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Phase II: High Resolution Digital Elevation Models (DEMs) and Street-Level Imagery for Rock Cut Slope Inventory and Rockfall Hazard Rating

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Abstract:

Proactive management of geotechnical assets such as rock cut slopes along highways includes performing inventory and evaluating rockfall hazard ratings. Both activities are aimed at helping transportation agencies to proactively monitor and maintain rockfall prone rock cut slopes. Rock cut slope inventory involves locating rock cut slopes and collecting preliminary geometric/geologic attributes that may contribute to slope failure leading to rockfalls. Rockfall hazard rating provides a detailed analysis of the presence of rockfall hazard risk factors. The risk factors include geometric and geologic factors that are traditionally collected in the field requiring intensive time and monetary investment. An alternative method is the use of remotely acquired data such as the use of LiDAR and photogrammetry to measure geologic parameters on the desktop. This research project is a pilot test to investigate the use of high-resolution LiDAR-derived digital elevation models (DEMs) and street-level imagery from (www.Mapillary.com) to collect geometric and geologic data on the desktop. The proposed automated/semi-automated method will save time and money required for both rock slope inventory and rockfall hazard rating. The accuracy of automated soil/rock cut slope detection using digital elevation models (DEMs) and street-level imagery was found to be 86% when compared to traditional field collection methods and 95% in identifying rock cut slopes. Measurements of rockfall hazard parameters were also in close agreement to those measured in the field. The proposed method will streamline a desktop method, limit field visits and measurements, and enable infrastructure agencies to become more efficient in managing their rock slope assets.

FINAL REPORT

PHASE II: HIGH RESOLUTION DIGITAL ELEVATION MODELS (DEMS) AND STREET-LEVEL IMAGERY FOR ROCK CUT SLOPE INVENTORY AND ROCKFALL HAZARD RATING

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ABSTRACT

Proactive management of geotechnical assets such as rock cut slopes along highways includes performing inventory and evaluating rockfall hazard ratings. Both activities are aimed at helping transportation agencies to proactively monitor and maintain rockfall prone rock cut slopes. Rock cut slope inventory involves locating rock cut slopes and collecting preliminary geometric/geologic attributes that may contribute to slope failure leading to rockfalls. Rockfall hazard rating provides a detailed analysis of the presence of rockfall hazard risk factors. The risk factors include geometric and geologic factors that are traditionally collected in the field requiring intensive time and monetary investment. An alternative method is the use of remotely acquired data such as the use of LiDAR and photogrammetry to measure geologic parameters on the desktop. This research project is a pilot test to investigate the use of high-resolution LiDAR-derived digital elevation models (DEMs) and street-level imagery from (www.Mapillary.com) to collect geometric and geologic data on the desktop. The proposed automated/semi-automated method will save time and money required for both rock slope inventory and rockfall hazard rating. The accuracy of automated soil/rock cut slope detection using digital elevation models (DEMs) and street-level imagery was found to be 86% when compared to traditional field collection methods and 95% in identifying rock cut slopes. Measurements of rockfall hazard parameters were also in close agreement to those measured in the field. The proposed method will streamline a desktop method, limit field visits and measurements, and enable infrastructure agencies to become more efficient in managing their rock slope assets.

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Phase II: High Resolution Digital Elevation Models (DEMs) and Street-Level Imagery for Rock Cut Slope Inventory and Rockfall Hazard Rating

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INTRODUCTION

Geotechnical assets include slopes, both cut slopes and embankment slopes, retaining walls, and material sources. Geotechnical asset management (GAM) of cut slopes near roadways is becoming more common to proactively manage potentially unstable cut slopes as opposed to reactively addressing a failed slope (Beckstrand et al., 2019). Accurate database and condition assessment of cut slopes are necessary for a proactive decision-making protocol to develop risk-reducing corrective actions (Beckstrand et al., 2019). Rock cut slopes adjacent to roadways are common geotechnical assets in mountainous regions such as Virginia's Appalachia. Rock cut slopes can fail globally as rockslides or most commonly as rockfalls. Performing inventory of existing rock cut slopes and rating their rockfall hazard risk are the main components of managing rock cut slopes. Slope inventory involves locating and collecting preliminary geometric/geologic attributes. Conversely, a rockfall hazard rating provides a detailed analysis of the presence of rockfall hazard risk factors. Both efforts are aimed at helping agencies to proactively monitor and maintain potentially problematic rock cut slopes.

Rock slope failure in the form of rockfalls is mainly due to geometric and geologic factors. Geometric factors are defined as slope angle and slope height. The main geologic factors behind rock slope failures are the presence of unfavorably oriented discontinuities, low shear strength along discontinuities, and the presence of differential weathering. External causes such as rainfall events, groundwater seepage, surface water, freeze-thaw cycles, tree root wedging, earthquake tremors, and animal disturbances also promote rockfall generation (Higgins and Andrew, 2012). The impact of rockfalls can vary depending on the width of the roadway, effectiveness of rockfall catchment, rockfall size, and the driver's ability to avoid collision with a rockfall on the roadway.

Transportation agencies use a system of rating to evaluate the likelihood of rockfall events and impact factors. Oregon's rockfall hazard rating system (RHRS) is the first of such methods used by departments of transportation to rate rock cut slopes by characterizing them with respect to the risk of rockfall events and their potential impacts on motorists and roadways. Eighteen states in the US have adopted Oregon's RHRS (Santi et al., 2009). Other states such as Arizona, Colorado, Idaho, New Jersey, Vermont, New York, Ohio and Tennessee use modified versions of the RHRS to meet their unique geologic and other attributes (Stover, 1992; Eliassen & Ingraham, 2000; Fish & Lane, 2001; Vandewater et al. 2005; Miller, 2003; Shakoor and Martin, 2005).

In 2019, FHWA produced a comprehensive slope hazard rating guideline under the 'Unstable Slope Management Program' (USMP) (Beckstrand et al., 2019). The USMP put forward a comprehensive hazard and risk rating system for slopes that can potentially be affected by landslides and/or produce rockfalls. The USMP system for rock slope hazard rating closely mirrors its predecessor, Oregon's RHRS, by tabulating spatial, geometric/geologic attributes of rock cut slopes and assigning numerical scores for hazard and risk factors.

Determination of geologic and geometric attributes for the USMP-based slope rating system requires extensive time to drive to individual rock slope sites and take onsite measurements. As an alternative, remote sensing methods such as the use of street-level LiDAR and photogrammetry have been used to measure geologic parameters at slope sites (Lato et al., 2009; Lato and Voge, 2012; Voge et al, 2013; Nguyen et al., 2011; Sturzenegger and Stead 2009; Kemeny and Turner, 2008). Swanger and Admassu (2018) introduced the use of Google Earth and Google Street View to measure geologic as well as geometric parameters.

This research project, funded by the Virginia Transport Research Council (VTRC) is set to test the use of airborne-LiDAR derived high-resolution digital elevation models (DEMs) and street-level imagery to collect geometric and geologic data on the desktop for the purpose of both rock slope inventory and USMP-based rockfall hazard rating. In Virginia, where this study is based, there is an estimated 1200 miles of rock cut slope according to correspondence with Dr. Brian Bruckno of VDOT. However, there is no accurate database of rock cut slope locations or assessment of their conditions. This research will suggest a methodology for the collection of data pertaining to rock slope inventory and rockfall hazard rating from remotely sensed LiDAR based DEMs and street-level photographic images.

PURPOSE AND SCOPE

Building a database of rock cut slope inventory and assessing rock cut slopes' rockfall hazard requires extensive field-based data collection that may not be feasible considering the vast size of mountainous terrain in Virginia. The purpose of this study is to determine if the use of DEMs and street-level imagery, rather than field data collection, can yield a rock slope inventory and a rockfall hazard rating. The objectives are to:

- Develop a desktop methodology, implementing a digital elevation model (DEMs) and street-level imagery, for generating a rock slope inventory, and USMP-based rockfall hazard rating system;
- Evaluate the accuracy of the approach compared to field data collection, and
- Quantify the time saved using the proposed methodology.

The scope of rock cut slope inventory is limited to Routes 211, 220, and 259 within the VDOT Staunton District and the rockfall hazard rating is based on 13 sites from Staunton, Lynchburg, and Salem Districts.

METHODS

Rock Cut Slope Inventory

Routes 211, 220, and 259 in the Staunton District of VDOT, as depicted in Figure 1, were selected as a study site for the project. The thirteen Rockfall Hazard Rating System (RHRS) sites are used in this study to evaluate the proposed methodology for the USMP-based rockfall hazard rating and are also depicted in Figure 1. Geometric and geologic parameters that would have required field visits were selected to be evaluated for this study.

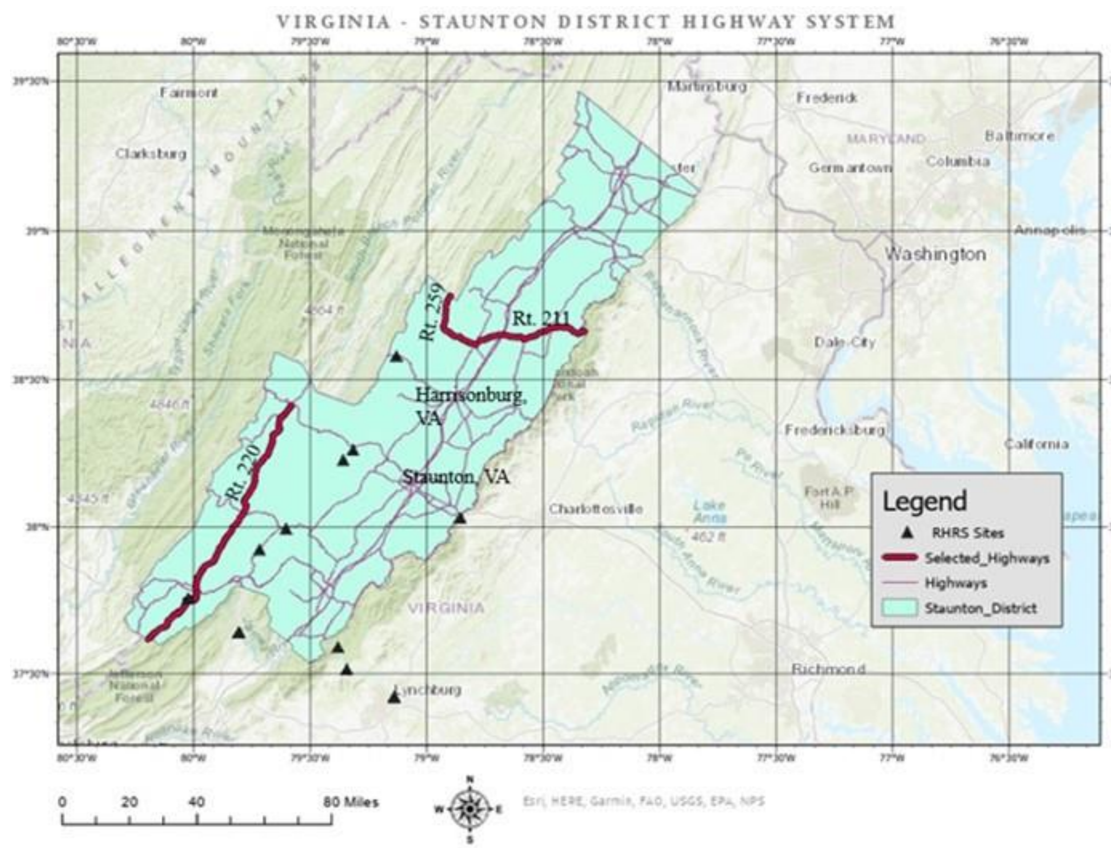


Figure 1. Location Map of the Study Sites (Rt. 211, 220, and 259) within the Staunton District of VDOT (Base map Source: ESRI, Garmin, FAO, USGS, EPA, NPS)

Site information including its designation, and geographic location, as well as site parameters for building slope inventory have been identified for each location and are summarized below:

1) Slope Geometry
   a. Slope height
   b. Slope length
   c. Slope azimuth
   d. Slope angle
2) Geologic Characteristics (presence of potential for undercutting-induced, plane, wedge and toppling failures

A cut slope is inventoried based on the following criteria:

1) Slope must be continuous and have a unique slope azimuth. A continuous cut slope can be subdivided into more than one slope if the road is winding.
2) Slope must be 10 ft and higher in height.
3) Slope must have a rock exposure of > 50 %.

ArcGIS Pro Version 3.4.2 was used to visualize and process DEMs and street-level imagery. A 1-meter DEM produced by the USGS 3DEP program (USGS, 2025) site was downloaded from the Open Topography online repository. The DEM elevation accuracy is 10 centimeters (4 inches). Rock cut slopes were located, and their geometric attributes were determined using raster and vector operations in ArcGIS. Geologic characteristics were visually evaluated by investigating Mapillary or IVISION street-level imagery. Mapillary is a free web platform which allows users to upload geo-located street-level photographic images whereas IVISION is a commercial street-level imagery service licensed to VDOT. Mapillary can be integrated with ArcGIS allowing the user to open street-level images within the ArcGIS environment. Since some of the existing Mapillary imagery do not have a consistent quality, street-level 360^0 images were collected with a GoPro camera (Model: GoPro Max 360 Action Camera with a photo resolution of 5760X2880). For the study sites within the Staunton District; images of 23 miles on Route 211, 53 miles on Route 220, and 17 miles on Route 259 were uploaded onto the Mapillary platform and accessed on the ArcGIS interface. The GoPro 360 camera mounted to a height of 0.7 m from vehicle's roof was used to capture continuous imagery as depicted in Figure 2.

