

# Using High Resolution Digital Elevation Models (DEMs) and Street Level Imagery for Rock Cut Slope Inventory and Rockfall Hazard Rating

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# Using High Resolution Digital Elevation Models (DEMs) and Street Level Imagery for Rock Cut Slope Inventory and Rockfall Hazard Rating

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Virginia Transportation Research Council  
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VTRC 25-Rx



# PURPOSE

- Develop a desktop methodology using digital elevation model (DEMs) and street-level imagery
  - ❑ Rock cut slope inventory
    - Regional scale location, geometry, preliminary geology
  - ❑ USMP-based rockfall hazard/risk rating system on selected sites
- Evaluate the accuracy of the approach compared to field data collection
- Quantify the time saved using the proposed methodology

# BACKGROUND

- Geotechnical Asset Management (GAM)
  - Rock/soil cut slopes, retaining walls, and material sources
  - Geotechnical assets typically handled using a reactive approach
  - Provide guidance to manage geotechnical assets
    - Building an inventory of unstable slopes
    - Assess their condition
    - Establishing performance standards and service life criteria,
    - Identifying and developing risk reduction corrective actions, and
    - Prioritizing and taking risk reduction corrective actions.

# BACKGROUND

- Geotechnical Asset Management (GAM)
  - Need for proactive approaches
    - Oregon's Rockfall Hazard Rating System (RHRS)
    - Assessing hazard/risk of rockfall

CATEGORY			RATING CRITERIA AND SCORE			
			POINTS 3	POINTS 9	POINTS 27	POINTS 81
SLOPE HEIGHT			25 FT	50 FT	75 FT	100 FT
DITCH EFFECTIVENESS			Good catchment	Moderate catchment	Limited catchment	No catchment
AVERAGE VEHICLE RISK			25% of the time	50% of the time	75% of the time	100% of the time
PERCENT OF DECISION SIGHT DISTANCE			Adequate site distance, 100% of low design value	Moderate sight distance, 80% of low design value	Limited site distance, 60% of low design value	Very limited sight distance, 40% of low design value
ROADWAY WIDTH INCLUDING PAVED SHOULDERS			44 feet	36 feet	28 feet	20 feet
GEOLOGIC CHARACTER	CASE 1	STRUCTURAL CONDITION	Discontinuous joints, favorable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation
		ROCK FRICTION	Rough, irregular	Undulating	Planar	Clay infilling or slickensided
	CASE 2	STRUCTURAL CONDITION	Few differential erosion features	Occasional erosion features	Many erosion features	Major erosion features
		DIFFERENCE IN EROSION RATES	Small difference	Moderate difference	Large difference	Extreme difference
	BLOCK SIZE		1 FT	2 FT	3 FT	4 FT
	QUANTITY OF ROCKFALL/EVENT		3 cubic yards	6 cubic yards	9 cubic yards	12 cubic yards
CLIMATE AND PRESENCE OF WATER ON SLOPE		Low to moderate precipitation; no freezing periods, no water on slope	Moderate precipitation or short freezing periods or intermittent water on slope	High precipitation or long freezing periods or continual water on slope	High precipitation and long freezing periods or continual water on slope and long freezing periods	
ROCKFALL HISTORY		Few falls	Occasional falls	Many falls	Constant falls	

Oregon State Highway Division (Pierson et al. 1990)

# BACKGROUND

- Need for proactive approaches
  - FHWA's unstable slope management program (USMP)
  - Assessing hazard/risk of rockfall

SLOPE RATING FORM – SITE INFORMATION					
Management Area:					Date:
<b>Hazard Type (select all that apply within one of the categories):</b> Rockfall Planar   Wedge   Toppling   Raveling/Undermining   Rock Avalanche   Indeterminate Rock Failures   Differential Erosion   Landslide Above, Below, or Across Route Translational   Rotational   Debris Flow   Shallow Slump   Erosional Failure					
Road/Trail No.:	<input type="radio"/> Trail <input type="radio"/> Road	Road/Trail Class:	Rater:		
Beginning Mile Marker:	End Marker:	Side:	Weather:		
Begin Lat. (xx.xxxxx): Coord.: Long. (-xxx.xxxxx):	End Lat. (xx.xxxxx): Coord.: Long. (-xxx.xxxxx):	Datum:	AADT:		
Length of Affected Road/Trail (ft):	Slope Height (rock) / Axial Length (slide) (ft):		Slope Angle (°):		
Sight Distance (ft):	Usable Roadway/Trail Width (ft):		Speed Limit (mph):		
Ditch Width (ft): RANGE	Ditch Depth (ft): RANGE	Ditch Slope (H:V): RANGE	Blk Size (ft)/Volume (cy):		
Annual Rainfall (in): RANGE	Sole Access Route <input type="checkbox"/> Yes <input type="checkbox"/> No	Fixes Present <input type="checkbox"/> Yes <input type="checkbox"/> No	Photo # Range:		
Comments:					
PRELIMINARY RATING					
Category Rating	3	9	27	81	Score
A. Landslide – Roadway Width Affected	0-5 Percent	6-25 Percent	26-50 Percent	51-100 Percent	
B. Landslide – Slide/Erosion Effects	Visible crack or slight deposit of material / minor erosion	1 inch offset, or 6-inch deposit of material / major erosion will affect travel in < 5 yrs	2-inch offset or 12-inch deposit/ mod. erosion impacting travel annually	4-inch offset or 24-inch deposit/ severe erosion impacting travel consistently	
C. Landslide – Roadway Length Affected	25 ft	100 ft	225 ft	400 ft	CALC
D. Rockfall – Ditch Effectiveness (consider launch features)	Good	Moderate	Limited	No Catchment	
E. Rockfall – Rockfall History	Few Falls	Occasional Falls	Many Falls	Constant Falls	
F. Rockfall – Block Size or Volume per Event	1 ft or 3 yd <sup>3</sup>	2 ft or 6 yd <sup>3</sup>	3 ft or 9 yd <sup>3</sup>	4 ft or 12 yd <sup>3</sup>	CALC
G. All – Impact on Use	Full use continues with minor delay	Partial use remains. Use modification required, short (3 mi/30 min.) detour available	Use is blocked – long (>30 min) detour available or less than 1 day closure	Use is blocked – no detour available or closure longer than 1 week	
H. All – AADT / Usage / Economic or Recreational Importance (highest rating applies)	50 Rarely Used Insignificant economic / rec. importance	200 Occasionally used Minor economic / rec. importance	450 Frequently used Moderate economic / rec. importance	800 Constantly used Significant economic / rec. importance	CALC FOR AADT ONLY
LANDSLIDES TOTAL (A+B+C+G+H)					CALC
ROCKFALL TOTAL (D+E+F+G+H)					CALC
Preliminary Rating Good (15-21 pts)   Fair (22-161 pts)   Poor (>161 pts) Sites rated as Fair or Poor receive detailed evaluation (complete back page)					

