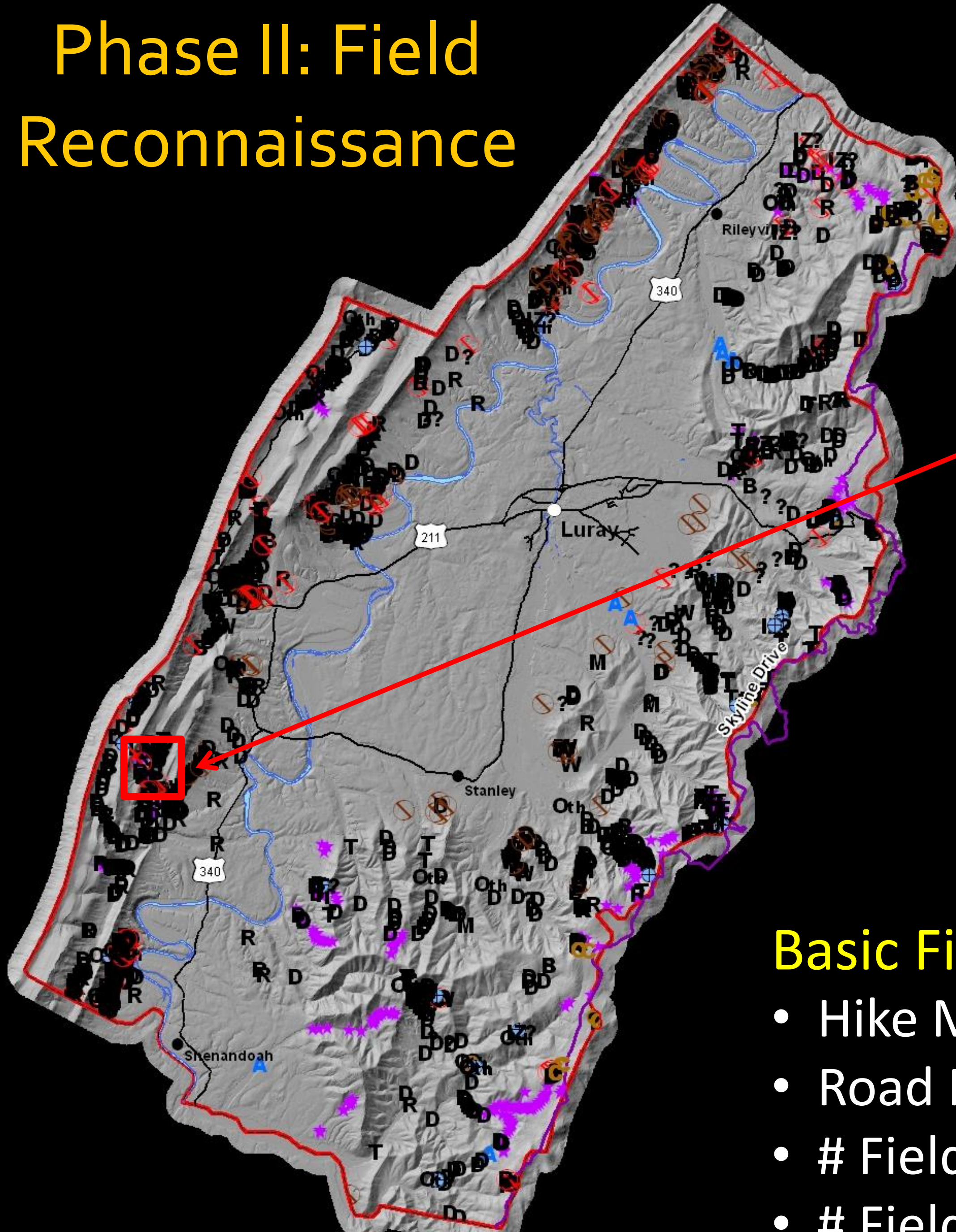
Ancient Deposits (Qd3 and Qd4)