Figure 2. 360 GoPro Camera Mounted on a Vehicle

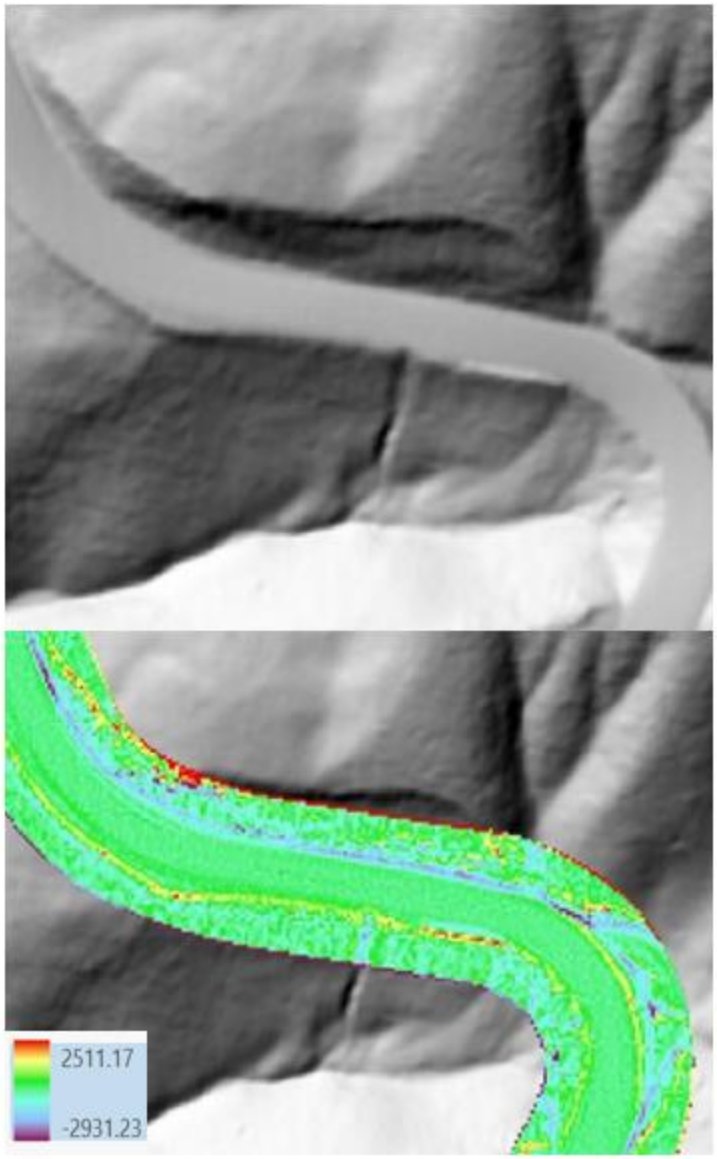
The 360-image allows a global view of the roadway. In addition to the study sites, images were taken along Route 33 for 21 miles, Route 250 for 40 miles, and Route 42 for 24 miles, within the Staunton District and Route 501 for 32 miles in the Lynchburg District. A total of 210 miles of 360 imagery was collected and uploaded. IVISION imagery provides a high-quality front-view-only image. Since IVISION is not accessible directly from the ArcGIS interface, it was not used for slope inventory unless the Mapillary image was of poor quality. The comparison between the Mapillary and INVISION images on the same stretch of road is depicted in Figure 3.

Figure 3. Street-level Imagery from: a) Mapillary synced with ArcGIS; b) IVISION web application

Identifying Rock Cut Slopes from DEMs

DEMs within a 30m buffer were separated by using the ‘Extract DEM’ tool. Cut slopes were first mapped by visually identifying them and digitally tracing them on a Hillshade map. A Hillshade map contains a grayscale image that mimics the effect of a light source on a landscape, representing terrain elevation changes through variations in light and shadow that make cut slopes visible as shown in Figures 4a. The success of automated slope identification was evaluated by comparing the results with visually mapped rock cut slopes and field located rock cut slopes.

The process of automated slope identification on DEMs started with calculating slope values using ArcGIS raster tool. The slope raster was reclassified and areas with > 30 degrees were classified as cut slopes and exported as slope polygons. Slope angle, slope aspect (slope facing direction measured in azimuthal 0 – 360^0 direction), surface curvature, and slope roughness (standard deviation of elevation), were also calculated using ArcGIS raster tools.



a)
b)

Figure 4. Hillshade Map: a) showing a cut slope (sloping towards the roadway) and an embankment slope (sloping away from the road); b) the same Hillshade map overlain with curvature values showing low curvature values (in blue to purple) adjacent to a cut slope and high curvature values (yellow to red) adjacent to an embankment slope

This initial slope classification resulted in a mix of cut slopes and embankment slopes adjacent to roadways. To separate cut slopes, surface curvature values were calculated from the DEM. Curvature is the rate of change of slope within a 3X3 window. Curvature determines if the surface is upwardly concave, such as a hilltop with a positive curvature, or convex, such as in the instance of a valley with a negative curvature. Negative curvature values indicate areas where the topography abruptly slopes upward. Curvature values were exported as aggregated point features within slope polygons. Slopes adjacent to negative curvature values (< -20) are typically cut slopes and therefore selected as cut slopes as depicted in Figure 4. The identified cut slopes were split based on their general aspect (NE, SE, SW, NW). To separate rock cut slopes from soil cut slopes, slope roughness was used since rock bearing cut slopes have rougher surfaces than soil slopes. Slope roughness was estimated by the standard deviation of elevation within a 3-meter X 3-meter window. Slope polygons containing high roughness values (standard deviation of elevation > 1) were selected as candidate rock cut slopes and further evaluated by visual inspection on Mapillary imagery as shown in Figure 5.

To further verify if a given candidate rock cut slope is comprised of rock, or if it is conversely more of comprised of soil, Mapillary images were investigated (Figure 5). Slopes with 50% bed rock exposures, as determined from visual inspection, were classified as rock cut slopes. After determining that a given slope is dominantly rock, its polygon will be classified as a rock cut slope. Figure 6 summarizes the automated slope identification methodology in the form of a flow chart. Appendix A provides a step-by-step approach of the automated slope identification.

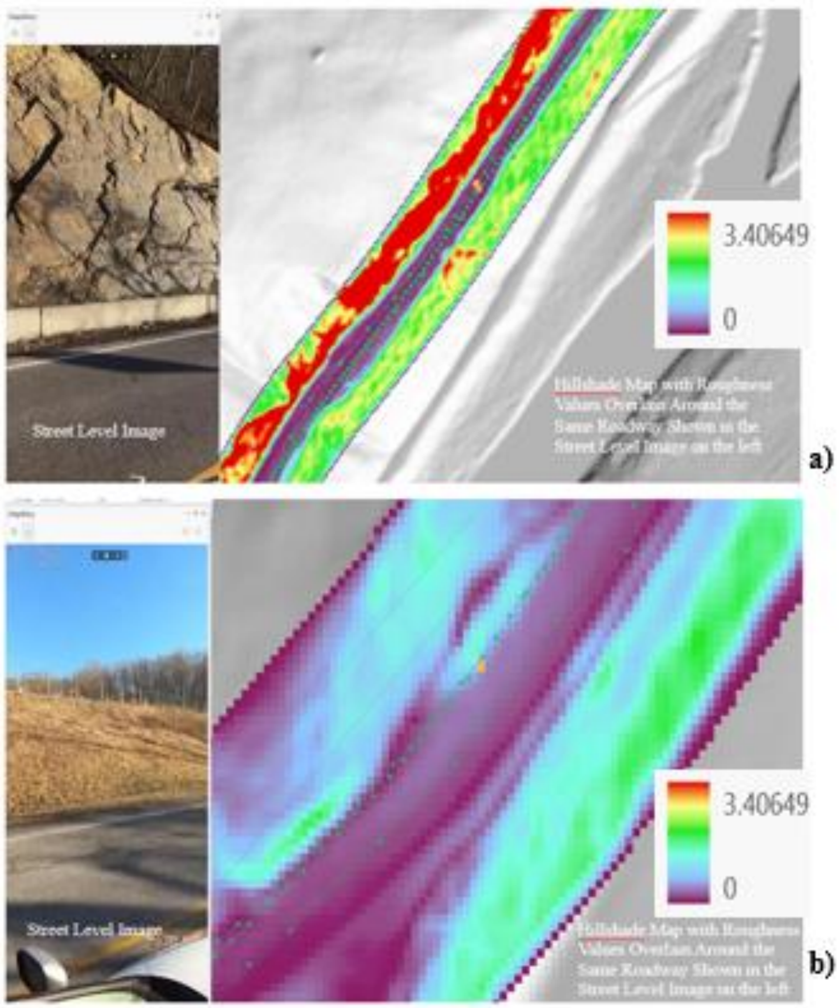


Figure 5. Slope on a Street-level Image: a) rock slope having high roughness value (in red as shown around the same roadway on a Hillshade map); b) soil slope with low roughness value (green as shown on a Hillshade map)

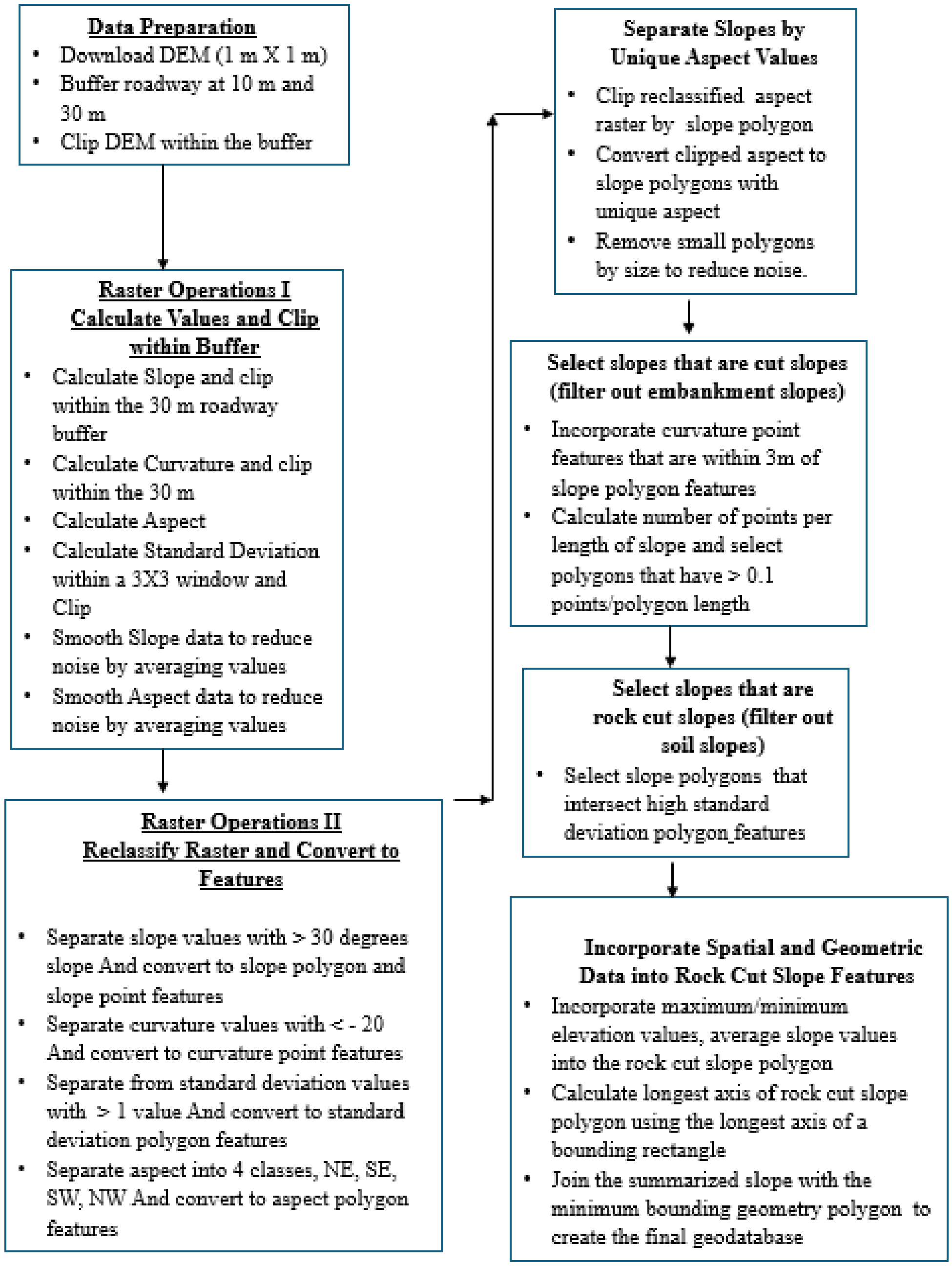
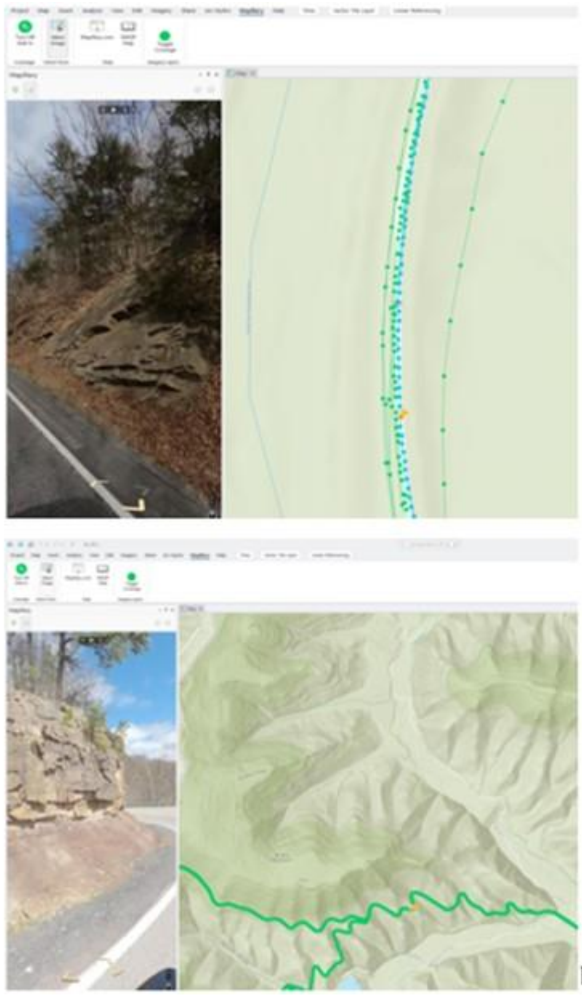