SLOPE RATING FORM – DETAILED SLOPE HAZARD RATING						
Category Rating		3	9	27	81	Score
I. All – Slope Drainage		Slope appears dry or well drained; surface runoff well controlled	Intermittent water on slope; mod. well drained; or surface runoff moderately controlled	Water usually on slope; poorly drained; or surface runoff poorly controlled	Water always on slope; very poorly drained; or surface water runoff control not present	
J. All – Annual Rainfall		0-10"	10-30"	30-60"	60"+	
K. All – Slope Height (rockfall) / Axial length of slide (landslide)		25 ft	50 ft	75 ft	100 ft	CALC
Select One Unstable Slope Type  Rockfalls (add D, E, F)  Geologic Character Case 1 Case 2	L. Thaw Stability (cold climates)	Unfrozen/Thaw Stable	Slightly Thaw Unstable	Moderately Thaw Unstable	Highly Thaw Unstable	
	M. Instability-Related Maint. Frequency	Every 10 years	Every 5 years	Every 2 years	Every year	
	N. Movement History	Minor movement or sporadic creep	Up to 1 inch annually or steady annual creep	Up to 3 inches per event, one event per year	>3" per event, >6" annually, more than 1 event per year (includes all debris flows)	
	O. Rockfall-Related Maint. Frequency	Normal, scheduled maintenance	Patrols after every storm event	Routine seasonal patrols	Year-round patrols	
	P. Structural Condition	Favorable	Random	Adverse Discontinuous	Adverse Continuous	
	Q. Rock Friction	Rough/Irregular	Undulating	Planar	Clay infilled/ Slickensided	
	R. Structural Condition	Few differential erosion features	Occasional differential erosion features	Many differential erosion features	Major differential erosion features	
	S. Diff. in Erosion Rates	Small difference	Moderate difference	Large difference	Extreme difference	
	T. LANDSLIDE HAZARD TOTAL (A+B+C+J+K+L+M+N)					CALC
	U. ROCKFALL HAZARD TOTAL (D+E+F+I+J+K+O+(greatest of P+Q or R+S))					CALC
DETAILED RISK RATING						
V. Route Width or Trail Width	36 ft 14 ft	28 ft 10 ft	20 ft 6 ft	12 ft 2 ft	CALC	
W. Human Exposure Factor	12.5% of the time	25% of the time	37.5% of the time	50% of the time	CALC for roads	
X. % of Decision Sight Distance (Judge avoidance ability on trails)	Adequate, 100% of low design value	Moderate, 80% of low design value	Limited, 60% of low design value	Very Limited, 40% of low design value	CALC for roads	
Y. Right of Way (R/W) Impacts (If Left Unattended)	No R/W implications	Minor effects beyond R/W	Private property, no structures affected	Structures, roads, RR, utilities, or Parks affected		
Z. Environmental/Cultural Impacts if Left Unattended	None/No potential to cause effects	Likely to effect/No hist. prop. affected	Likely to adversely affect/Finding of no adverse effect	Current adverse effects/Adverse effect		
AA. Maintenance Complexity	Routine effort/In-House	In-House Maint./ Special project	Specialized equip./contract	Complex/Dangerous effort/location/ contract		
BB. Event Cost	\$0-2k	\$2-25k	\$25-100k	>\$100k		
CC. RISK TOTALS: (G+H+V+W+X+Y+Z+AA+BB)					CALC	
TOTAL USMP SCORE: LANDSLIDES (T+CC) OR ROCKFALL (U+CC)					CALC	
Total USMP Score Good (< 200 pts)   Fair (200 - 400 pts)   Poor (> 400 pts)						



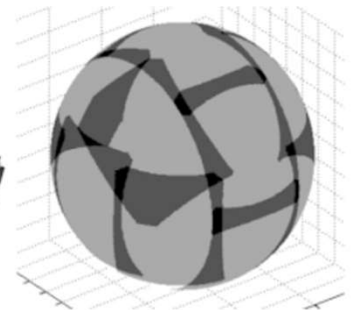
# BACKGROUND

- Field Data Collection
  - Time
  - Money
  - Safety



# BACKGROUND

- Alternative Data Collection Methods
  - Remote sensing methods such as LiDAR and street-level photogrammetry





# METHODS - Cut Slope Inventory

## DEMs

Home

### Virginia LiDAR Download Application

**vgin** VGIN Administrator  
Virginia Geographic Information Network

#### Summary

VA most current LiDAR (point cloud and DEM) download application of USGS and NOAA data.

[View Full Details](#)