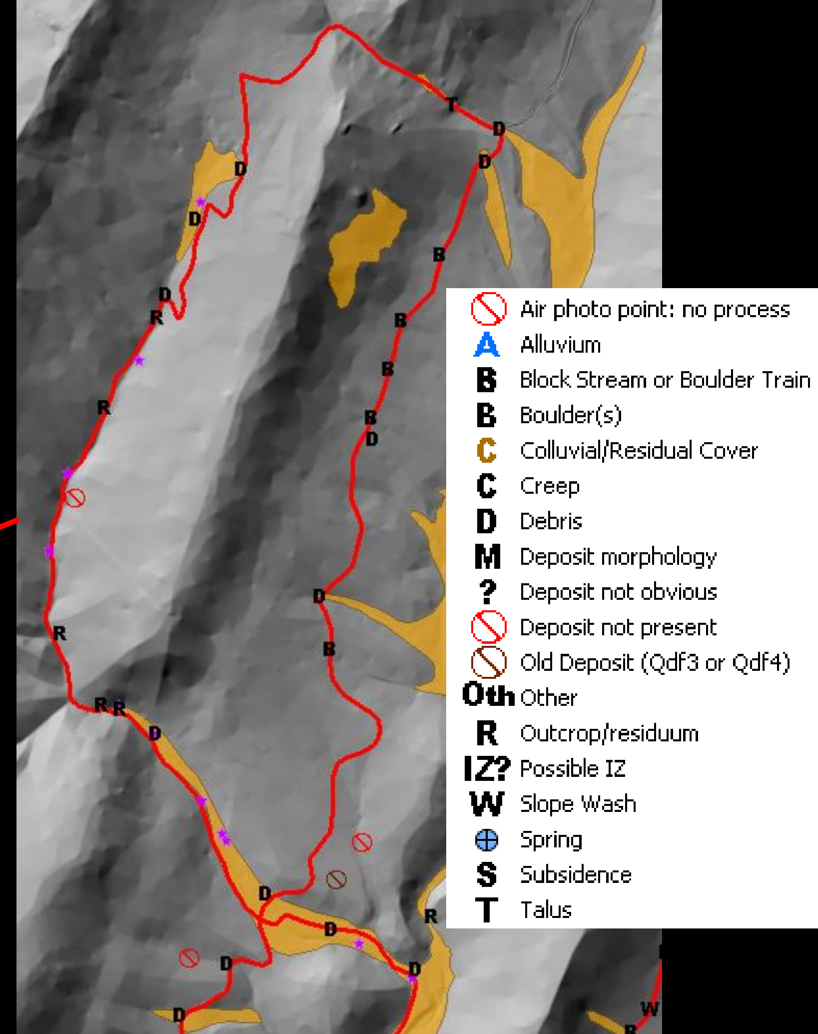
Not Mapped



- Rounded-Subrounded quartzite cobbles to boulders (where visible)
- Flatter topography
- Sometimes perched on higher hilltops

Phase II: Field Reconnaissance

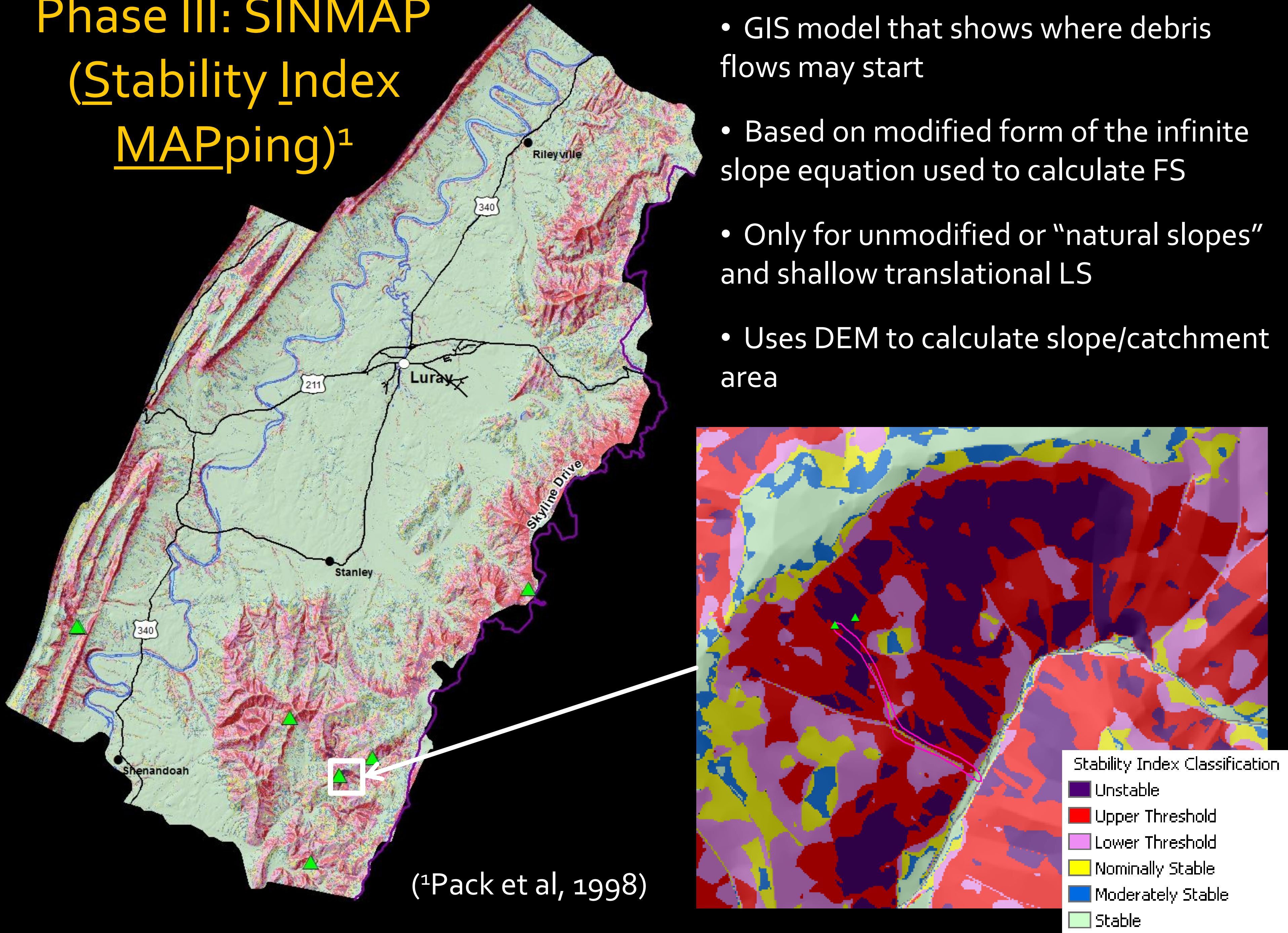




Basic Field Work Stats

- Hike Miles Traversed: 154 mi
- Road Miles Traversed: 110 mi
- # Field Notes collected DGMR: 1411
- # Field Notes collected JMU: 292