Figure 6. Flow Chart Summarizing Automated Slope Identification Methodology

Evaluating Geologic Characteristics from Street-Level Imagery

Rock cut slopes fail in the form of rockfalls due to plane, wedge, and toppling failures, which result from adverse orientation of discontinuities. Additionally, differential weathering typically affecting weak/strong interlayered sedimentary rocks also lead to rockfall generation. For rock cut slopes, the presence of any of the rockfall causing geologic attributes were evaluated using Mapillary imagery as shown in Figure 7a. For cases where Mapillary images were not visible, IVISION imagery was used as shown in Figure 7b. The presence or non-presence of geological factors leading to rockfalls was added as an attribute(s) to each polygon representing a rock cut slope.



a)

b)

Figure 7. Slope Image: a) showing plane failure on a rock cut slope; b) showing undercutting due to differential weathering between sandstone and shale units

Spatial and Geometric Data Collection from DEMs

Spatial and geometric data including slope height, slope length, slope angle, and centroid location of each rock cut slope identified in section 'Identifying Rock Cut Slopes from DEMs' are calculated and incorporated into each slope polygon as summarized below.

1) Slope Height: Elevation point features are incorporated into each slope and max/min values for each slope polygon is calculated. The slope height is the difference between maximum and minimum values.
2) Slope Angle: Slope point features are incorporated into each slope polygon and the average value for each polygon is calculated.
3) Slope Length: Rectangles bounding each slope are generated and its longest dimension, which approximates the slope length, is assigned to each slope.

4) Using ‘calculate geometry’ function the x,y coordinate of the centroid of each slope polygon is calculated.

The attributes of each slope polygon contain site designation, latitude/longitude of the slope line midpoint, slope length, slope height, slope angle, slope aspect, and type of instability if present are listed in Table 1 and Appendix B.

Table 1. Example Rock Cut Slope Inventory Database

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

Field Verification of Slope Inventory

Field verification of rock slope inventory was performed by verifying the presence of rock cut slopes along sections of Routes 211, 220, 259 included in the study. The GPS locations of rock cut slopes were recorded using a smart phone application, FieldClino. No other physical measurements were made at the inventoried sites. The locations recorded by FieldClino were compared to rock cut slopes identified by the DEM/street-level imagery method described above ‘identifying rock cut slopes’ section.

Rockfall Hazard Rating

The USMP rockfall hazard rating is a two-tiered rating system involving preliminary and detailed ratings. Rock cut slopes with a total preliminary rating score of 21 (fair to poor rating) will advance to the detailed rating. Traditionally, most of the data used to assign scores is collected in the field while other pertinent information can be obtained from historical data from highway agencies and weather data archives such as NOAA. Parameters that require field verification used in this evaluation include Hazard Type, Lat/Long, Route Length, Slope Height, Slope Angle, Sight Distance, Roadway Width, Catchment Ditch Width, Rockfall Size, Slope Drainage, Structural Condition, Rock Friction, Differential Erosion Features, Differential Erosion Rates (Beckstrand et al., 2019). Table 2 provides a comprehensive summary of all parameters incorporated within the USMP-Rockfall rating. Data for the parameters shown in *italics* were selected for evaluation using DEM/street-Level Imagery method as they often require field verification (Table 2). Some parameters such as slope height were scored based on direct quantitative measurements whereas other parameters such as structural conditions were rated based on visual inspections in the field.

Table 2. USMP-RHRS Parameters.

	Parameters[a]	Traditional Data Source	Data Source Used
Site Information	*Hazard Type*	Field Visit	Street-Level Imagery
	Route No.	VDOT	ArcGIS Bae 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
	Annual Rainfall	NOAA	
Preliminary Rating Parameters	*Rockfall – Ditch Effectiveness*	Field Visit	Street-Level Imagery
	Rockfall – Rockfall History	VDOT	
	Rockfall – Block Size	Field Visit	ArcGIS Aerial Imagery
	Impact on Use	VDOT	
	AADT / Usage / Economic or Recreational Importance	VDOT	
Detailed Rating Parameters	*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	
	Event Cost	VDOT	

[a] Parameters in italics were selected for evaluation in this Study. AADT = Annual average daily traffic.

Thirteen sites were selected to evaluate desktop data collection method for the USMP-based rockfall hazard rating system from DEM/street-Level imagery using ArcGIS tools. Based on knowledge of Virginia's bedrock geology, the 13 sites were assumed to give a good geologic representation. Out of the 13 sites, 8 are in Staunton District, 4 are in Lynchburg District, and 1 is in Salem District. The ratings are based on exponential scores of 3, 9, 29 and 81 for each parameter.

DEM data was downloaded and Hillshade maps were produced for each of the thirteen rock cut slopes. The outline of the slope was digitized as a polygon on the Hillshade map. Elevation, slope angle, and slope were calculated for each slope polygon. Parameters such as slope height were quantitatively measured in ArcGIS whereas other qualitative parameters such as differential erosion features were evaluated and scored by visually inspecting Mapillary and IVISION imagery.

Quantitative /Qualitative Measurements

On the slope polygon, the location of the midpoint of the slope was recorded from the ArcGIS pro project. Using the ruler tool in ArcGIS Pro, slope length, roadway width, and catchment ditch width were measured. Figure 8 shows an aerial photo and a Hillshade map of a rock cut slope along with a street-level Mapillary image.

Based on visual inspection of Mapillary and IVSION imagery, the effectiveness of catchment ditches, presence of slope drainage, rock friction, structural condition, presence of differential erosion, and estimation of differential erosion rates were estimated and scores assigned.

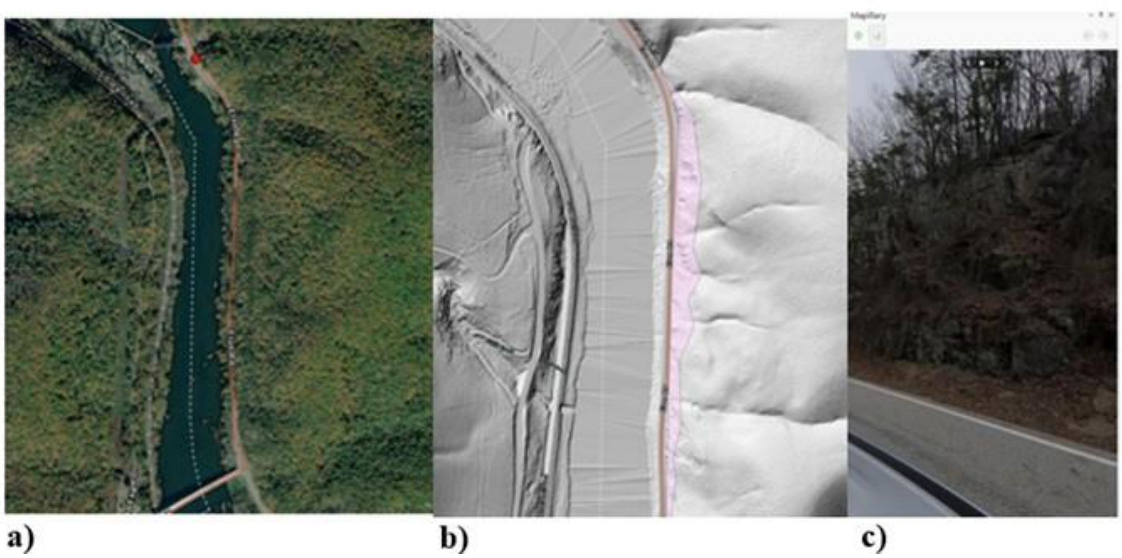


Figure 8. View of a Cut Slope: a) aerial photo; b) high resolution Hillshade showing outline of the same cut slope; and c) corresponding Mapillary image

A parameter that was indirectly estimated was the decision sight distance (DSD) measurement. DSD is the shortest distance that a 6-inch object can be visible from a driving position (3.5 ft from road surface). Using just GIS and street-level imagery, it is impossible to make the DSD measurement. To mimic the field DSD measurement, the shortest straight-line distance from the end of the slope cut (Shortest Straight Distance -SSD) was measured using the ruler tool in ArcGIS. The SSD measured by this method was much higher and no good correlation with DSD exists based on the data points used.

Field Verification of Rockfall Hazard Rating

Both quantitative measurements and qualitative scoring was collected by the Principal Investigator (PI), Yonathan Admassu in 2019-20 and again for this study in 2024-25 on just qualitative parameters at the 13 sites as detailed Appendix C. Slope length, roadway width, decision sight distance, and catchment ditch width, were measured with a measuring tape. Slope height measurement in the field was made using a laser range finder and transit compass. Using the laser range finder, the distance to the crest of the slope is obtained and the vertical angle is determined with a transit compass. The slope height is the sum of eye height of the evaluator and the vertical distance from the eye height to slope crest (Sine of vertical angle from eye height to slope crest * distance to slope crest). Additional field data collected by Dr. Brian Bruckno of VDOT in 2019 was used in this study. Dr. Bruckno's data is contained in Appendix D.

RESULTS AND DISCUSSION

Rock Cut Slope Inventory

A total of 20.6 miles of cut slopes, both rock and soil, adjacent to roadways have been located using the automated methods and are detailed in Table 3. Based on the visual identification of slopes on Hillshade maps the total mileage of cut slopes was 23.9 miles. Therefore, 86.2 % of rock/soil slope cuts were picked by the automated method. For cut slopes that are 25 ft high and above, all slopes (100%) were detected by the automated method. Out of 8.6 miles of rock cut slopes verified in the field, 8.2 miles (95.3 %) or 142 sites were identified using the automated methods (Table 3). These results are based on threshold values such as curvature < -20, or slope > 30 degrees, that are chosen by the PI through trial and errors. Other users may change threshold values in order to take specific area conditions into consideration. Visual inspection of the results is necessary to check if they are wrongly identified rock cut slopes or soil slopes.

Table 3 Summary of Rock Slope Inventory Data

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
Total	20.6 mi	23.9 mi	8.2 mi	142 Sites	8.6 mi

The cut slopes that were missed by the automated method are mostly shorter slopes of less than 10 ft high, or slopes located farther away from the roadway. Out of a total of 23.9 miles of cut slope, only 20.6 miles (86%) were identified by the Automated desktop method. There were no embankment slopes that were misidentified as cut slopes. Rock cut slopes were first identified by the use of surface roughness and later confirmed by visual inspection on Mapillary's street-level imagery. Automated method identified 95% of rock cut slopes, 8.2 miles out of 8.6 miles.

The use of DEMs and street-level imagery provided great tools for performing inventory of slope cuts. The time needed to automatically generate cut slopes and visual verification on the Hillshade map for the study routes 211, 220, and 259 was approximately 2 hours. On average, it required 1–2 minutes to determine whether a slope consisted of rock or soil, followed by an additional 5–10 minutes to classify the type of rock slope failure using a Mapillary image. The total time to pick all cut slopes (23.9 miles) and identify 8.2 miles of rock cut slope consisting of 142 sites was 25.6 hours so it took about 10.8 minutes per rock slope site.

The estimated time of performing field-based inventory at each site is around 30 minutes and the average round trip from Harrisonburg, VA (the base location for this study) was 3 hours. Based on an 8-hour workday, it will take around 15 days to complete the inventory of 142 sites, which translates to 51 minutes per site.

Rockfall Hazard Rating

The result of direct measurements of quantitative values/scores and semi-quantitative parameters using high resolution DEMs and visual descriptions using Mapillary and IVISION are summarized in Table 4.

Comparing the quantitative data (route width, slope length, slope height) collected on the desktop versus data collected in the field shows large differences especially for slope length and slope height (8ft to 1100ft for slope length, and 4ft to 80ft for slope height) as shown in Table 5. The differences for slope lengths are due to not having the same start and end point while measuring. The difference in slope height measurements done in the field is impacted by the surveyor's limited vertical field of view from road. The desktop measurements of route width, slope length, and slope height, using DEMs / aerial photography is more accurate as it is based on high resolution DEMs and aerial imagery that clearly show the dimension of a given slope.

Qualitative parameters such as catchment ditch effectiveness and geologic characteristics are subjective to the surveyor's experience and judgement and can lead to variable scores. Therefore, field collected data for qualitative parameters were compared among the three sources as shown by bar graphs as shown in Figures 9 through 13.