#### Details

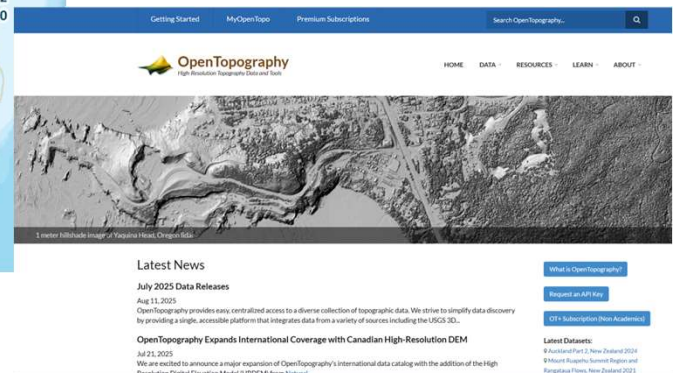
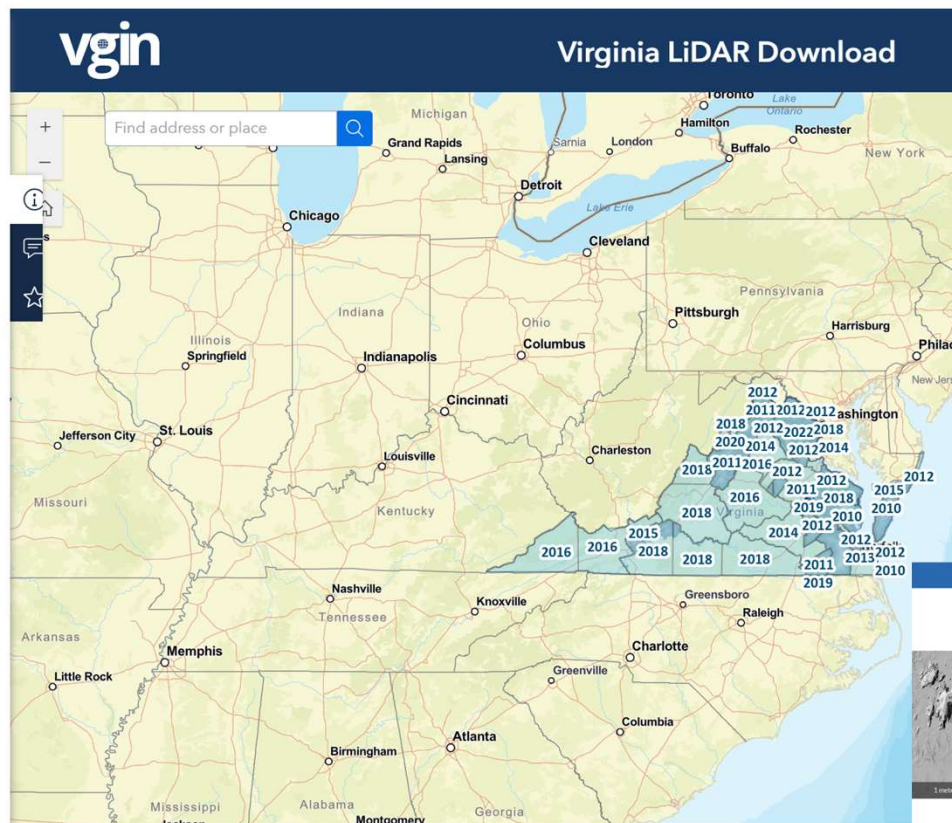
**Application**  
Web Experience

**December 4, 2024 at 3:30:47 PM EST**  
Date Updated

**January 26, 2024 at 2:06:04 PM EST**  
Published Date

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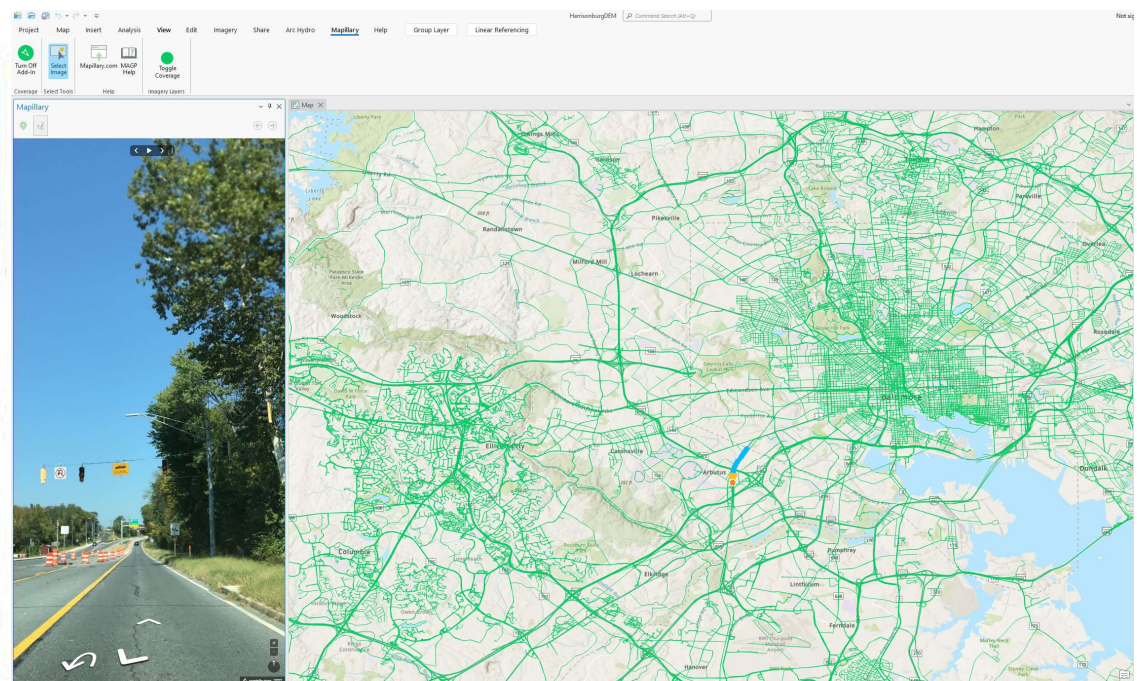


<https://vgin.vdem.virginia.gov/apps/VGIN::virginia-lidar-download-application/explore>