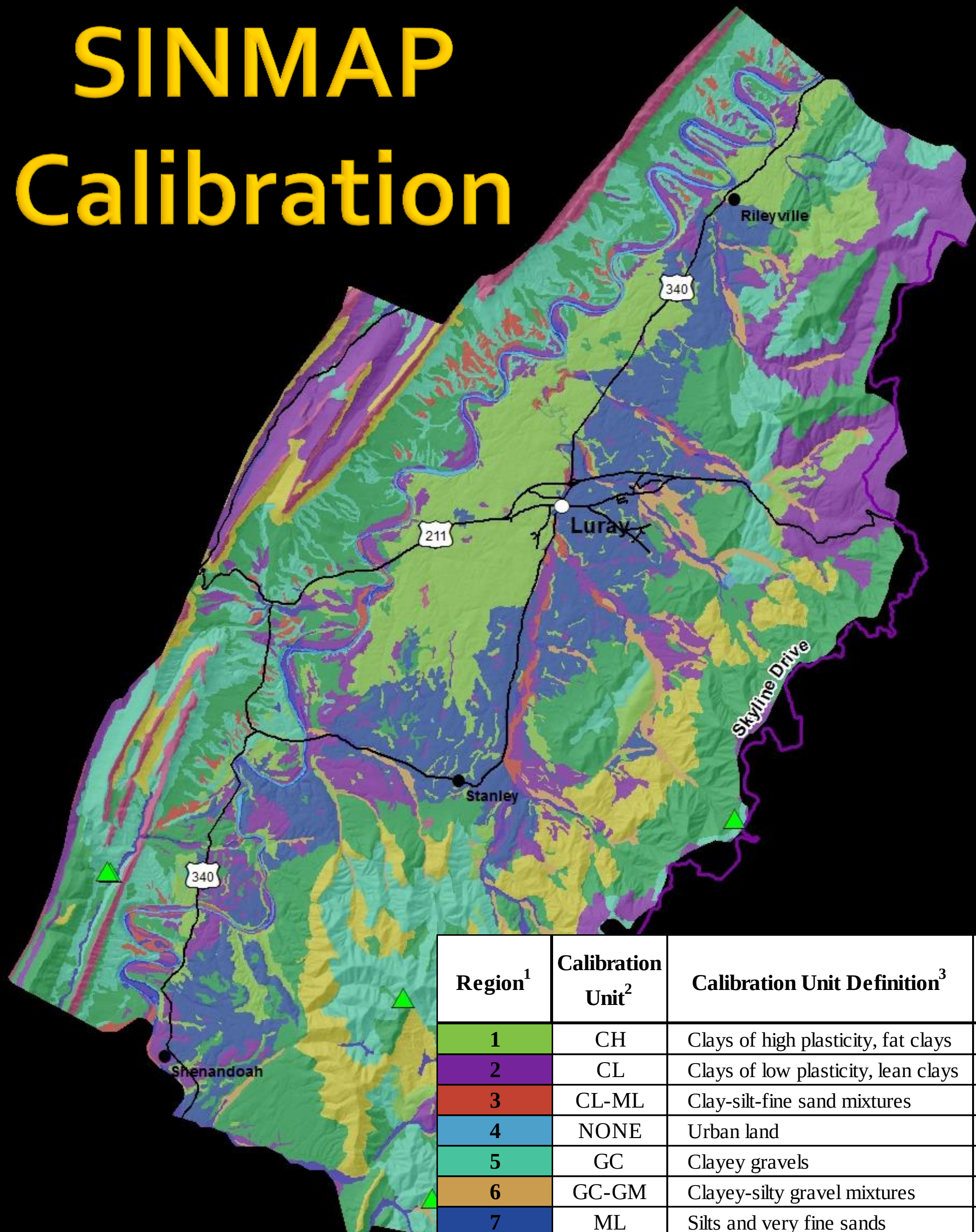
Phase III: SINMAP (Stability Index MAPping)[1]



- GIS model that shows where debris flows may start
- Based on modified form of the infinite slope equation used to calculate FS
- Only for unmodified or "natural slopes" and shallow translational LS
- Uses DEM to calculate slope/catchment area

([1]Pack et al, 1998)

SINMAP Calibration



Upper and Lower Bounding Parameter Values:

- Soil Friction Angle (ϕ)
- Soil Cohesion (C_s)
- Root Cohesion (C_r)
- Transmissivity (T)
- Recharge (R): ≥ 5 inches/24 hrs

Parameters Derived From:

- Soil Testing (9 field sites)
- USDA-NRCS Soil Mapping
- County Water Well Logs (adjust depth)
- Level I Stability Analysis (LISA) Manual; Hammond et al, 1992

Region[1]	Calibration Unit[2]	Calibration Unit Definition[3]	T/R (m) Low[4]	T/R (m) High[4]	Dimensionless Cohesion Low[5]	Dimensionless Cohesion High[5]	Friction Angle (degrees) Low[6]	Friction Angle (degrees) High[6]
1	CH	Clays of high plasticity, fat clays	0.49	439.47	0.17	0.07	23	33
2	CL	Clays of low plasticity, lean clays	1.06	176.97	0.11	0.15	24	34
3	CL-ML	Clay-silt-fine sand mixtures	0.85	584.00	0.23	0.05	26	36
4	NONE	Urban land	0.00	53.07	0.00	0.18	25	42
5	GC	Clayey gravels	9.14	132.73	0.05	0.15	31	43
6	GC-GM	Clayey-silty gravel mixtures	14.75	742.64	0.07	0.09	33	43
7	ML	Silts and very fine sands	1.44	353.94	0.17	0.06	26	36
8	ROCK	Rock outcrop	0.00	148.53	0.00	0.11	33	45
9	SC	Clayey sands	2.60	475.29	0.11	0.16	29	41
10	SC-SM	Sand-silt-clay mixtures	3.02	594.11	0.23	0.11	29	39
11	SM	Silty sands	17.70	594.11	0.06	0.11	29	39