There is agreement for qualitative assessment between DEM/Mapillary street-level imagery-derived rating scores and both PI's field data and VDOT's field data, as indicated in Table 6. For example, the catchment ditch effectiveness rating was similar for 10 of the 13 sites.

However, VDOT's scores appeared very different for 8 sites especially for rock friction and differential erosion characterization; only 5 of the site's ratings were similar. Rock friction values for sites 4, 5, and 13 showed a significant variation which could be due to differences in evaluator's description of rock friction characteristics. Another notable variation was in characterizing differential erosion rates. Descriptions used for all rockfall hazard rating systems including the USMP method, should be accompanied by pictorial representation of all geological characteristics to make rockfall hazard rating reproducible.

Table 4. Summary of Qualitative/Semi-Quantitative Measurements for USMP-Based Rockfall Hazard Rating

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

Table 5. Comparison of Linear Measurement from Field

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	60	90	60
Site 9	2465	1021	24	23	46	101	90	70
Site 10	522	860	21	20	91	160	90	65
Site 11	191	1094	25	21	29	65	90	70
Site 12	3190	934	26	24	156	131	90	65
Site 13	1252	1200	20	26	25	33	90	60

Table 6. Number of Sites Rated Similar between the DEM/Street-level Imagery Method and Field

Parameter	Number of Sites with Similar Rating	
	Measured by PI	Measured by VDOT Personnel
Catchment Ditch Effectiveness	10	8
Structural Condition	8	6
Rock Friction	10	5
Differential Erosion Features	8	5
Differential Erosion Rates	9	5

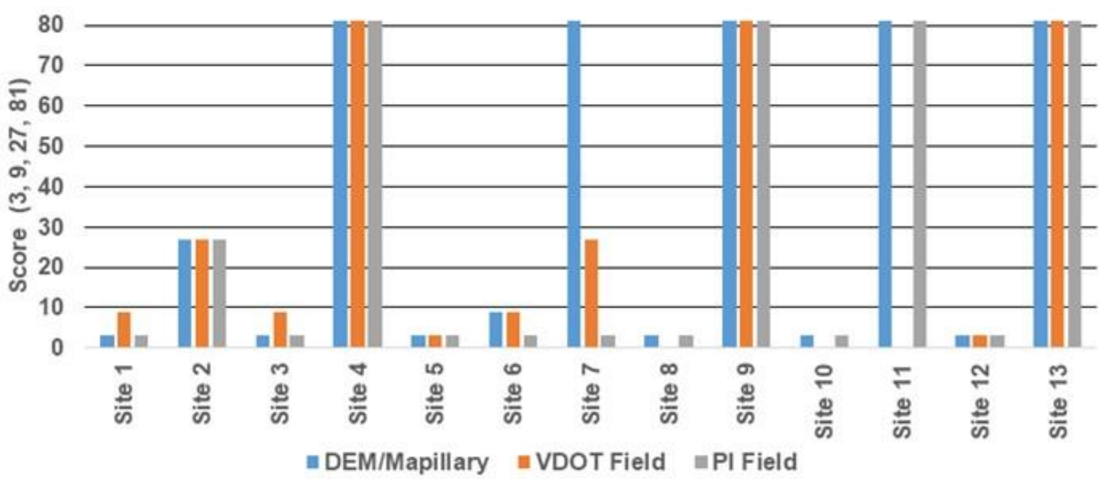


Figure 9. Comparison of 'Catchment Ditch Effectiveness' Scores

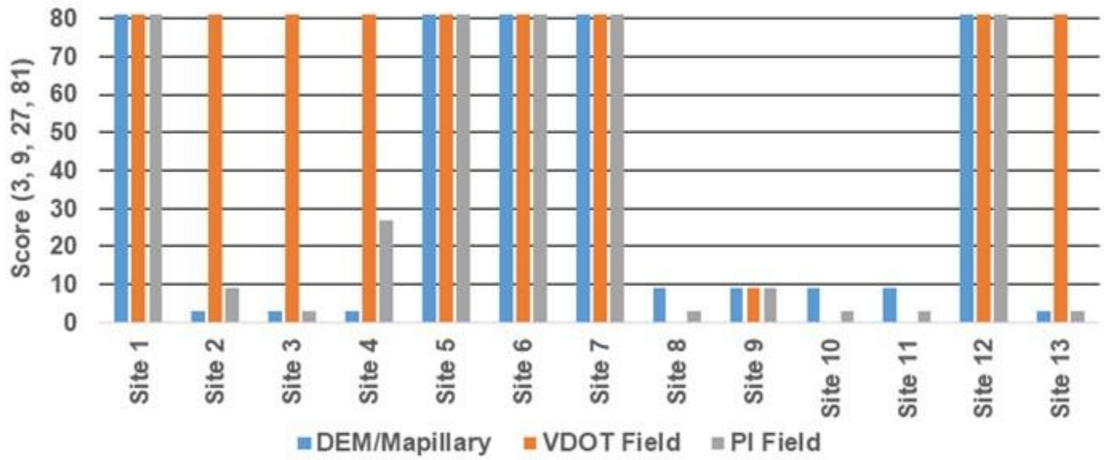


Figure 10. Comparison of 'Structural Condition' Scores

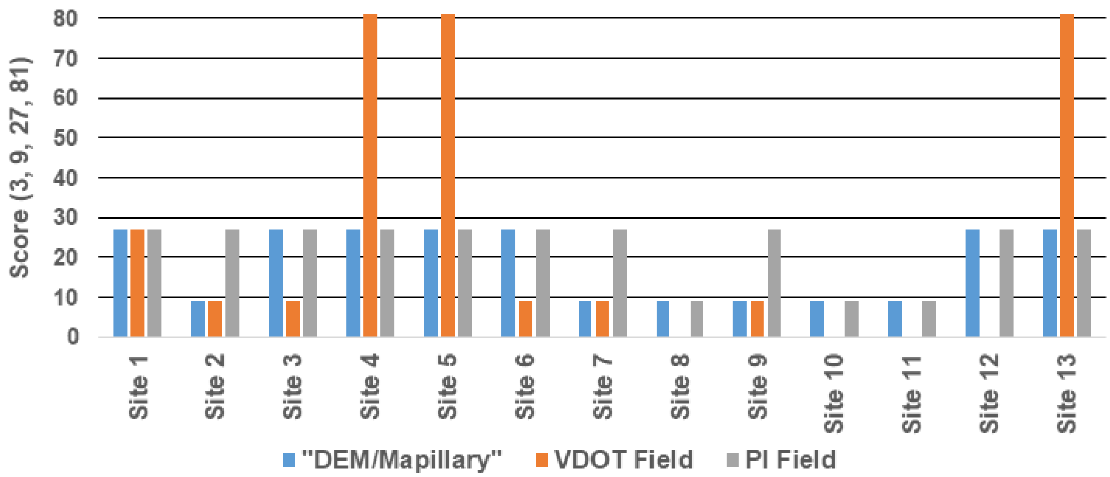


Figure 11. Comparison of 'Rock Friction' Scores

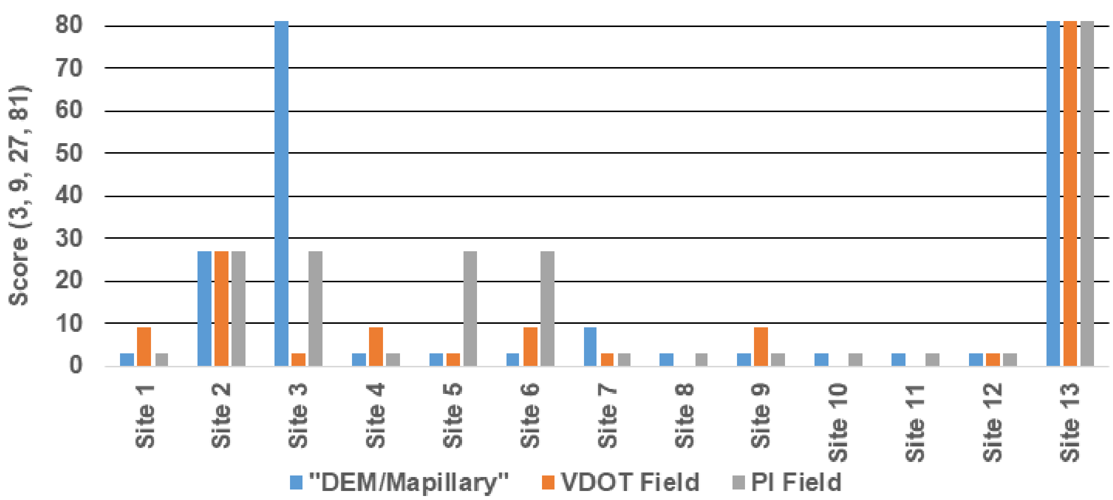


Figure 12. Comparison of 'Differential Erosion Features' Scores

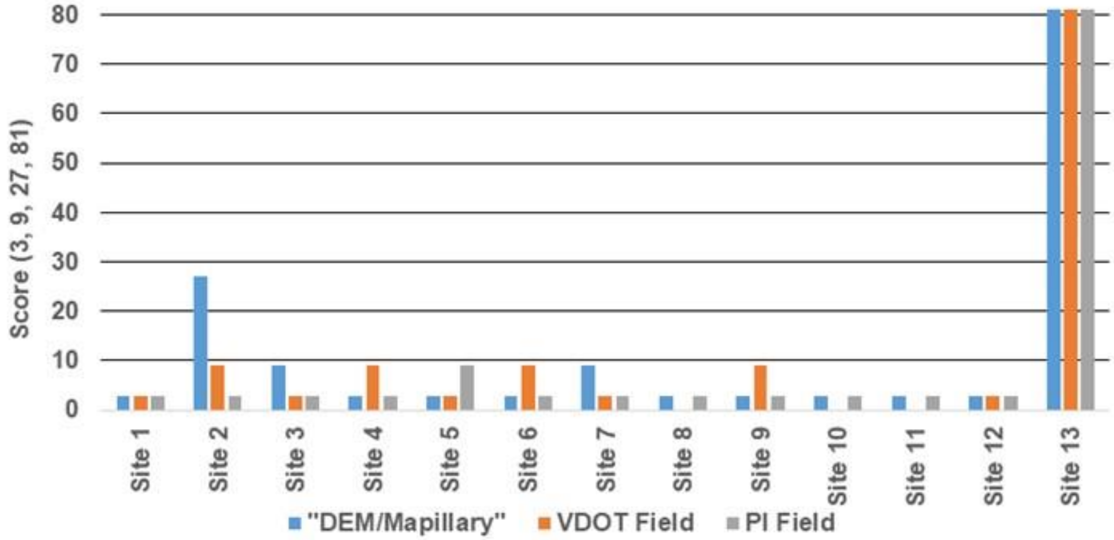


Figure 13. Comparison of 'Differential Erosion Rates' Scores

Most quantitative parameters such as slope height, slope angle, and route width are more accurately measured with ArcGIS tools. However, there is no good way of estimating DSD using DEMs/street-level imagery or aerial imagery. The SSD, although not the same as DSD, can be a good measure of how much distance there is for a driver to make veer away from a fallen rock. The SSD value is adjusted based on the posted speed limit as % SSD calculated as follows with details listed in Table 7:

% SSD = (Measured SSD/AASHTO Recommended Speed Limit) *100

Table 7. AASHTO Recommended DSD Based on Speed Limit

Speed Limit	Recommended DSD (ft)
25	375
30	450
35	525
40	600
45	675
50	750

The time required to make USMP-RHRS evaluations on the desktop took approximately 45 minutes per site totaling 9.8 hours. If 8-hour workday is considered, it will be 10.6 sites per day. On the other hand, field data collection took 2-3 hours per site. Considering the travel time of 3 hours, it took 6.5 days (8-hour workday) to collect data from the 13 sites at a rate of 2 sites per day which equates to 4-hours per site.

The remaining data required to complete the USMP rating such as rainfall, human exposure factor, rockfall history, maintenance complexity, and event cost are obtained VDOT archives and personnel. Annual rainfall can be obtained from NOAA dataset.

Based on the results and experiences gained through this study, it is more efficient to design a three-tiered rockfall hazard evaluation that involves automated cut slope identification and visual inspection of street-level imagery.

I. A ‘preliminary rating’ for rock cut slopes with a height greater than 50 ft and a length of 60 ft or more based on automated slope identification. The preliminary rating will include catchment ditch effectiveness, block size/volume, slope drainage, and geologic character on street-level imagery. Geologic character will include the parameters of structural condition, rock friction, differential erosion features, and differential erosion rates as shown in Table 8. Catchment ditch effectiveness and geologic character ratings should be standardized, and photographic examples should be provided. Each of these parameters will be rated and scored.

II. Rock cut slopes with greater than 18 preliminary rating points (three parameters rated at 3 points and two parameters rated at 9 points) will advance to the ‘detailed hazard rating’ phase as detailed in Table 9. Detailed ratings will include determining rockfall related maintenance frequency, rockfall history, AADT, and annual rainfall.

III. Rock cut slopes with scores greater than 18 ‘detailed hazard rating’ (three parameters scored 3 each and one parameter scored 9) will be further selected for ‘rockfall risk rating’ based on route width, human exposure factor, % shortest straight distance (% SSD), right of way, environmental/cultural impacts if left unattended, maintenance complexity, and event cost as detailed in Table 10.