<https://opentopography.org/>

# METHODS - Cut Slope Inventory

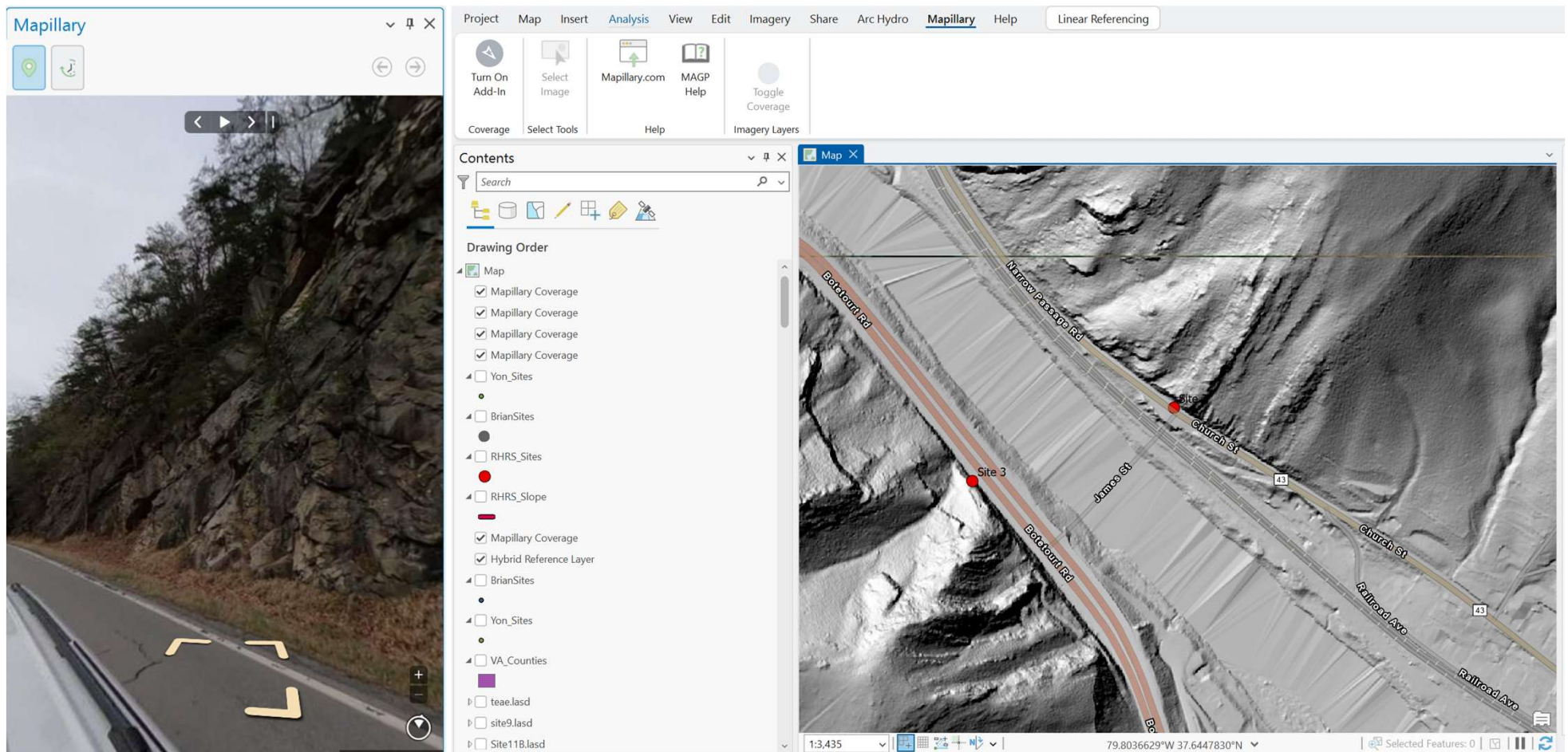
## Street Level Imagery -Mapillary





# METHODS - Cut Slope Inventory

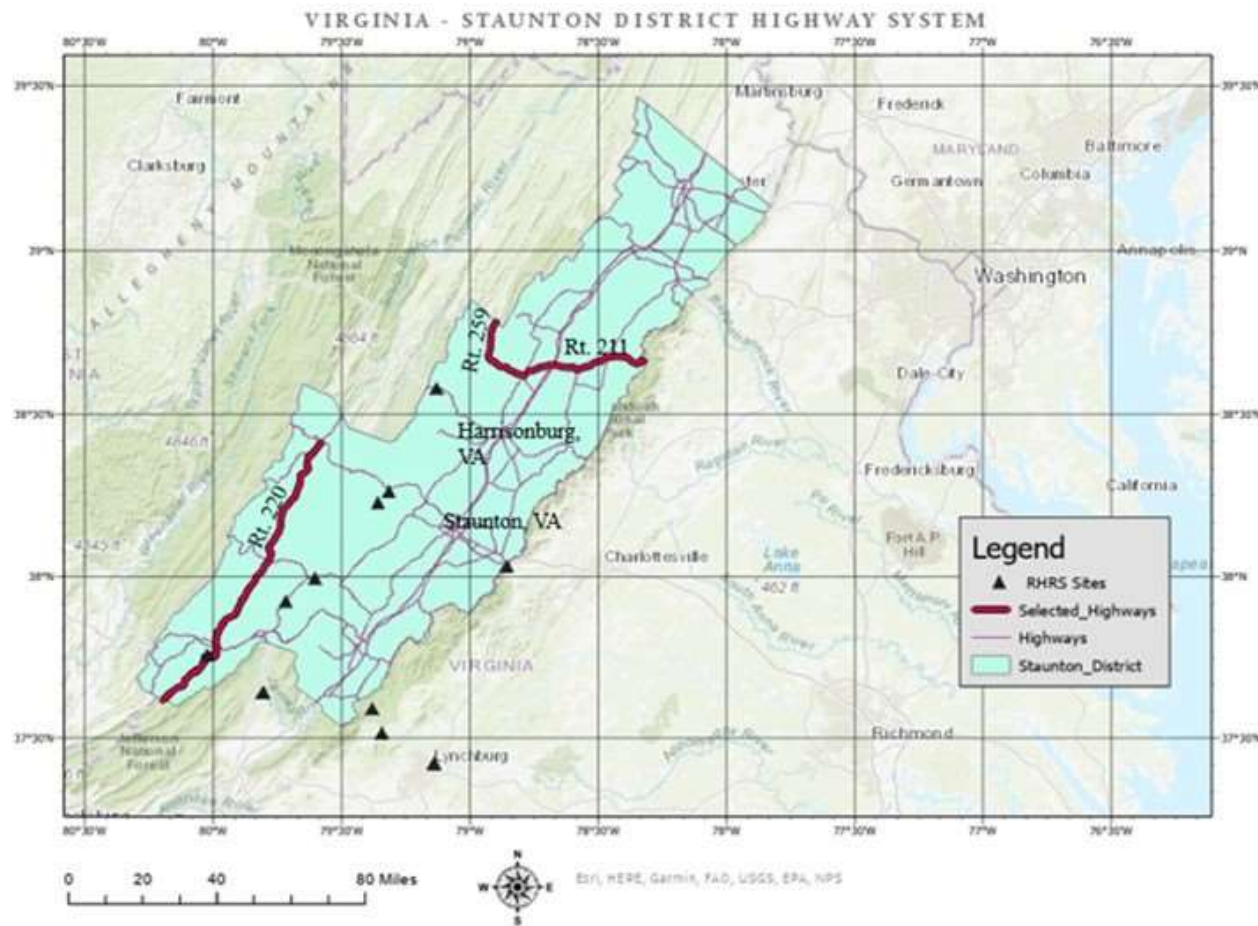
## DEMs/Street level imagery



# METHODS - Cut Slope Inventory

## Rock Cut Slope Inventory

Routes 211, 220, and 259 in the Staunton District of VDOT





# METHODS - Cut Slope Inventory

## DEM/ ArcGIS

### Automated

Rock Cut Slope Identification

Slope Angle

Slope Aspect

Slope Length

Location (Lat./Long.)