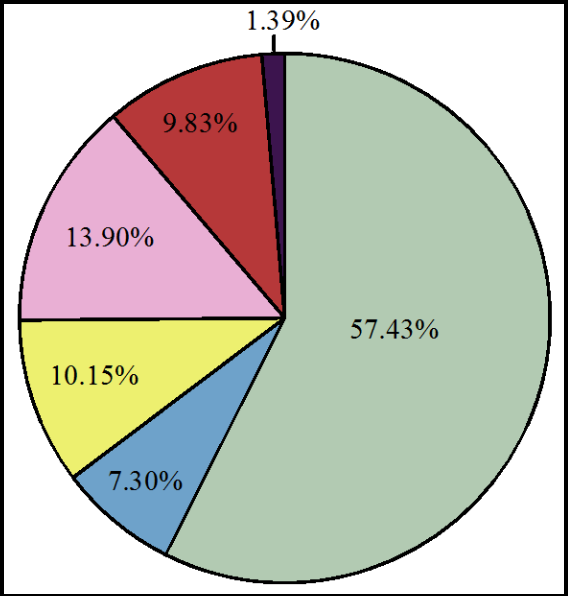
SINMAP Results

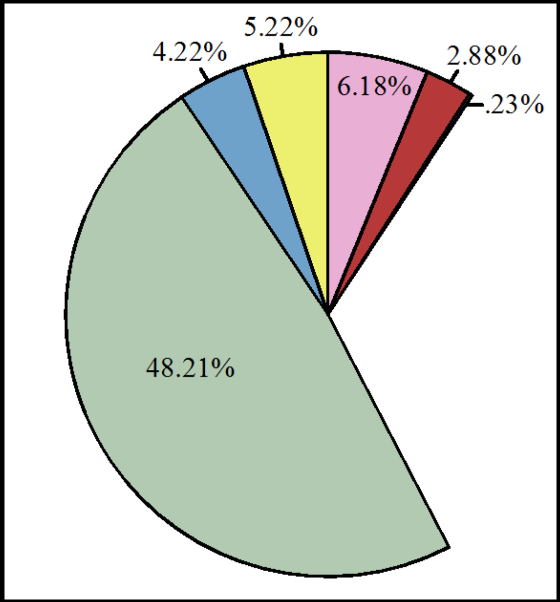
High: 11.2%
- Unstable
- Upper Threshold

Moderate: 13.9%
- Lower Threshold

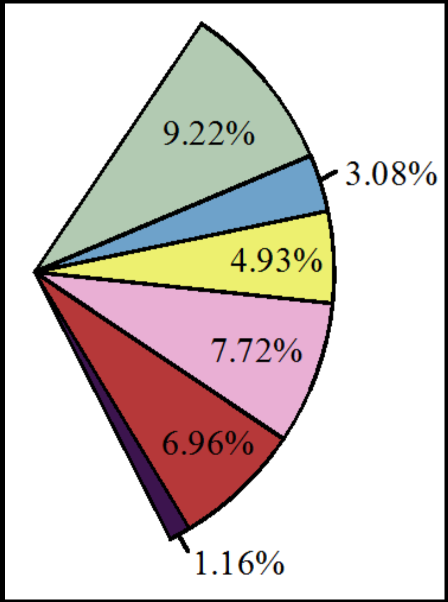
Low: 78.8%
- Nominally Stable
- Moderately Stable
- Stable

Countywide





Private Lands
(70% of County)



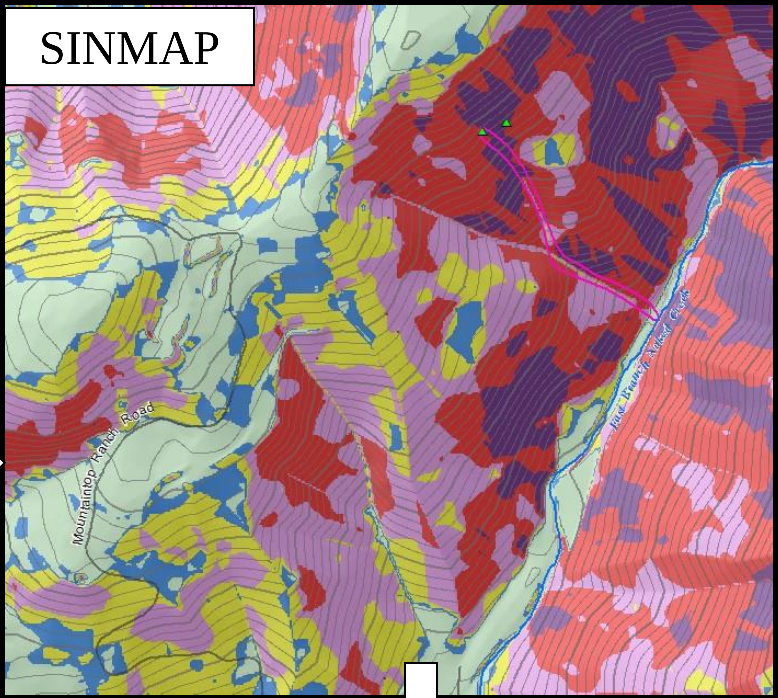
Public Lands
(30% of County)