Table 8. USMP-Based Preliminary Rockfall Hazard Rating

Score	3	9	27	81
Catchment Ditch Effectiveness	Good	Moderate	Limited	No Catchment
Block Size/Volume	1 ft^3/ yd^3	2 ft^3/6 yd^3	3 ft^3/9 yd^3	4 ft^3/12 yd^3
Slope Drainage	Slope appears dry or well drained, surface runoff well controlled	Intermittent water on slope, moderately well drained, surface runoff moderately controlled	Water usually on slope, poorly drained, surface runoff poorly controlled	Water always on slope, very poorly drained, surface runoff control not present
Structural Condition	Favorable	Random	Adverse Discontinuous	Adverse continuous
Rock Friction	Rough/Irregular	Undulating	Planar	Clay-infilled/Slickensides
Differential Erosion Features	Few differential erosion features	Occasional differential erosion features	Many differential erosion features	Major differential erosion features
Differential Erosion Rates	Small difference	Small difference	Small difference	Small difference

Table 9. USMP-Based Detailed Rockfall Hazard Rating

Score	3	9	27	81
Rockfall related maintenance	Normal, scheduled maintenance	Patrols after every storm event	Routine seasonal patrols	Year-round patrols
Rockfall history	Few falls	Occasional falls	Many falls	Constant falls
AADT	50	200	450	800
Annual rainfall	0-10"	10-30"	30-60"	<60"

Table 10. USMP-Based Detailed Rockfall Risk Rating

Score	3	9	27	81
Route width	36ft	28ft	20ft	12ft
Human exposure factor	12.5%	25%	37.5%	50%
% Shortest straight distance	100 %	80%	60%	40%
Right of way	No R/W implications	Minor effects beyond R/W	Private property, no structures affected	Structures, roads, RR utilities, or parks affected
Environmental / cultural impacts if left unattended	None / No potential to cause effects	Likely to affect / No historical property affected	Likely to adversely affect / Finding of no adverse effect	Current adverse effects / Adverse effect
Maintenance complexity	Routine effort / In-house	In-house maintenance / Special project	Specialized equipment / contract	Complex / Dangerous effort / Location / Contract
Event cost	$0-2k	$2-25k	$25-100k	> 100k

Future Research Needs

In addition to the traditional slope rating system, the feasibility of timely digital monitoring, such as terrestrial or drone LiDAR, of the most problematic cut slopes should be explored. This would create a dataset that can be used for change detection analysis to determine the performance of a given rock cut slope over time. Permanent control points must be set if LiDAR scanning is used. This will allow accurate coordination. Another attractive method that should be explored is using object detection models to identify hazard indicators such as overhangs and the presence of accumulated rockfall debris.

CONCLUSIONS

- *The use of high resolution (i.e. 1m×1m) DEM in conjunction with street-level imagery is an efficient tool to collect data for rock cut slope inventory.* For a roadway covering 23.9 miles of cut slope, the accuracy of identifying all soil or rock cut slope was 86%, whereas for slopes of 25 ft or higher, which are considered to be critical (VDOT, 2024), the accuracy was 100 %. For rock cut slopes, 95% were identified. The DEM/street-level imagery method needed an average of 10.8 minutes per site whereas the field-based method required an average of 51 minutes per site.

- *The use of DEM/street level imagery method for collecting data for USMP based geometric/geologic rockfall hazard rating also showed great promise in terms of accuracy, time savings and employee safety.* Compared to field collection by the PI, data collected by the DEM/street-level imagery method showed identical rockfall ratings more than two-thirds of the time. There were 13 sites and 5 rockfall rating parameters that could be measured at each site. For 45 of the 65 site-parameter combinations, field collection by the PI and DEM/street-level imagery method gave the same result. Only 2.0 sites per day could be studied using field data collection, compared to 10.6 sites per day using the DEM/ street - level imagery method. Whereas field data collection exposes the surveyor to traffic, this risk is eliminated by the DEM/ street-level imagery method.

- *While the use of DEM/street level imagery saves time, development and modification of the initial workflow requires roughly 6-8 hours by an analyst who has some familiarity with the workflow*. Although most of these hours are a one-time investment in creating the workflow, a few additional hours are required to understand the workflow well enough to make changes which may become necessary as new data become available, or GIS software evolves. Such maintenance requires a moderate level of familiarity with the ArcGIS software.

RECOMMENDATIONS

1. *If VDOT decides to implement an Unstable Slope Management Program (USMP), then VDOT Materials Division, with assistance from VTRC, should consider the DEM/street-level imagery method as one of the desktop or remote sensing methods to create an inventory of cut slopes higher than 25 feet.*

2. *If VDOT decides to implement USMP, then VDOT Materials Division and VTRC should determine the feasibility of using the DEM/street-level imagery method to perform a rockfall hazard rating within the USMP framework.*

3. *If VDOT decides to implement USMP, then VDOT Materials Division, Districts, and VTRC should consider training select VDOT personnel on how to use DEM/street level imagery method to prepare slope inventory and assess rockfall hazard*.

IMPLEMENTATION AND BENEFITS

Researchers and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and to determine the benefits of doing so. This process is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

The implementation of this project's recommendations is contingent on VDOT's decision to establish a USMP system as currently VDOT does not have any such (well defined and/or structured) system in place either on district or statewide level. VDOT's materials division is currently assessing the feasibility, through a separate feasibility study, of establishing a USMP as part of the department's resiliency effort. If the decision is made to establish a USMP, either on a full scale or pilot basis, a working group will be set up involving various stakeholders to oversee the implementation of the system. The data collection system, as outlined in this study, will be reviewed by the group for implementation and incorporation into the USMP system after reviewing all other viable options. Because two dates--the specific time frame of deciding the establishment of USMP and the subsequent decision by the working group on which data collection methods will be allowed--are unknown, the date of implementation of these recommendations are unknown.

If the USMP is established, if the working group allows this desktop method as a tool, and if sufficient funding can be obtained, then VDOT Materials Division and VTRC will complete these recommendations within 24 months of such decision as follows.

- *With regard to Recommendation 1 and Recommendation 2*, VDOT Materials Division will evaluate the DEM/street-level imagery method as a viable option for USMP when a decision about establishing a centralized USMP (full scale or pilot) is taken. This research showed the DEM/street-level imagery method is feasible but did not compare its efficiency with that of other remote sensing methods, and thus VDOT Materials Division will consider it alongside other methods at the appropriate time.

- *With regard to Recommendation 3*, the PI of this study will provide the necessary training to VDOT personnel on use of DEM/street level imagery method for slope inventory and USMP evaluation as arranged by VDOT and JMU. VDOT Materials Division, VTRC and respective districts will provide logistical support as resources become available. Such training will consider some of the slopes selected for the USMP pilot project and may be slopes on selected roadways in Staunton, Salem and Lynchburg districts, where most rock cut slopes in Virginia can be found. Either vehicle-mounted 360º cameras or available Mapillary data will be used as street level imagery. During the training, a subset of the cut slopes will be considered to conduct preliminary and detailed rockfall hazard rating analysis. The preliminary rating will apply to rock cut slopes with greater than 50 ft height and greater than 60 ft length and will be based on the parameters shown in Table 8. The detailed hazard rating will be based on the criteria in Tables 9 and 10, with the use of SSD (in lieu of DSD).

Benefits

The benefit of using DEM/street-level imagery for rock cut slope inventory and USMP-based rockfall hazard rating system can be quantified in terms of saving time and money in addition to avoiding safety issues associated with field-based assessments.

The average time rate of conducting rock cut slope inventory was 10.8 minutes/site using DEM/street-level imagery, whereas field-based inventory was 51 minutes/site. Field visits to the 142 sites would have required 15 days at a cost of $7,800, based on $ 520 per day for wages for two staff. In addition to wages, the driving cost would have been $1491 (based on $0.71/mile for 2100 miles or 140 miles per day) to visit the 142 sites. Therefore, the total cost (wage + travel cost) to perform cut slope inventory data in the field is $9,291. However, using DEM/street-level imagery would cost $1,280 in wages (at $50/hour for 25.6 hours) for the same 142 rock cut slopes sites. The top half of Table 11 summarizes these costs for the 142 sites.

For preparing an inventory of rock cut slopes for a section of roadway consisting of 23.9 miles of cut slope, the cost savings were $8,011 ($9,291 minus $1,280) for the desktop method over field visits. If VDOT has a total of 1200 miles of rock cut slope, the cost saving will be approximately $400,000 in addition to safety benefits. Additional savings will be in the hazard rating work. It is important to note this cost does not include other factors required in a geotechnical asset management program such as management of traffic, data storage and management expenses.

Table 11. Cost-Benefit Summary of DEM/Street-level Imagery and Field Method

Tasks	No of Sites	Method	Total Time (days)[a]	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

[a] 8-hour workday. DEM = digital elevation model; USMP = unstable slope management program; RHRS = rockfall hazard rating system.

For the USMP based rockfall hazard rating system (RHRS) data collection, there were 13 sites that required 6.5 days of effort. The total wage costs are $3,380 (i.e. $520 per day multiplied by 6.5 days). The driving costs are $646 (based on $0.71/mile for 910 miles or 140 miles per day) for all 13 sites. Total estimated cost for field rating is $3,380 + $646 = $4,026, which is $310 per site. By contrast, for DEM/street-level imagery, the time required was 9.75 hours which, at $50 per hour, would be a cost of $487.50 for all 13 sites or $37.50 for a single site. The bottom half of Table 11 summarizes the cost for hazard rating.

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Appendix A. Rock cut slope inventory data collection methodology

Data Preparation

1) Download DEM from Opentopography.
2) Buffer roadway at 10 m and 30 m. *Tool: Buffer, Output:Buffer_10m.shp, Buffer_30m.shp*
3) Clip DEM within the buffer. *Tool: Extract By Mask, Output:DEM_30m.tif*

Raster Operations - Calculate Values and Clip within Buffer

4) Calculate Slope and clip within the 30 m roadway buffer. *Tools: Slope ; Extract By Mask, Output:Slope1.tif*
5) Calculate Curvature and clip within the 30 m. *Tools: Curvature ; Extract By Mask, Output:Curvature1.tif*
6) Calculate Aspect. *Tools: Aspect ; Extract By Mask, Output:Aspect1.tif*
7) Calculate Standard Deviation within a 3X3 window and Clip. *Tool: Focal Statistics ; Extract By Mask, Output:Std_Dev1.tif*
8) Smooth Slope data to reduce noise by averaging values within a moving 5X5 window and clip within 30m buffer. *Tool: Focal Statistics ; Extract By Mask, Output:Slope2.tif*
9) Smooth Aspect data to reduce noise by averaging values within a moving 10X10 window and clip within 30m buffer. *Tool: Focal Statistics ; Extract By Mask, Output:Aspect2.tif*

Raster Operations - Reclassify Raster

10) Separate slopes from *Slope2.tif* with > 30 degrees slope. *Tool: Reclassify, Output:Slope3.tif*
11) Separate curvature values < - 20 from *Curvature1.tif.* Tool: Reclassify, *Output:Curvature2.tif*
12) Separate from *Std_Dev1.tif* values with > 1 value. Tool: Reclassify, *Output: Std_Dev2.tif*
13) Separate aspect from *Aspect1.tif* into 4 classes, NE (0-90), SE (91-180), SW (181-269), NW (270-359). Tool: Reclassify, *Output: Aspect2.tif*

Vector Operations I - Convert Raster to Features

14) Convert *DEM_30m.tif* to point features. Tool: Raster to Point, *Output: Elevation.shp*
15) Convert *Slope3.tif* to polygon features and (separate gridcode values for > 30 degrees). Tool: Raster to Polygon, *Output: Slope3.shp*
16) Convert *Slope2.tif* to point features. Tool: Raster to Polygon, *Output: SlopePoint.shp*
17) Convert *Curvature2.tif* to point features (separate gridcode values for < -20). Tool: Raster to Point, *Output: Curvature2.shp*
18) Select *Curvature2.shp* points within the 10m buffer, Tool Select By Attribute, *Output Curvature3.shp*

19) Convert *Std_Dev2.tif* to polygon features (separate gridcode values for > 1). Tool: Raster to Polygon, *Output: Std_Dev2.shp*

Separate Slopes by Unique Aspect

20) Clip *Aspect3.tif* by *Slope3.shp.* Tool: Extract by Mask, Output Aspect3.tif
21) Convert Aspect4.tif to polygon feature. Tool: Raster to Polygon, *Output: Slope4.shp*
22) Remove small polygons by size to reduce noise. Tool: Select by Attributes

Select slopes that are cut slopes (filter out embankment slopes)

23) Incorporate *Curvature3.shp* features that are within 3m of *Slope4.shp.* Tool: Summarize Nearby, *Output: Slope 5.shp*
24) Calculate number of points per length of slope and select polygons that have > 0.1 points/polygon length. Tool: Add Field and add formula (curvature points count/length), Select By Attribute, *Output: Slope 6.shp*

Select slopes that are rock cut slopes (filter out soil slopes)

25) Select Slope6.shp features that intersect *Std_Dev2.shp* features. Tool: Select by Attributes, Output: Slope7.shp
26) Visually verify identified slopes to remove spurious polygons.

Incorporate Spatial and Geometric Data into Rock Cut Slope Features

27) Incorporate maximum/minimum elevation values from *Elevation.shp* , average slope values from *SlopePoint.shp* into Slope7.shp. Tool: Summarize Within. *Output:Summarized_Slope7.shp*
28) Calculate longest axis of Summarized_Slope7.shp using the longest axis of a bounding rectangle. Tool: Minimum Bounding Geometry, *Output:MBGeometry.shp*
29) Join outputs from steps 30 and 31 create the final geodatabase.