## Street-Level Imagery

Preliminary Geologic  
Characterization

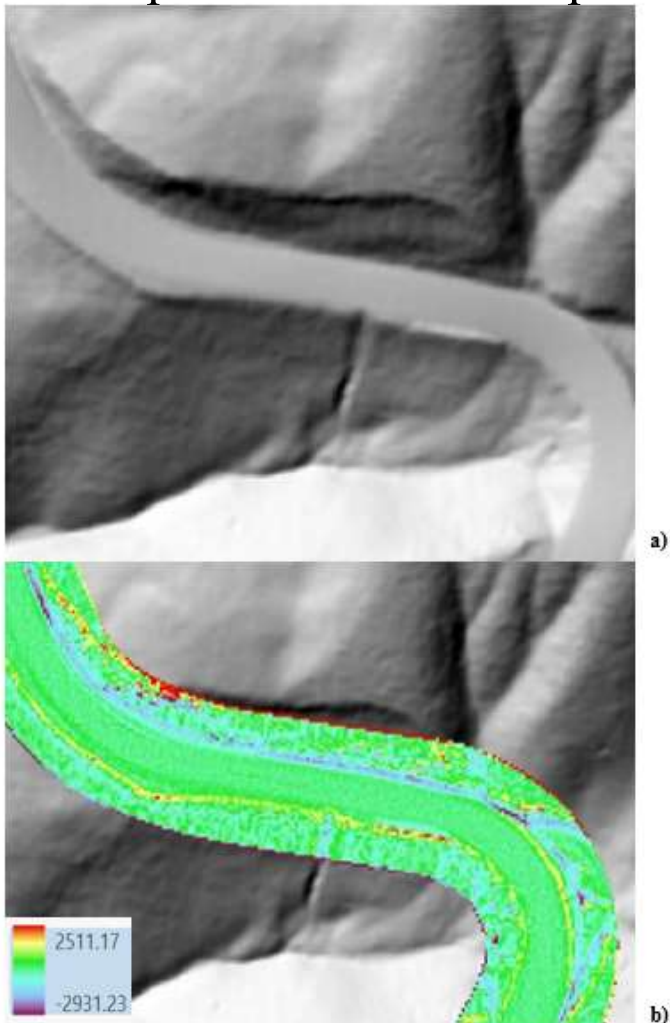
## Field Verification

Collect GPS Locations of Rock Cut  
Slopes

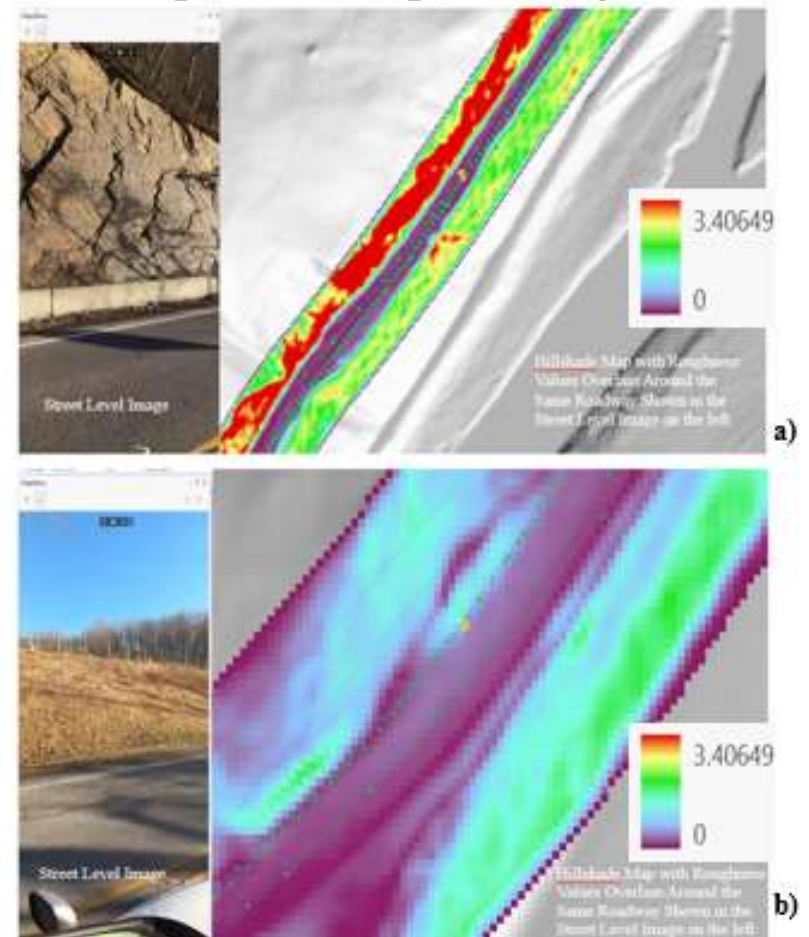
# METHODS - Cut Slope Inventory

## Identifying Rock Cut Slopes from DEMs

Cut slope/Embankment slope - Curvature



Soil slope/rock slope - Roughness



# METHODS - Cut Slope Inventory

Spatial and Geometric Data Collection from DEMs Evaluating Geologic Characteristics from Street-Level Imagery

Slope Height: Difference between maximum and minimum values.