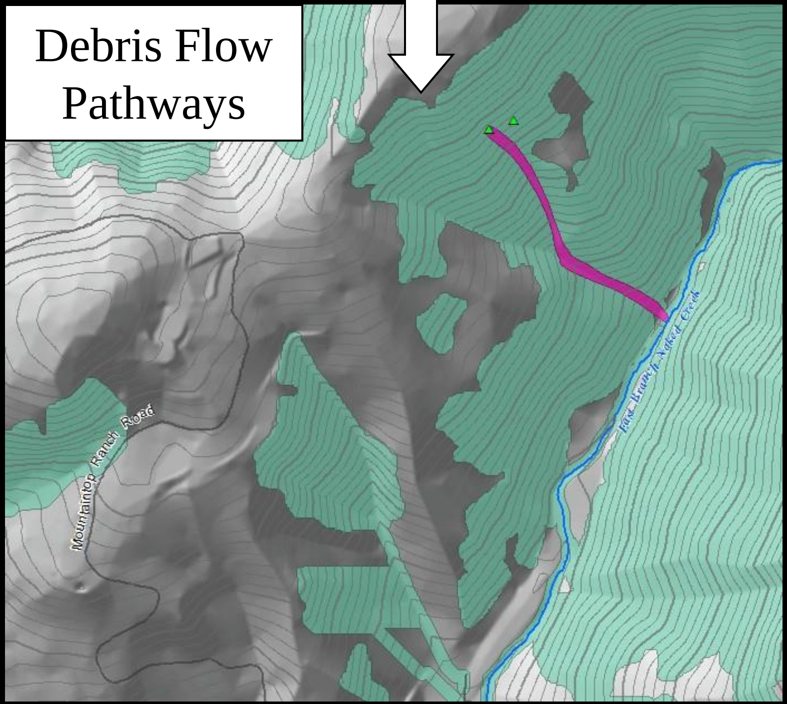
Phase IV: Debris Flow Pathways

Where debris flows might go

Methodology

- Hydrologic Flow paths generated from high hazard SINMAP zones using the DEM.
- Flow paths buffered to 65 ft (20 m) wide.
- Flow paths terminated:
  - At slopes of 3 degrees in areas > 0.25 acres.
  - When they encounter the 500-year floodplain
  - When they encounter mapped impoundments >0.25 acres.
  - At bases of cut slopes.





Mapped debris flow pathways

Potential debris flow pathways (from SINMAP)

Past debris flow activity (deposits)

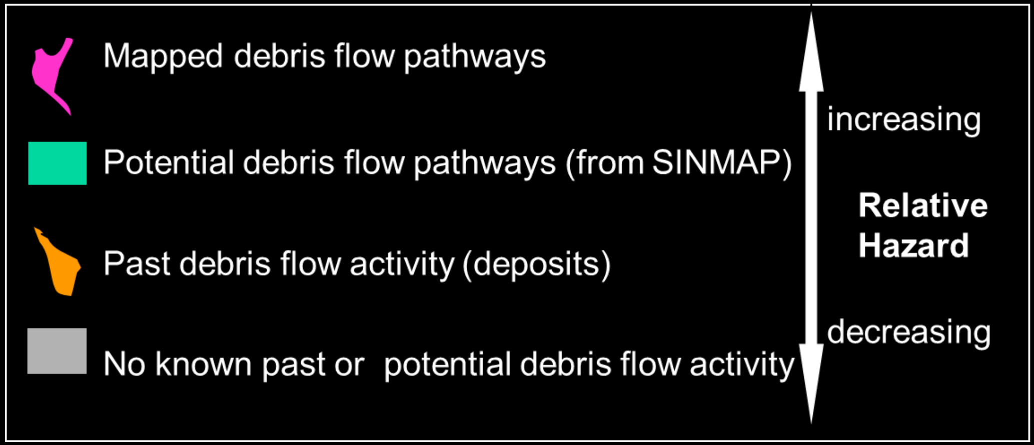
No known past or potential debris flow activity