Appendix B. Rock Cut Slope Inventory

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
Rt_211-11	SW	28.2	559.9	34.4	38.66439	-78.3737
Rt_211-12	SW	29.7	574.1	46.3	38.65949	-78.3295
Rt_211-13	SW	29.1	128.6	19.8	38.65944	-78.3676
Rt_211-14	SE	31.3	128.6	23.2	38.65943	-78.3678
Rt_211-15	SW	26.9	128.6	28.2	38.65932	-78.3683
Rt_211-16	SW	29.3	106.8	16.2	38.64929	-78.6637
Rt_211-17	SE	25.6	106.8	16.8	38.64922	-78.6636
Rt_211-18	NW	27.7	159.6	19.6	38.64641	-78.5339
Rt_211-19	SW	26.9	159.6	20.3	38.64624	-78.534
Rt_211-20	SW	29.3	433.0	48.2	38.64419	-78.5944
Rt_211-21	SE	29.7	484.7	50.0	38.64428	-78.5967
Rt_211-22	SE	36.4	132.9	34.2	38.6425	-78.556
Rt_211-23	SE	37.3	87.7	28.9	38.64246	-78.5564
Rt_211-24	SW	31.0	132.9	36.1	38.64243	-78.5566
Rt_211-25	SE	25.3	94.4	16.1	38.64412	-78.642
Rt_211-26	NW	30.3	704.5	55.9	38.64244	-78.5534
Rt_211-27	NW	28.1	542.8	29.1	38.6454	-78.7058
Rt_211-28	SW	34.6	460.0	46.6	38.64316	-78.612
Rt_211-29	SE	33.4	460.0	132.6	38.64433	-78.61
Rt_211-30	NW	31.7	574.4	58.3	38.64253	-78.6149
Rt_211-31	SE	29.1	191.3	35.3	38.64151	-78.5897
Rt_211-32	SW	36.0	103.0	46.0	38.64152	-78.6181
Rt_211-33	SE	33.6	103.0	40.5	38.6415	-78.618
Rt_211-34	NW	32.6	103.0	57.6	38.64148	-78.6184
Rt_211-35	SE	26.7	465.7	45.8	38.63986	-78.6066
Rt_211-36	SE	32.6	563.4	83.0	38.63924	-78.6091
Rt_211-37	SE	26.9	261.9	23.5	38.63753	-78.5681
Rt_211-38	SE	32.8	510.1	44.0	38.63376	-78.5777
Rt_211-39	SW	34.3	154.8	44.0	38.63365	-78.5765
Rt_211-40	SE	33.0	154.8	44.9	38.63361	-78.5764
Rt_211-41	SW	35.2	232.8	47.4	38.63353	-78.5757
Rt_211-42	SE	29.9	331.1	28.6	38.63342	-78.5751

Slope Id	Slope Aspect	Average Slope (Deg)	Slope Length (ft)	Slope Height(ft)	Centroid Latitude	Centroid Longitude
Rt_259-1	NW	34.4	371.7	59.9	38.77097	-78.9065
Rt_259-2	SW	33.1	522.6	57.0	38.73173	-78.9163
Rt_259-3	SW	34.0	282.3	50.7	38.73073	-78.916
Rt_259-4	NW	29.4	170.2	25.8	38.72334	-78.918
Rt_259-5	SW	24.2	169.9	16.2	38.72302	-78.9181
Rt_259-6	SE	23.9	93.8	15.1	38.699	-78.9184
Rt_259-7	NW	24.7	131.5	15.7	38.69885	-78.9187
Rt_259-8	SW	36.6	108.2	51.7	38.68158	-78.9266
Rt_259-9	SW	36.8	100.3	28.1	38.68143	-78.9268
Rt_259-10	SW	35.5	367.5	40.4	38.6809	-78.9271
Rt_259-11	SW	30.8	172.3	24.2	38.68021	-78.9274
Rt_259-12	SW	33.3	551.9	29.3	38.67927	-78.9278
Rt_259-13	SW	34.7	351.4	36.1	38.67755	-78.9284
Rt_259-14	NW	38.2	2042.0	88.4	38.67893	-78.9278
Rt_259-15	SW	33.5	118.7	51.2	38.67633	-78.9288
Rt_259-16	NW	38.9	170.6	52.1	38.67608	-78.9288
Rt_259-17	NW	36.7	219.5	50.7	38.67556	-78.929
Rt_259-18	NW	35.6	97.7	40.8	38.67509	-78.929
Rt_259-19	SW	31.1	1272.7	51.7	38.67406	-78.9288
Rt_259_20	SW	26.0	241.8	22.3	38.65922	-78.9032
Rt_259_21	SW	26.0	241.8	22.3	38.65922	-78.9032
Rt_259_22	NE	23.4	107.0	13.7	38.65897	-78.903
Rt_259_23	SW	28.9	326.1	31.0	38.65631	-78.8976
Rt_259_24	SW	23.7	147.9	17.1	38.65565	-78.8965
Rt_259_25	SW	24.9	112.6	18.8	38.6554	-78.8961
Rt_259_26	SW	24.8	171.4	17.0	38.65457	-78.8948
Rt_259_27	SW	26.2	444.0	21.0	38.65378	-78.8938
Rt_259_28	SW	32.2	755.8	55.4	38.65334	-78.8927
Rt_259_29	SW	29.8	1074.8	118.8	38.65276	-78.8913
Rt_259_30	SW	25.2	94.0	18.9	38.65144	-78.8907
Rt_259_31	SW	30.6	1064.5	59.5	38.64893	-78.8888
Rt_259_32	SE	23.6	125.3	14.6	38.64542	-78.8717
Rt_259_33	SW	29.3	215.1	44.3	38.64519	-78.8649
Rt_259_34	SW	29.1	451.0	35.3	38.64441	-78.8856
Rt_259_35	SE	29.0	176.9	22.1	38.64418	-78.885
Rt_259_36	SE	30.0	459.7	42.0	38.64416	-78.8789
Rt_259_37	SE	25.3	265.5	18.5	38.64404	-78.8839
Rt_259_38	SW	25.7	160.0	19.4	38.64398	-78.8816
Rt_259_39	SW	37.8	1373.5	229.9	38.64385	-78.8625
Rt_259_40	SW	24.2	190.4	18.6	38.64102	-78.8589
Rt_259_41	SW	25.1	271.4	22.0	38.63897	-78.8549
Rt_259_42	NE	23.3	126.5	15.2	38.63634	-78.8505
Rt_259_43	SW	25.4	109.1	19.2	38.63301	-78.8427
Rt_259_44	SE	28.9	137.3	33.2	38.63187	-78.8389
Rt_259_45	NE	29.6	365.2	33.0	38.63177	-78.8384
Rt_259_46	SW	27.7	65.8	21.7	38.63162	-78.8373

Slope Id	Slope Aspect	Average Slope (Deg)	Slope Length (ft)	Slope Height(ft)	Centroid Latitude	Centroid Longitude
Rt 220-1	SE	26.5	130.8	22.6	38.23502	-79.69651
Rt 220-2	SE	24.6	99.1	16.8	38.22853	-79.70041
Rt 220-3	SE	27.5	477.3	50.0	38.22108	-79.70748
Rt 220-4	SW	23.3	148.1	17.5	38.21725	-79.71075
Rt 220-5	SE	27.6	586.1	40.1	38.21746	-79.71078
Rt 220-6	SE	25.6	270.9	23.2	38.21308	-79.71555
Rt 220-7	SE	25.3	216.6	23.7	38.20119	-79.72812
Rt 220-8	SE	29.7	356.6	39.2	38.1902	-79.7336
Rt 220-9	SE	26.7	196.5	22.6	38.18913	-79.73394
Rt 220-10	NE	31.2	142.2	28.8	38.18771	-79.73424
Rt 220-11	SE	30.7	108.0	17.8	38.18642	-79.7335
Rt 220-12	NE	30.1	443.3	26.7	38.18659	-79.73368
Rt 220-13	SE	28.1	168.0	21.4	38.18611	-79.73333
Rt 220-14	NW	27.4	543.3	36.9	38.17757	-79.7354
Rt 220-15	NW	32.5	280.0	53.2	38.17377	-79.73907
Rt 220-16	SW	29.8	439.4	51.6	38.17314	-79.7391
Rt 220-17	NE	25.9	244.3	27.7	38.17081	-79.73819
Rt 220-18	NE	26.3	93.0	19.3	38.17062	-79.73774
Rt 220-19	SE	28.9	78.2	28.4	38.17055	-79.73756
Rt 220-20	NE	29.5	109.6	27.0	38.17046	-79.73738
Rt 220-21	NE	32.2	636.8	43.0	38.16856	-79.73583
Rt 220-22	NE	25.2	141.0	22.3	38.16751	-79.73431
Rt 220-23	SW	27.2	131.1	20.5	38.1657	-79.7336
Rt 220-24	SE	33.5	439.1	80.0	38.16561	-79.73387
Rt 220-25	NE	32.1	81.8	28.4	38.16493	-79.734
Rt 220-26	SE	30.7	941.3	81.0	38.16375	-79.73446
Rt 220-27	NE	34.3	118.3	45.5	38.16147	-79.73556
Rt 220-28	SE	32.4	482.7	63.3	38.16104	-79.73563
Rt 220-29	SE	31.9	452.4	57.5	38.15873	-79.73639
Rt 220-30	SE	28.7	186.0	20.5	38.15682	-79.7369
Rt 220-31	SE	26.5	482.2	48.4	38.15249	-79.73807
Rt 220-32	SE	29.1	359.6	62.2	38.15019	-79.73993
Rt 220-33	SE	27.8	242.0	33.0	38.14814	-79.74159
Rt 220-34	NE	34.7	177.6	68.9	38.14615	-79.7423
Rt 220-35	SE	32.5	113.1	56.5	38.14597	-79.74229
Rt 220-36	SE	31.9	127.6	52.7	38.14502	-79.74137
Rt 220-37	NE	33.2	267.5	50.1	38.1448	-79.74121
Rt 220-38	SE	28.9	254.7	33.4	38.14469	-79.74112
Rt 220-39	SE	26.5	431.6	37.4	38.1434	-79.74121
Rt 220-40	SW	25.9	103.2	17.1	38.14275	-79.74113
Rt 220-41	SW	28.7	148.6	15.8	38.14255	-79.74119
Rt 220-42	NW	29.0	295.3	26.4	38.14234	-79.74119
Rt 220-43	NW	30.4	166.1	30.2	38.14154	-79.74132
Rt 220-44	SW	29.8	167.3	31.2	38.14131	-79.74139
Rt 220-45	NW	31.2	89.9	32.0	38.14108	-79.74141

Slope Id	Slope Aspect	Average Slope (Deg)	Slope Length (ft)	Slope Height(ft)	Centroid Latitude	Centroid Longitude
Rt 220-46	SW	28.3	116.4	28.4	38.14093	-79.74148
Rt 220-47	NW	28.7	667.7	69.9	38.13912	-79.74352
Rt 220-48	NW	29.3	402.1	48.0	38.13751	-79.7459
Rt 220-49	NW	25.6	406.5	21.6	38.13547	-79.74815
Rt 220-50	NW	27.0	154.9	24.7	38.13454	-79.7487
Rt 220-51	NW	28.9	296.4	26.0	38.13272	-79.74894
Rt 220-52	SW	27.1	417.2	29.5	38.13269	-79.74895
Rt 220-53	NW	26.9	286.8	26.5	38.12512	-79.75144
Rt 220-54	NW	30.4	170.3	38.8	38.11956	-79.75483
Rt 220-55	NW	27.1	258.2	33.2	38.11173	-79.76321
Rt 220-56	NW	26.5	295.5	28.9	38.11031	-79.76485
Rt 220-57	NW	26.4	599.7	52.3	38.10853	-79.76628
Rt 220-58	NW	28.2	690.9	64.7	38.10715	-79.76764
Rt 220-59	NW	30.1	189.1	32.7	38.10576	-79.76862
Rt 220-60	NW	30.2	435.7	40.8	38.10004	-79.77413
Rt 220-61	NE	24.5	116.3	17.9	38.08413	-79.78653
Rt 220-62	NE	25.8	343.1	36.4	38.08381	-79.78586
Rt 220-63	SW	24.8	468.3	31.4	38.07899	-79.78293
Rt 220-64	SW	27.7	611.8	45.2	38.07648	-79.77961
Rt 220-65	SW	31.7	270.1	51.6	38.07583	-79.77836
Rt 220-66	SW	30.9	539.8	66.5	38.07485	-79.77707
Rt 220-67	SW	26.0	107.7	19.2	38.07302	-79.77468
Rt 220-68	NE	33.7	526.5	58.6	38.07313	-79.77529
Rt 220-69	NW	31.7	370.2	38.8	38.05792	-79.77714
Rt 220-70	NW	35.5	562.4	81.8	38.05637	-79.77767
Rt 220-71	SW	23.7	138.7	19.6	38.04909	-79.78528
Rt 220-72	NW	24.7	205.2	19.0	38.04877	-79.78556
Rt 220-73	NW	27.4	126.5	22.5	38.04408	-79.78821
Rt 220-74	SW	27.1	146.2	20.1	38.04391	-79.78824
Rt 220-75	SW	26.4	233.3	23.1	38.04321	-79.78775
Rt 220-76	NW	29.0	314.9	39.4	38.03898	-79.78935
Rt 220-77	NW	28.6	334.2	32.8	38.03765	-79.79172
Rt 220-78	NW	25.2	241.0	20.2	38.03059	-79.80066
Rt 220-79	NW	29.2	197.8	26.8	38.02332	-79.8049
Rt 220-80	SW	27.5	103.3	16.0	38.02112	-79.80585
Rt 220-81	NW	26.2	228.6	19.4	38.02107	-79.80583
Rt 220-82	NW	27.1	311.8	20.7	38.02032	-79.80616
Rt 220-83	SE	23.9	166.5	19.2	38.01854	-79.80689
Rt 220-84	SW	23.6	98.0	14.1	38.01667	-79.80836
Rt 220-85	SW	25.9	263.4	19.9	38.01594	-79.80808
Rt 220-86	SE	27.0	211.2	26.1	37.99971	-79.82863
Rt 220-87	SE	31.3	364.6	37.2	37.99915	-79.82959
Rt 220-88	SW	29.0	411.5	36.0	37.99904	-79.83018
Rt 220-89	NE	31.3	510.7	47.9	37.99773	-79.83256
Rt 220-90	SE	23.9	97.1	14.4	37.9944	-79.83239
Rt 220-91	SE	24.3	106.3	15.3	37.97222	-79.85063