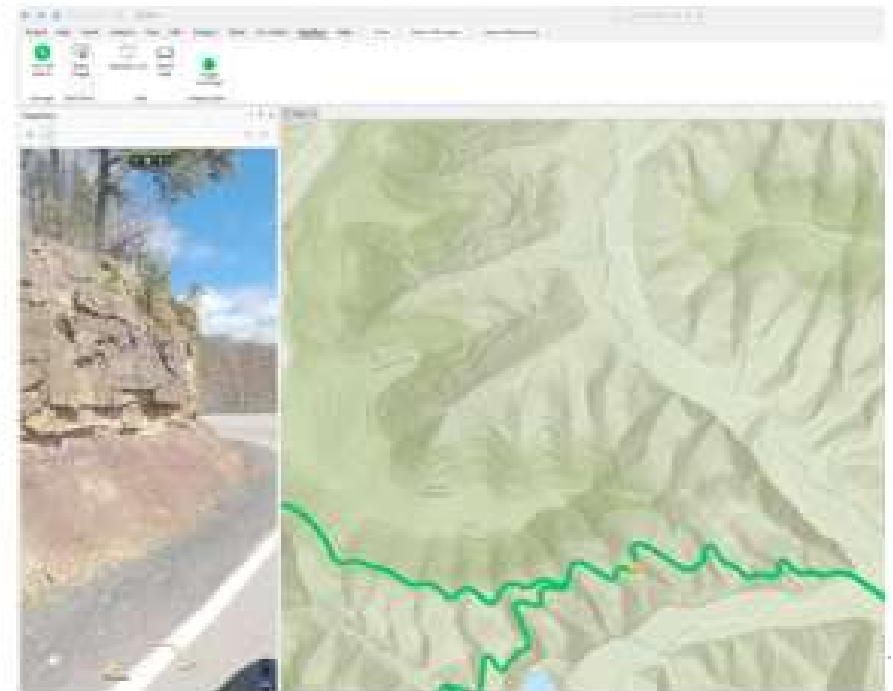
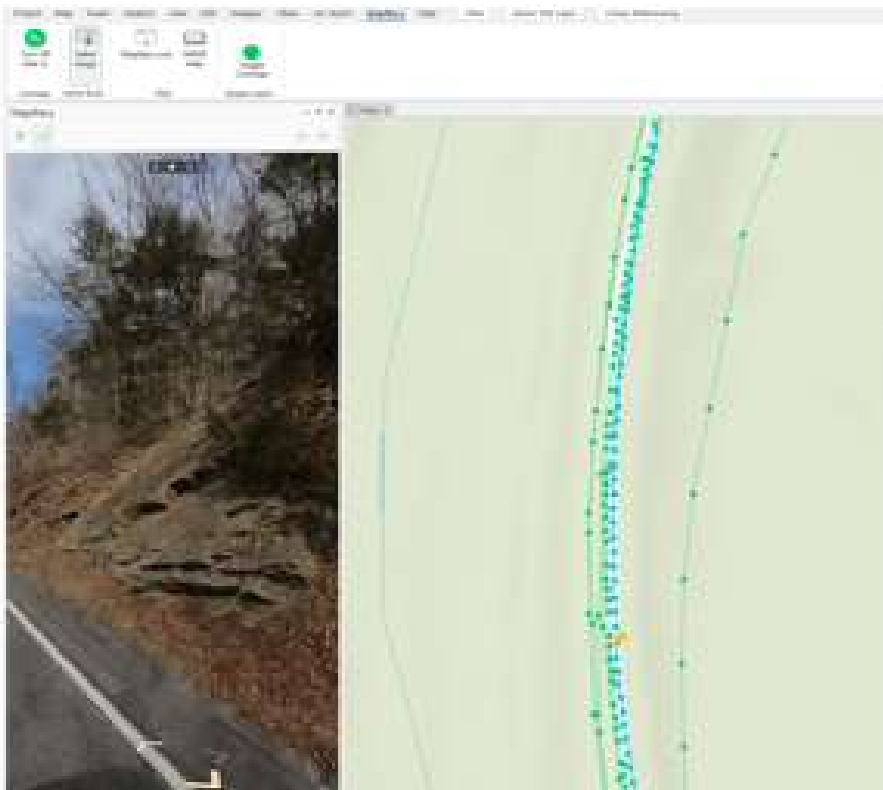
Slope Angle: Average slope angle value for each polygon is calculated.

Slope Length: Length of rectangles bounding each slope

Midpoint Coordinate: Calculate the x,y coordinate of the centroid of each slope polygon using 'calculate geometry' function

# METHODS - Cut Slope Inventory

Evaluating Geologic Characteristics from Street-Level Imagery





# RESULTS - Cut Slope Inventory

- 142 Rock cut slopes

Slope Id	Slope Aspect	Average Slope (Deg)	Slope Length (ft)	Slope Height(ft)	Centroid Latitude	Centroid Longitude
Rt_211-1	NW	25.0	107.5	19.0	38.6747	-78.4462
Rt_211-2	SE	22.1	99.3	15.7	38.67071	-78.3812
Rt_211-3	NE	30.9	318.9	36.8	38.66881	-78.3793
Rt_211-4	SW	28.6	318.9	35.4	38.66859	-78.3794
Rt_211-5	SE	30.8	318.9	23.3	38.66847	-78.3789
Rt_211-6	SW	36.5	679.8	91.6	38.66884	-78.3788
Rt_211-7	SW	28.6	358.6	32.1	38.66734	-78.3773
Rt_211-8	SW	30.4	285.2	47.8	38.66566	-78.3747
Rt_211-9	NE	29.6	238.2	31.1	38.66343	-78.3314
Rt_211-10	SW	33.4	475.1	58.7	38.66362	-78.3313

# RESULTS- Cut Slope Inventory

- 20.6 miles of rock/soil cut slopes /23.9 miles  
- 86.2 %
- Cut slopes > 25 ft high - 100%
- 8.2 miles rock cut slopes / 8.6 miles of  
verified - 95.3 %

Route No	Mileage of Slope Cut (Automated Method)	Mileage of Slope Cut (Visually Mapped on Hillshade)	Mileage of Rock Slope (Automated Method)	Number of Slope Cuts (Automated Method)	Mileage of Rock Slope (Field Verified)
220	12 mi	13.8 mi	4.4 mi	59 Sites	4.7 mi
211	5.7 mi	7.1 mi	2.1 mi	37 Sites	2.1 mi
259	2.9 mi	3 mi	1.7 mi	46 Sites	1.8 mi