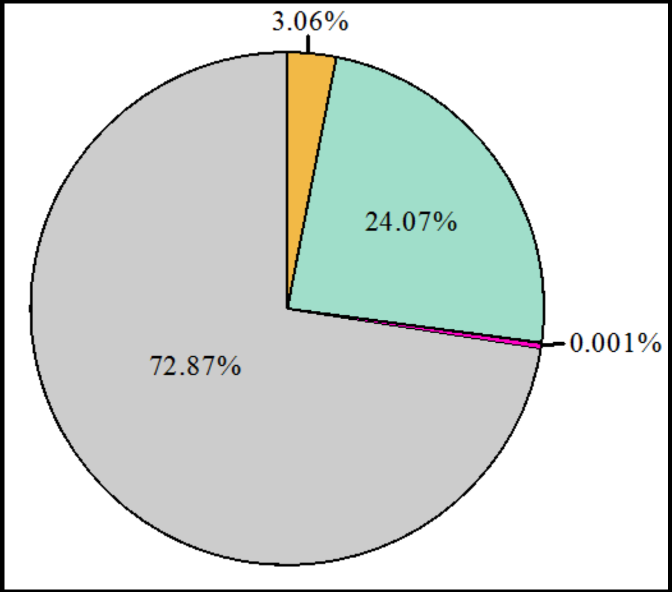
increasing

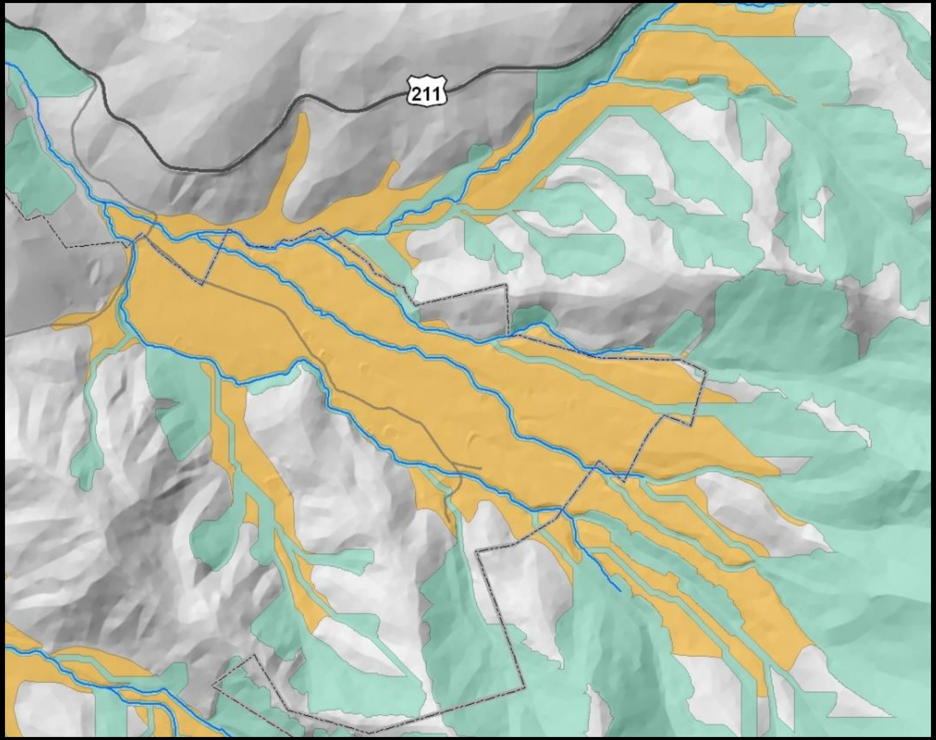
Relative Hazard

decreasing

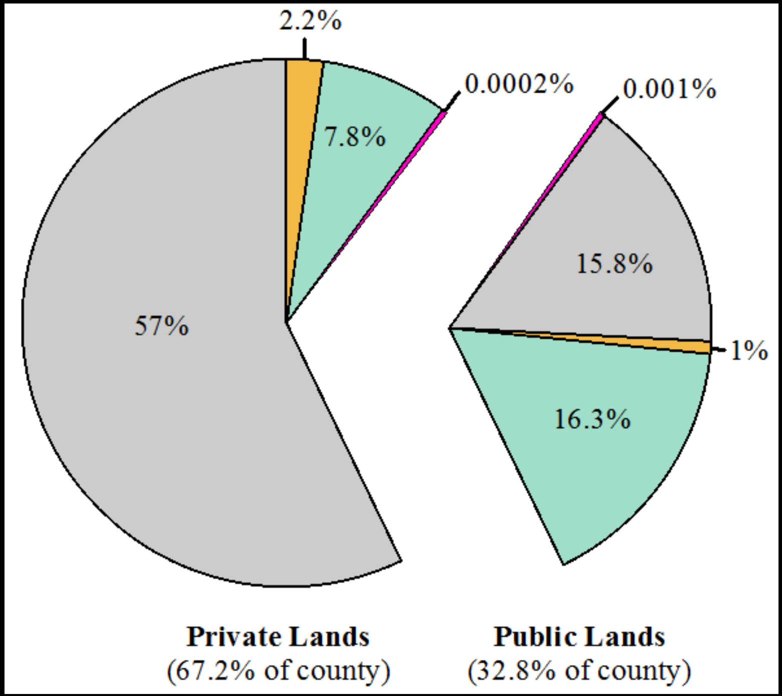
DFP Results



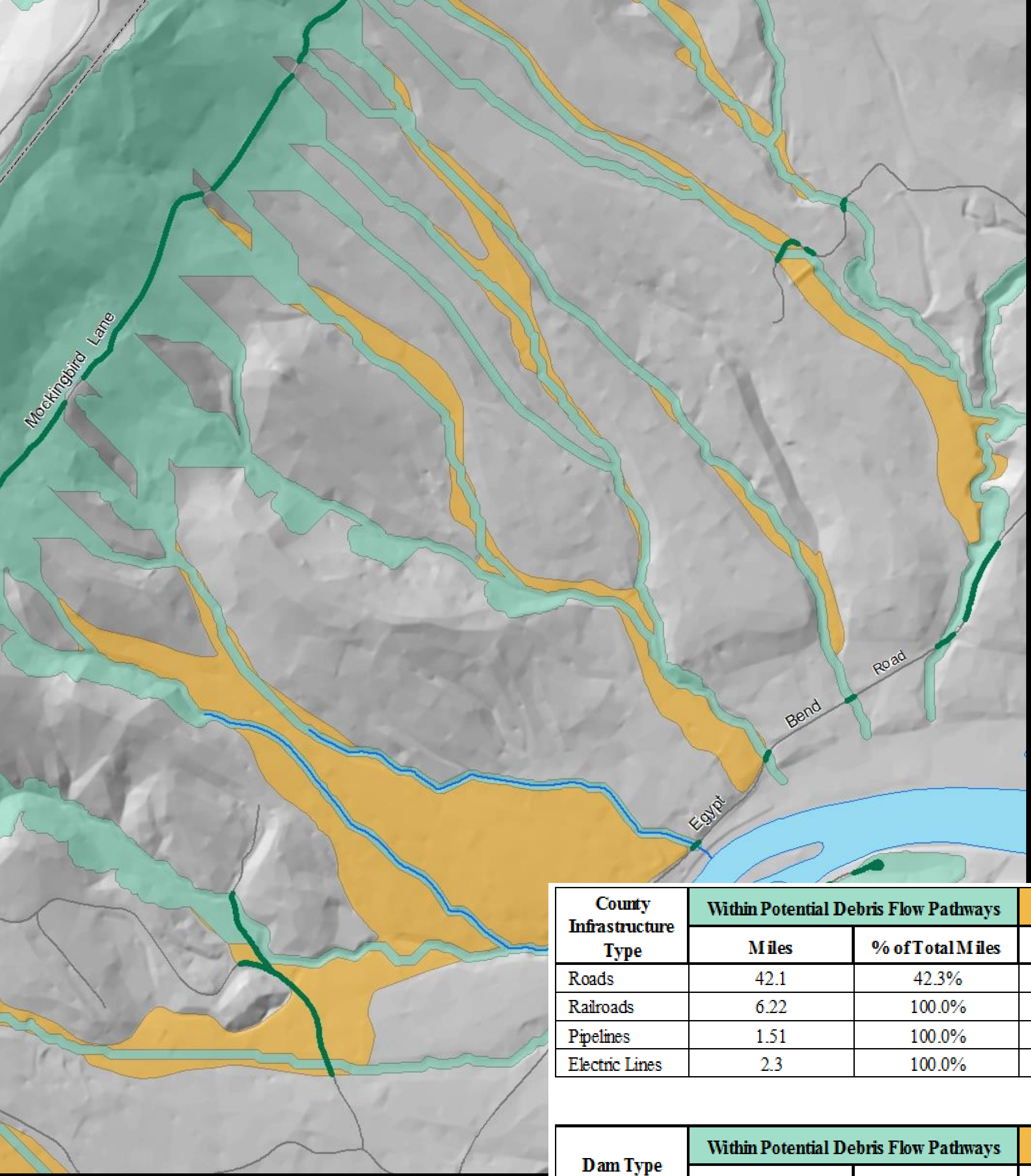