Slope Id	Slope Aspect	Average Slope (Deg)	Slope Length (ft)	Slope Height(ft)	Centroid Latitude	Centroid Longitude
Rt 220-92	SE	29.8	391.9	34.3	37.97097	-79.85154
Rt 220-93	SE	27.8	247.0	28.8	37.95979	-79.86373
Rt 220-94	SW	27.5	162.4	23.9	37.95801	-79.8645
Rt 220-95	SW	37.6	551.1	97.2	37.95697	-79.86421
Rt 220-96	SW	30.1	99.5	16.5	37.94454	-79.8726
Rt 220-97	NW	30.6	720.6	52.9	37.94524	-79.87207
Rt 220-98	NW	24.9	260.0	19.8	37.92338	-79.889
Rt 220-99	SE	23.8	222.2	16.9	37.89809	-79.90418
Rt 220-100	SE	23.8	158.8	15.3	37.89756	-79.90436
Rt 220-101	SE	24.3	848.9	23.7	37.89581	-79.90545
Rt 220-102	SW	29.1	273.5	21.3	37.88183	-79.9131
Rt 220-103	SE	28.1	114.9	21.4	37.88164	-79.91461
Rt 220-104	SW	27.0	184.8	19.7	37.8815	-79.91559
Rt 220-105	SE	33.4	813.7	70.8	37.88104	-79.91706
Rt 220-106	SW	30.4	343.0	34.1	37.88038	-79.9181
Rt 220-107	SE	27.6	452.1	31.1	37.88001	-79.92038
Rt 220-108	SW	23.8	103.2	15.8	37.87724	-79.92449
Rt 220-109	SE	27.3	675.1	29.4	37.87632	-79.92638
Rt 220-110	SE	25.6	536.9	20.6	37.8738	-79.9314
Rt 220-111	SE	31.8	702.5	46.0	37.87264	-79.93405
Rt 220-112	SE	31.7	1143.3	80.4	37.87073	-79.94134
Rt 220-113	SE	29.1	294.8	30.6	37.86997	-79.94423
Rt 220-114	NW	34.8	214.8	87.5	37.86738	-79.94769
Rt 220-115	NE	36.7	238.4	98.9	37.86741	-79.94841
Rt 220-116	NE	35.2	155.9	52.2	37.86714	-79.94865
Rt 220-117	NE	40.6	92.4	64.6	37.86705	-79.94832
Rt 220-118	NE	28.8	262.5	32.3	37.86668	-79.9519
Rt 220-119	NW	29.5	332.9	26.6	37.86301	-79.95507
Rt 220-120	NW	32.9	511.4	71.5	37.86158	-79.9557
Rt 220-121	SW	31.1	148.3	27.6	37.86053	-79.95744
Rt 220-122	NW	32.9	415.3	57.5	37.86077	-79.95692
Rt 220-123	NE	28.4	132.7	21.9	37.85594	-79.96322
Rt 220-124	NW	26.9	267.7	25.4	37.8559	-79.95977
Rt 220-125	NE	29.7	392.8	56.9	37.85602	-79.96087
Rt 220-126	NW	28.4	423.4	39.9	37.85568	-79.96405
Rt 220-127	SW	29.0	295.5	32.4	37.85487	-79.96429
Rt 220-128	SE	27.7	146.8	34.8	37.85354	-79.96463
Rt 220-129	SW	32.6	239.9	44.6	37.8535	-79.96427
Rt 220-130	SE	30.1	312.1	39.5	37.85326	-79.96373
Rt 220-131	SW	29.2	195.9	28.1	37.85321	-79.9633
Rt 220-132	NW	31.3	139.3	31.8	37.85278	-79.963
Rt 220-133	SW	30.1	238.5	39.4	37.85243	-79.963
Rt 220-134	NW	29.2	472.9	46.2	37.85176	-79.96363
Rt 220-135	SW	36.3	80.7	43.6	37.85127	-79.96732
Rt 220-136	SE	37.0	123.2	42.6	37.85128	-79.96719
Rt 220-137	NW	32.1	142.1	48.2	37.85126	-79.96756

Slope Id	Slope Aspect	Average Slope (Deg)	Slope Length (ft)	Slope Height(ft)	Centroid Latitude	Centroid Longitude
Rt 220-138	SE	34.1	99.0	24.2	37.85101	-79.96647
Rt 220-139	SW	26.4	142.8	23.3	37.85105	-79.96775
Rt 220-140	SE	26.2	90.4	19.8	37.85087	-79.9692
Rt 220-141	SW	31.9	326.4	64.2	37.85105	-79.96396
Rt 220-142	SE	33.8	106.2	22.5	37.85082	-79.96629
Rt 220-143	NE	26.7	226.7	29.6	37.85073	-79.96879
Rt 220-144	NW	28.6	232.8	28.5	37.85065	-79.96803
Rt 220-145	NW	29.5	359.5	39.6	37.85071	-79.96998
Rt 220-146	NE	36.0	747.2	78.2	37.85063	-79.96623
Rt 220-147	SW	32.9	694.3	76.1	37.84967	-79.97003
Rt 220-148	SE	32.1	280.8	23.7	37.84811	-79.96855
Rt 220-149	SW	38.1	568.9	69.1	37.84827	-79.96878
Rt 220-150	SE	34.9	92.2	65.7	37.84811	-79.96794
Rt 220-151	NW	30.7	271.8	47.8	37.8395	-79.97172
Rt 220-152	SW	32.0	864.5	73.3	37.83494	-79.97484
Rt 220-153	NW	24.9	92.9	20.3	37.83385	-79.97724
Rt 220-154	SW	33.9	95.4	52.0	37.83325	-79.97524
Rt 220-155	SE	34.9	98.0	51.7	37.83323	-79.97516
Rt 220-156	NE	36.7	583.5	76.8	37.83341	-79.97619
Rt 220-157	SE	38.0	132.5	56.9	37.83325	-79.9754
Rt 220-158	SW	26.5	168.6	23.6	37.833	-79.97729
Rt 220-159	SW	27.4	422.3	37.2	37.83231	-79.97727
Rt 220-160	SW	27.4	133.8	26.8	37.82908	-79.97989
Rt 220-161	NW	31.6	352.8	51.3	37.82912	-79.97917
Rt 220-162	NW	28.6	282.6	41.1	37.82899	-79.98041
Rt 220-163	NW	26.6	97.6	20.9	37.82823	-79.98151
Rt 220-164	NW	31.2	297.0	46.5	37.82696	-79.9825
Rt 220-165	NW	39.5	1907.8	125.7	37.82466	-79.98468
Rt 220-166	SW	24.3	172.2	20.8	37.81872	-79.9849
Rt 220-167	SW	31.5	711.5	75.7	37.81796	-79.98428
Rt 220-168	SW	26.1	118.7	18.3	37.81692	-79.98386
Rt 220-169	NW	32.7	89.5	50.0	37.81661	-79.98359
Rt 220-170	SW	33.7	94.3	50.8	37.81652	-79.98366
Rt 220-171	NW	33.3	107.3	54.6	37.81644	-79.98364
Rt 220-172	SW	29.2	103.5	35.0	37.81639	-79.98377
Rt 220-173	NW	33.2	446.7	63.5	37.81532	-79.98392
Rt 220-174	SW	31.3	83.6	44.3	37.81482	-79.98413
Rt 220-175	NW	31.0	165.5	41.6	37.81457	-79.98421
Rt 220-176	SW	28.7	104.2	30.6	37.81437	-79.98433
Rt 220-177	NW	33.4	79.9	28.0	37.81297	-79.98467
Rt 220-178	SW	28.5	231.2	37.4	37.81284	-79.98471
Rt 220-179	NW	33.9	302.4	63.2	37.81232	-79.98475

Appendix C. Rockfall hazard rating data collected in field by the PI

Site Designation	**Site 1**		
Start Latitude	37.99434	Start Longitude	-79.60439
End Latitude	37.99516	End Longitude	-79.60339
Speed Limit (mph)	45		
Road Width (ft)	27		
Slope Length (ft)	1392		
Sight Distance			
Slope Angle (deg)	44		
Slope Height (ft)	73		
Catchment Ditch Width (ft)	12	Catchment Ditch Depth (ft)	1
Rock Block Size (ft)	0.5		

Ditch Effectiveness		**Joints**		
Good Catchment	**3**	Discontinuous/Favorable	3	
Moderate Catchment	9	Discontinuous/Random	9	
Limited Catchment	27	Discontinuous/Adverse	27	
No Catchment	81	Continuous/Adverse	**81**	
Rock Friction		**Diff. Erosion Features**		
Rough/Irregular	3	Few	**3**	
Undulating	9	Occasional	9	
Planar	**27**	Many	27	
Clay Infill/Slicks	81	Major	81	
Diff. Erosion Rates				
Small Difference	**3**			
Moderate Difference	9			
Large Diff/ Fav. Struct.	27			
Large Diff. Unfav. Struct.	81			

Site Designation	**Site 2**			
Start Latitude	37.6417	Start Longitude		-79.80344
End Latitude		End Longitude		
Speed Limit (mph)	40			
Road Width (ft)	23			
Slope Length (ft)	1160			
Sight Distance	234			
Slope Angle (deg)	90			
Slope Height (ft)	84			
Catchment Ditch Width (ft)/Depth (ft)	6	Catchment Ditch Depth (ft)		1
Rock Block Size (ft)	2-3			
Ditch Effectiveness		**Joints**		
Good Catchment	**3**	Discontinuous/Favorable	**3**	
Moderate Catchment	9	Discontinuous/Random	9	
Limited Catchment	27	Discontinuous/Adverse	27	
No Catchment	81	Continuous/Adverse	81	
Rock Friction		**Diff. Erosion Features**		
Rough/Irregular	3	Few	3	
Undulating	9	Occasional	9	
Planar	**27**	Many	**27**	
Clay Infill/Slicks	81	Major	81	
Diff. Erosion Rates				
Small Difference	**3**			
Moderate Difference	9			
Large Diff/ Fav. Struct.	27			
Large Diff. Unfav. Struct.	81			

Site Designation	**Site 3**			
Start Latitude	37.63971	Start Longitude		-79.80565
End Latitude		End Longitude		
Speed Limit (mph)	40			
Road Width (ft)	38.2			
Slope Length (ft)	1740			
Sight Distance	94			
Slope Angle (deg)	90			
Slope Height (ft)	135			
Catchment Ditch Width (ft)/Depth (ft)	19	Catchment Ditch Depth (ft)		0.5
Rock Block Size (ft)	2-3			
Ditch Effectiveness		**Joints**		
Good Catchment	**3**	Discontinuous/Favorable	**3**	
Moderate Catchment	9	Discontinuous/Random	9	
Limited Catchment	27	Discontinuous/Adverse	27	
No Catchment	81	Continuous/Adverse	81	
Rock Friction		**Diff. Erosion Features**		
Rough/Irregular	3	Few	3	
Undulating	9	Occasional	9	
Planar	**27**	Many	**27**	
Clay Infill/Slicks	81	Major	81	
Diff. Erosion Rates				
Small Difference	**3**			
Moderate Difference	9			
Large Diff/ Fav. Struct.	27			
Large Diff. Unfav. Struct.	81			

Site Designation	**Site 4**		
Start Latitude	37.22815	Start Longitude	-79.3581
End Latitude	37.22752	End Longitude	-79.3591
Speed Limit (mph)	35		
Road Width (ft)	23		
Slope Length (ft)	443.7		
Sight Distance	494		
Slope Angle (deg)	60		
Slope Height (ft)	39		
Catchment Ditch Width (ft)/Depth (ft)	2	Catchment Ditch Depth (ft)	0
Rock Block Size (ft)			
Ditch Effectiveness		**Joints**	
Good Catchment	3	Discontinuous/ Favorable	3
Moderate Catchment	9	Discontinuous/ Random	9
Limited Catchment	27	Discontinuous/ Adverse	**27**
No Catchment	**81**	Continuous/Adverse	81
Rock Friction		**Diff. Erosion Features**	
Rough/Irregular	3	Few	**3**
Undulating	9	Occasional	9
Planar	**27**	Many	27
Clay Infill/Slicks	81	Major	81
Diff. Erosion Rates			
Small Difference	**3**		
Moderate Difference	9		
Large Diff/ Fav. Struct.	27		
Large Diff. Unfav. Struct.	81		