# METHODS - Rockfall Hazard Rating

## DEM-Hillshade Map/ ArcGIS

Lat/Long

Slope Height

Slope Angle

Slope Length

Catchment Ditch Width/Depth

Route Width or Trail Width

*Percent of Decision Sight Distance*  
*(Judge avoidance ability on trails) –*  
*SSD (Shortest Straight Distance)*

## Street-Level Imagery

Rockfall – Block Size

Slope Drainage

Structural Condition

Rock Friction

Differential Erosion Features

Differential Erosion Rates

Detailed Rating Parameters

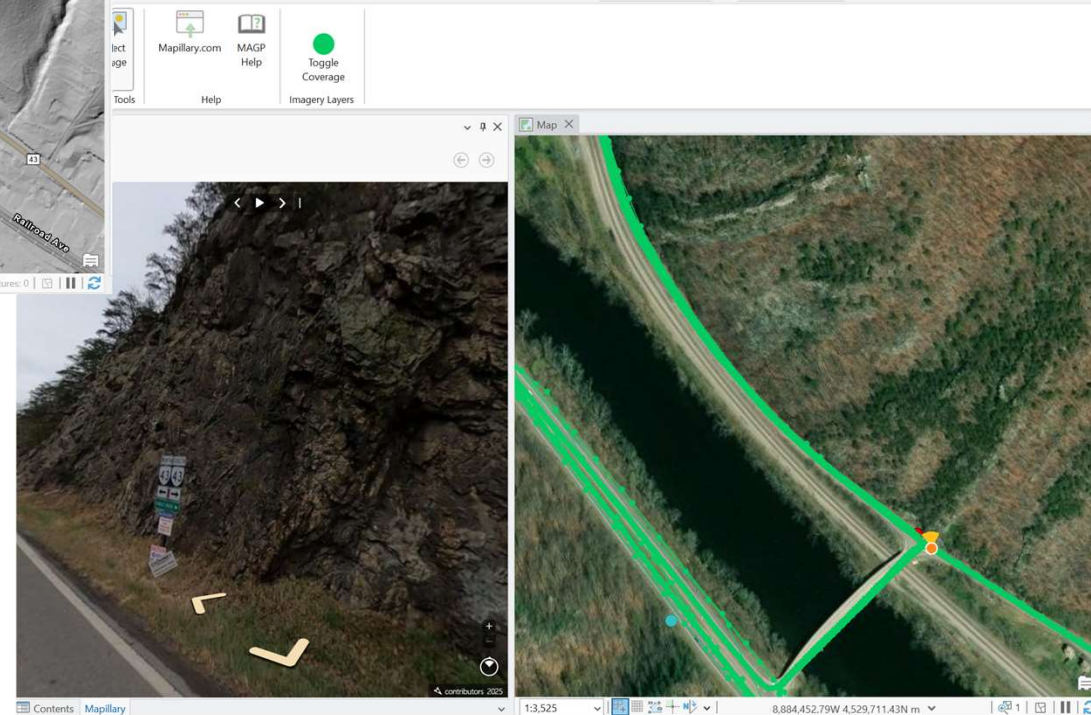
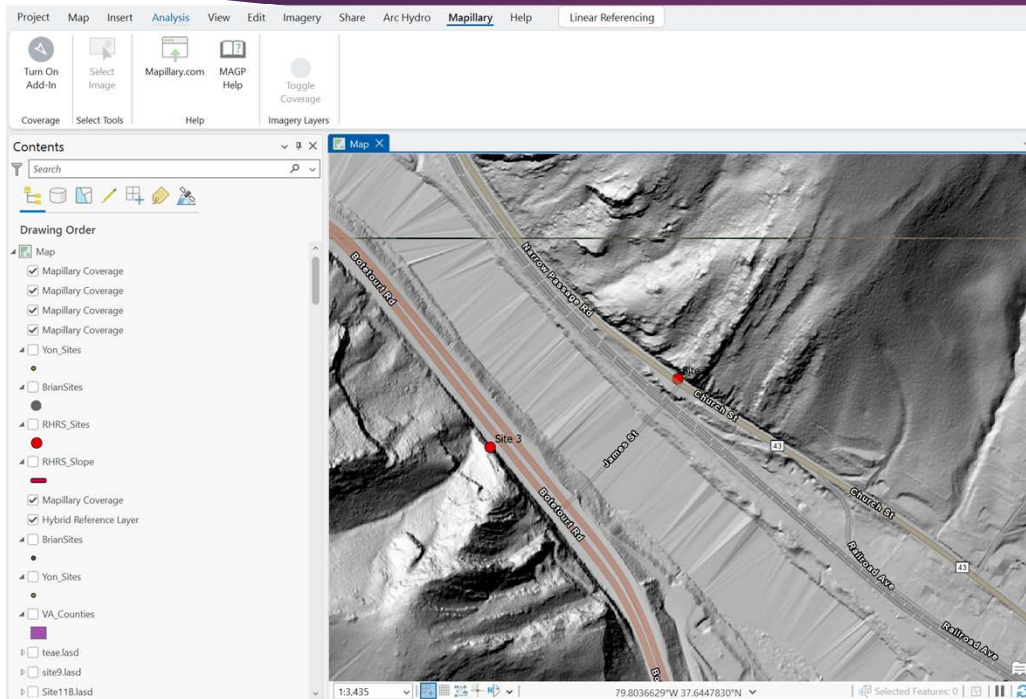
## Field Verification