Jewel Hollow – E. Page County



Public Infrastructure vs. DFP



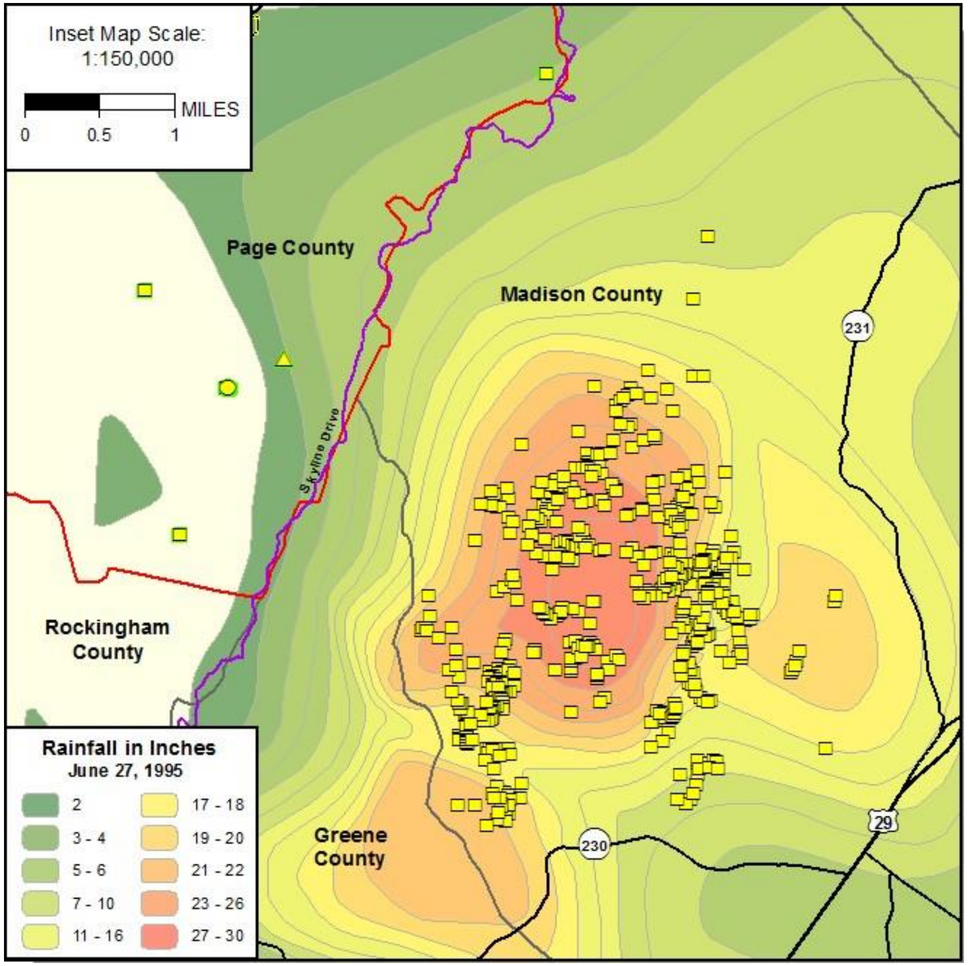
- Dark green lines indicate potentially impacted roads
- Designed to guide EM personnel during flood event