Qualitative/quantitative measurements

	Parameters	Traditional Data Source	Data Source Used
Site Information	Hazard Type	Field Visit	Street-Level Imagery
	Route No.	VDOT	ArcGIS Base Map
	Beginning Mile Marker	Field Visit	
	Lat/Long	Field Visit	
	Road Length Affected	Field Visit	ArcGIS Aerial Imagery
	Slope Height	Field Visit	ArcGIS Tools
	Slope Angle	Field Visit	ArcGIS Tools
	Sight Distance	Field Visit	ArcGIS Aerial Imagery
	Affected Roadway Width	Field Visit	ArcGIS Aerial Imagery
	Catchment Ditch Width/Depth	Field Visit	ArcGIS Aerial Imagery
Preliminary Rating Parameters	Annual Rainfall	NOAA	
	Rockfall – Ditch Effectiveness	Field Visit	Street-Level Imagery
	Rockfall – Rockfall History	VDOT	
	Rockfall – Block Size	Field Visit	ArcGIS Aerial Imagery
	Impact on Use	VDOT	
Detailed Rating Parameters	AADT / Usage / Economic or Recreational Importance	VDOT	
	Slope Drainage	Field Visit	ArcGIS Aerial Imagery
	Annual Rainfall	NOAA	
	Slope Height	Field Visit	ArcGIS Tools
	Rockfall-Related Maintenance Frequency	VDOT	
	Structural Condition	Field Visit	ArcGIS Aerial Imagery
	Rock Friction	Field Visit	Street-Level Imagery
	Differential Erosion Features	Field Visit	Street-Level Imagery
	Differential Erosion Rates	Field Visit	Street-Level Imagery
	Route Width or Trail Width	Field Visit	ArcGIS Aerial Imagery
	Human Exposure Factor	VDOT	VDOT
	Percent of Decision Sight Distance (Judge avoidance ability on trails)	Field Visit	Street-Level Imagery
	Right of Way	VDOT	
	Environmental/Cultural Impacts if Left Unattended	VDOT	
	Maintenance Complexity	VDOT	

# METHODS - Rockfall Hazard Rating ( RHRS)

## Quantitative /Qualitative Measurements





# RESULTS- Rockfall Hazard Rating ( RHRS)

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Site 13
Quantitative Measured Parameters Values													
Roadway Width (ft)	18	18	25	20	18	18	20	20	23	20	21	24	26
Road Length (ft)	253	1800	1165	435	557	253	1200	916	1021	860	1094	934	1200
Slope Height (ft)	83	80	50	64	102	83	115	60	101	160	65	131	33
Slope Angle (Deg.)	50	80	80	65	56	50	83	60	70	65	70	65	60
Sight Distance (ft)	516	1044	1651	197	189	516	292	2100	517	2400	470	5500	470
Rock Block Size (ft)	<1	4 to 5		<0.5	3 to 5	<1	2 to 3	4	1 to 2	4	5	5 to 10	3 to 5
Qualitative Determined Parameters Scores													
Catchment Ditch Effectiveness	3	27	3	81	3	9	81	3	81	3	81	3	81
Rockfall Size	3	81	81	3	81	3	27	81	9	81	81	81	81
Slope Drainage	3	3	3	3	3	3	3	3	9	3	3	27	3
Annual RF	27	27	27	27	27	27	27	27	27	27	27	27	27
Slope Height (ft)	81	81	9	9	81	27	81	81	81	81	81	81	9
Structural Condition	81	3	3	3	81	81	81	9	9	9	9	81	3
Rock Friction	27	9	27	27	27	27	9	9	9	9	9	27	27
Differential Erosion Features	3	27	81	3	3	3	9	3	3	3	3	3	81
Differential Erosion Rates	3	27	9	3	3	3	9	3	3	3	3	3	81

# RESULTS-Rockfall Hazard Rating ( RHRS)

## Field VS Desktop Data

Site	Field Slope Length (ft)	Slope Length (ft)	Field Roadway Width (ft)	Roadway Width (ft)	Field Slope Height (ft)	Slope Height (ft)	Field Slope Angle (degrees)	Slope Angle (degrees)			
Site 1	1392	253	27	18	73	83	44	50			
Site 2	1160	1800	23	18	84	80	90	80			
Site 3	1740	1165	38	25	135	50	90	80			
Site 4	443	435	23	20	39	64	60	65			
Site 5	1276	557	24	18	108	102	70	56			
Site 6	1450	253	24	18	144	83	90	50			
Site 7	30	1200	24	20	43	115	90	83			
Site 8	290	916	21	20	78	40	80	40			
Site 9	2465	1021	24	23	4	Parameter		DEM/Street-level Image VS Field (PI)		DEM/Street-level View VS Field (VDOT)	
Site 10	522	860	21	20	9	Catchment Ditch Effectiveness		10		8	
Site 11	191	1094	25	21	2	Structural Condition		8		6	
Site 12	3190	934	26	24	13	Rock Friction		10		5	
Site 13	1252	1200	20	26	2	Differential Erosion Features		8		5	
						Differential Erosion Rates		9		5	

# BENEFITS

Tasks	No of Sites	Method	Total Time (days) <sup>a</sup>	Average Time Per Site (minutes)	Total Cost	Average Cost Per Site
Inventory Preparation	142	DEM/Street-level Imagery	3.2	10.8	\$1,280	\$9.0
		Field	15	51	\$9,291	\$65.5
USMP RHRS	13	DEM/Street-level Imagery	1.2	45	\$490	\$37.5
		Field	6.5	240	\$4,026	\$310

# GAM RECOMMENDATIONS

## Integrated Inventory and Rockfall Hazard/Risk Rating

### DEM/GIS/Desktop Search

Slope Geometry, Location, Rockfall History, AADT, Human Exposure Factor, Annual Rainfall

### Street-Level Imagery

Catchment Ditch Effectiveness, Block size/volume, Slope Drainage, Geologic Characterization, Percent Shortest Straight Distance (% SSD)

### Field Assessment

Drainage, Geologic Characterization, Percent Shortest Straight Distance (% SSD)

### Detailed Impact Assessment

Impact on Use, Right of Way Impact (if left unattended)

,  
Environmental/Cultural Impact (if left unattended),  
Maintenance Complexity, and Event cost

### Performance Monitoring



# FUTURE RESEARCH NEEDS

## Performance Monitoring

- Digital monitoring, such as terrestrial or drone LiDAR,
- Using object detection models to identify hazard indicators such as overhangs and the presence of accumulated rockfall debris.

# CONCLUSIONS

- The use of high resolution (1m×1m) DEM in conjunction with street-level imagery is an efficient tool to collect data to manage rock cut slopes
  - Large areas can be covered
  - Relatively short time
  - Safe



**Thank You**



# USMP GAM Roadmap (Beckstrand et al., 2019)

Geotechnical Performance Goals

Inventory, USMP Rating and Condition Assessment

Performance Modeling and Measuring

Project Alternatives, Cost and Economic Analysis

Decision Support- Priority Selection, Short and Long Term Allocation  
of Funds

Monitor Performance