County Infrastructure Type	Within Potential Debris Flow Pathways		Within Areas of Past Debris Flows		Total Miles Within Pathways	County Total Miles	Total % Within Pathways
	Miles	% of Total Miles	Miles	% of Total Miles			
Roads	42.1	42.3%	57.5	57.7%	99.6	686.8	14.5%
Railroads	6.22	100.0%	0	0.0%	6.22	47.6	13.1%
Pipelines	1.51	100.0%	0	0.0%	1.51	11.2	13.5%
Electric Lines	2.3	100.0%	0	0.0%	2.3	17.6	13.1%

Dam Type	Within Potential Debris Flow Pathways		Within Areas of Past Debris Flows		Total Dams Within Pathways	County Total Dams	Total % Within Pathways
	# of Dams	% of All Dams	# of Dams	% of All Dams			
Dams - Outlines	18	64.3%	10	35.7%	28	225	12.4%
Dams - Points	10	52.6%	9	47.4%	19	157	12.1%

Lessons Learned

- Aerial photography not as helpful without a known storm event
  - But it is still absolutely necessary
- Don't underestimate the underlying geology
- Be flexible, adaptable
- More detail needed to accurately portray hazards to infrastructure (buy in from community)
  - Use HAZUS in the future?



Thanks!

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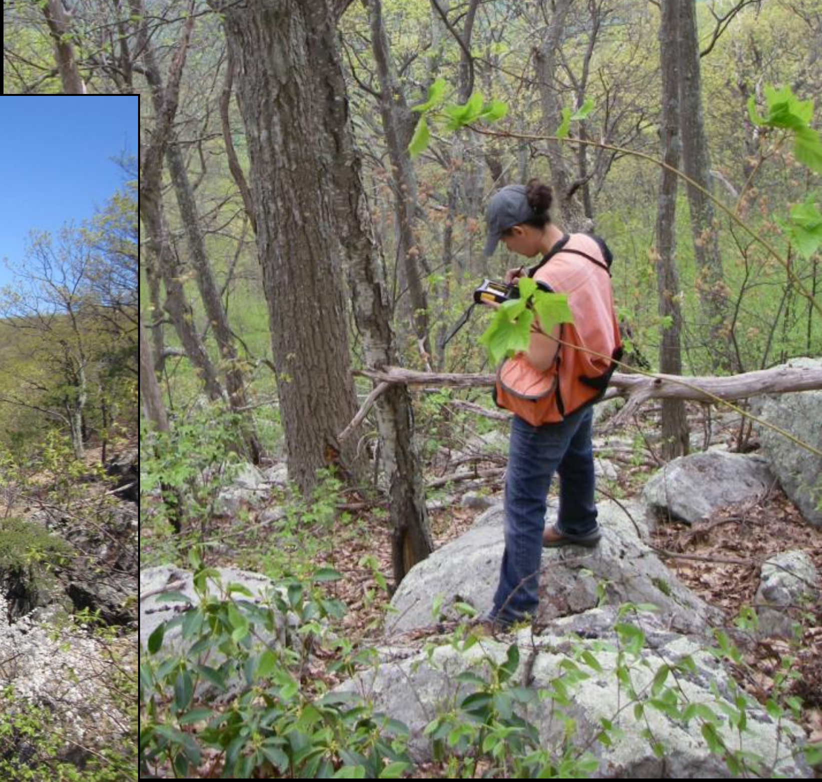
From JMU:
Dr. Scott Eaton
Billy Cheung
Steve Stone



Anne Carter Witt
VA Division of Geology and Mineral Resources
anne.witt@dmme.virginia.gov

Map Color Code	Predicted Stability Zone	Relative Debris/Earth Flow/Slide Hazard Ranking [1]	Stability Index Range [2]	Factor of Safety (FS) [3]	Probability of Instability [4]	Predicted Stability With Parameter Ranges Used in Analysis	Possible Influence of Stabilizing or Destabilizing Factors [5]
	Unstable	High	0	Maximum FS <1	100%	Range cannot model stability	Stabilizing factors required for stability
	Upper Threshold of Instability		0 - 0.5	>50% of FS ≤1	>50%	Optimistic half of range required for stability	Stabilizing factors may be responsible for stability
	Lower Threshold of Instability	Moderate	0.5 - 1	≥50% of FS >1	<50%	Pessimistic half of range required for instability	Destabilizing factors are not required for instability
	Nominally Stable	Low	1 - 1.25	Minimum FS = 1	___	Cannot model instability with most conservative parameters specified	Minor destabilizing factors could lead to instability
	Moderately Stable		1.25 - 1.5	Minimum FS = 1.25	___	Cannot model instability with most conservative parameters specified	Moderate destabilizing factors are required for instability
	Stable		>1.5	Minimum FS = 1.5	___	Cannot model instability with most conservative parameters specified	Significant destabilizing factors are required for instability

FS = factor of safety;
a = topographic catchment area
C = dimensionless cohesion = (**Cr** + **Cs**)/(**h**p_s**g**)
Cr = root cohesion; **Cs** = soil cohesion;
h = soil thickness; p_s = soil density; **g** = gravity constant
h_w = height of water;
R = recharge
r = water density (p_w) to soil density (p_s) ratio
T = soil transmissivity = soil hydraulic conductivity x **h**
Ø = soil internal angle of friction
θ = slope
h_w/h = Relative wetness $= \min\left(\dfrac{R\,a}{T\sin\theta}, 1\right)$