Site Designation	**Site 5**			
Start Latitude	38.26203	Start Longitude		-79.3163
End Latitude	38.26395	End Longitude		-79.3153
Speed Limit (mph)	35			
Road Width (ft)	24			
Slope Length (ft)	1276			
Sight Distance	129			
Slope Angle (deg)	70			
Slope Height (ft)	108			
Catchment Ditch Width (ft)/Depth (ft)	10	Catchment Ditch Depth (ft)		1
Rock Block Size (ft)	2			
Ditch Effectiveness		**Joints**		
Good Catchment	**3**	Discontinuous/Favorable		3
Moderate Catchment	9	Discontinuous/Random		9
Limited Catchment	27	Discontinuous/Adverse		27
No Catchment	81	Continuous/Adverse		**81**
Rock Friction		**Diff. Erosion Features**		
Rough/Irregular	3	Few		3
Undulating	9	Occasional		9
Planar	**27**	Many		**27**
Clay Infill/Slicks	81	Major		81
Diff. Erosion Rates				
Small Difference	3			
Moderate Difference	**9**			
Large Diff/ Fav. Struct.	27			
Large Diff. Unfav. Struct.	81			

Site Designation	**Site 6**		
Start Latitude	37.75585	Start Longitude	-80.0176
End Latitude	37.75839	End Longitude	-80.0236
Speed Limit (mph)	45		
Road Width (ft)	24		
Slope Length (ft)	1450		
Sight Distance	363		
Slope Angle (deg)	90		
Slope Height (ft)	144		
Catchment Ditch Width (ft)/Depth (ft)	9	Catchment Ditch Depth (ft)	0.5
Rock Block Size (ft)	2		
Ditch Effectiveness		**Joints**	
Good Catchment	**3**	Discontinuous/Favorable	3
Moderate Catchment	9	Discontinuous/Random	9
Limited Catchment	27	Discontinuous/Adverse	27
No Catchment	81	Continuous/Adverse	**81**
Rock Friction		**Diff. Erosion Features**	
Rough/Irregular	3	Few	3
Undulating	9	Occasional	9
Planar	**27**	Many	**27**
Clay Infill/Slicks	81	Major	81
Diff. Erosion Rates			
Small Difference	**3**		
Moderate Difference	9		
Large Diff/ Fav. Struct.	27		
Large Diff. Unfav. Struct.	81		

Site Designation	**Site 7**		
Start Latitude	37.92513	Start Longitude	-79.7165
End Latitude	37.92499	End Longitude	-79.718
Speed Limit (mph)			
Road Width (ft)	24		
Slope Length (ft)	30		
Sight Distance	394		
Slope Angle (deg)	90		
Slope Height (ft)	43		
Catchment Ditch Width (ft)	6	Catchment Ditch Depth (ft)	1
Rock Block Size (ft)	2		
Ditch Effectiveness		**Joints**	
Good Catchment	**3**	Discontinuous/Favorable	**3**
Moderate Catchment	9	Discontinuous/Random	9
Limited Catchment	27	Discontinuous/Adverse	27
No Catchment	81	Continuous/Adverse	81
Rock Friction		**Diff. Erosion Features**	
Rough/Irregular	3	Few	**3**
Undulating	**9**	Occasional	9
Planar	27	Many	27
Clay Infill/Slicks	81	Major	81
Diff. Erosion Rates			
Small Difference	**3**		
Moderate Difference	9		
Large Diff/ Fav. Struct.	27		
Large Diff. Unfav. Struct.	81		

Site Designation	**Site 8**			
Start Latitude	37.42611	Start Longitude		-79.1402
End Latitude	37.42721	End Longitude		-79.1405
Speed Limit (mph)	35			
Road Width (ft)	20.7			
Slope Length (ft)	290			
Sight Distance	669			
Slope Angle (deg)	90			
Slope Height (ft)	78			
Catchment Ditch Width (ft)		Catchment Ditch Depth (ft)		
Rock Block Size (ft)				
Ditch Effectiveness		**Joints**		
Good Catchment	**3**	Discontinuous/Favorable		3
Moderate Catchment	9	Discontinuous/Random		9
Limited Catchment	27	Discontinuous/Adverse		27
No Catchment	81	Continuous/Adverse		81
Rock Friction		**Diff. Erosion Features**		
Rough/Irregular	3	Few		**3**
Undulating	**9**	Occasional		9
Planar	27	Many		27
Clay Infill/Slicks	81	Major		81
Diff. Erosion Rates				
Small Difference	**3**			
Moderate Difference	9			
Large Diff/ Fav. Struct.	27			
Large Diff. Unfav. Struct.	81			

Site Designation	**Site 9**		
Start Latitude	37.59241	Start Longitude	-79.3803
End Latitude	37.58741	End Longitude	-79.3795
Speed Limit (mph)	55		
Road Width (ft)	24.6		
Slope Length (ft)	2465		
Sight Distance	264		
Slope Angle (deg)	90		
Slope Height (ft)	46		
Catchment Ditch Width (ft)	3.5	Catchment Ditch Depth (ft)	0.5
Rock Block Size (ft)	2-3		
Ditch Effectiveness		**Joints**	
Good Catchment	3	Discontinuous/Favorable	3
Moderate Catchment	9	Discontinuous/Random	**9**
Limited Catchment	27	Discontinuous/Adverse	27
No Catchment	**81**	Continuous/Adverse	81
Rock Friction		**Diff. Erosion Features**	
Rough/Irregular	3	Few	**3**
Undulating	9	Occasional	9
Planar	27	Many	27
Clay Infill/Slicks	81	Major	81
Diff. Erosion Rates			
Small Difference	**3**		
Moderate Difference	9		
Large Diff/ Fav. Struct.	27		
Large Diff. Unfav. Struct.	81		

Site Designation	**Site 10**		
Start Latitude	37.42611	Start Longitude	-79.1402
End Latitude	37.42721	End Longitude	-79.1405
Speed Limit (mph)	35		
Road Width (ft)	20.7		
Slope Length (ft)	522		
Sight Distance	378		
Slope Angle (deg)	90		
Slope Height (ft)	91		
Catchment Ditch Width (ft)		Catchment Ditch Depth (ft)	
Rock Block Size (ft)			
Ditch Effectiveness		**Joints**	
Good Catchment	**3**	Discontinuous/Favorable	**3**
Moderate Catchment	9	Discontinuous/Random	9
Limited Catchment	27	Discontinuous/Adverse	27
No Catchment	81	Continuous/Adverse	81
Rock Friction		**Diff. Erosion Features**	
Rough/Irregular	3	Few	**3**
Undulating	**9**	Occasional	9
Planar	27	Many	27
Clay Infill/Slicks	81	Major	81
Diff. Erosion Rates			
Small Difference	**3**		
Moderate Difference	9		
Large Diff/ Fav. Struct.	27		
Large Diff. Unfav. Struct.	81		

Site Designation	**Site 11**		
Start Latitude	37.517 05	Start Longitude	-79.344
End Latitude	37.514 9	End Longitude	-79.3385
Speed Limit (mph)	55		
Road Width (ft)	24.7		
Slope Length (ft)	191.4		
Sight Distance	794		
Slope Angle (deg)	90		
Slope Height (ft)	29		
Catchment Ditch Width (ft)		Catchment Ditch Depth (ft)	
Rock Block Size (ft)			
Ditch Effectiveness		**Joints**	
Good Catchment	3	Discontinuous/Favorable	**3**
Moderate Catchment	9	Discontinuous/Random	9
Limited Catchment	27	Discontinuous/Adverse	27
No Catchment	**81**	Continuous/Adverse	81
Rock Friction		**Diff. Erosion Features**	
Rough/Irregular	3	Few	**3**
Undulating	**9**	Occasional	9
Planar	27	Many	27
Clay Infill/Slicks	81	Major	81
Diff. Erosion Rates			
Small Difference	**3**		
Moderate Difference	9		
Large Diff/ Fav. Struct.	27		
Large Diff. Unfav. Struct.	81		

Site Designation	**Site 12**		
Start Latitude	38.04302	Start Longitude	-78.8024
End Latitude	38.04347	End Longitude	-78.8102
Speed Limit (mph)	70		
Road Width (ft)	26		
Slope Length (ft)	3190		
Sight Distance	198		
Slope Angle (deg)	90		
Slope Height (ft)	156		
Catchment Ditch Width (ft)	22	Catchment Ditch Depth (ft)	3
Rock Block Size (ft)			
Ditch Effectiveness		**Joints**	
Good Catchment	**3**	Discontinuous/Favorable	3
Moderate Catchment	9	Discontinuous/Random	9
Limited Catchment	27	Discontinuous/Adverse	27
No Catchment	81	Continuous/Adverse	**81**
Rock Friction		**Diff. Erosion Features**	
Rough/Irregular	3	Few	**3**
Undulating	9	Occasional	9
Planar	**27**	Many	27
Clay Infill/Slicks	81	Major	81
Diff. Erosion Rates			
Small Difference	**3**		
Moderate Difference	9		
Large Diff/ Fav. Struct.	27		
Large Diff. Unfav. Struct.	81		

Site Designation	**Site 13**		
Start Latitude	38.580828	Start Longitude	-78.8024
End Latitude	38.57971	End Longitude	-78.8102
Speed Limit (mph)	25		
Road Width (ft)	20		
Slope Length (ft)	1252		
Sight Distance			
Slope Angle (deg)	90		
Slope Height (ft)	25		
Catchment Ditch Width (ft)	2	Catchment Ditch Depth (ft)	<1
Rock Block Size (ft)			
Ditch Effectiveness		**Joints**	
Good Catchment	**3**	Discontinuous/Favorable	**3**
Moderate Catchment	9	Discontinuous/Random	9
Limited Catchment	27	Discontinuous/Adverse	27
No Catchment	81	Continuous/Adverse	81
Rock Friction		**Diff. Erosion Features**	
Rough/Irregular	3	Few	3
Undulating	9	Occasional	9
Planar	**27**	Many	27
Clay Infill/Slicks	81	Major	**81**
Diff. Erosion Rates			
Small Difference	3		
Moderate Difference	9		
Large Diff/ Fav. Struct.	27		
Large Diff. Unfav. Struct.	**81**		

Appendix D. Rockfall hazard rating data collected in field by the Dr. Brian Bruckno of VDOT

City/County	Route		Travel Direction	Side of the Road	Speed Limit
Milboro Springs	42	**Site 1**	South	West	55
Section Start	*Lat*		*Long*		
	37.994887		-79.603689		
Section End	*Lat*		*Long*		
	37.994409		-79.604367		

Slope Height	69					
Ditch Effectiveness	Raw Score	Vehicle Risk		Decision Sight Distance		Road Width
Good Catchment	3	ADT	1700	Actual DSD	230	18
Moderate Catchment	9	ADT Year	2019	AASHTO DSD	875	100
Limited Catchment	27	Slope Length	950	% DSD	26.3	
No Catchment	81	AVR%	23.17	DSD Score	100.0	
Final or Adjusted Score	9		72			

Case 1	Structural Condition	Raw Score	Rock Friction	Raw Score	Rockfall Characteristics	
	Discontinuous/Favorable	3	Rough/Irregular	3	Block Size (ft)	1
	Discontinuous/Random	9	Undulating	9		1
	Discontinuous/Adverse	27	Planar	**27**	Block Vol (cu. Yds)	1
	Continuous/Adverse	**81**	Clay Infill/Slicks	81	Final or Adjusted Score	**3**
Case 2	Diff. Erosion Features	Raw Score	Diff. Erosion Rates	Raw Score	Rockfall History	Raw Score
	Few	3	Small Difference	**3**	Few Falls	3
	Occasional	**9**	Moderate Difference	9	Occasional Falls	9
	Many	27	Large Diff/ Fav. Struct.	27	Many Falls	27
	Major	81	Large Diff. Unfav. Struct.	81	Constant Falls	**81**

City/County	Route	**Site 2**	Travel Direction	Side of the Road	Speed Limit
Eagle Rock	43		N	E	40

	Lat	*Long*
Section Start	37.642417	-79.804691
Section End	37.643003	-79.805772
Slope Height	60	

Ditch Effectiveness	Raw Score	Vehicle Risk		Decision Sight Distance		Road Width	
Good Catchment	3	ADT	1200	Actual DSD	150	Width	18
Moderate Catchment	9	ADT Year	2019	AASHTO DSD	600	Score	100
Limited Catchment	**27**	Slope Length	1000	% DSD	100.0		
No Catchment	81	AVR%	3.00	DSD Score	100.0		
Final or Adjusted Score	27						

	Structural Condition	Raw Score	Rock Friction	Raw Score	Rockfall Characteristics	
Case 1	Discontinuous/Favorable	3	Rough/Irregular	3	Block Size (ft)	1
	Discontinuous/Random	9	Undulating	**9**	Final or Adjusted Score	3
	Discontinuous/Adverse	27	Planar	27	Block Vol (cu. Yds)	0.5
	Continuous/Adverse	**81**	Clay Infill/Slicks	81		

	Diff. Erosion Features	Raw Score	Diff. Erosion Rates	Raw Score	Rockfall History	Raw Score
Case 2	Few	3	Small Difference	3	Few Falls	3
	Occasional	9	Moderate Difference	**9**	Occasional Falls	9
	Many	**27**	Large Diff/ Fav. Struct.	27	Many Falls	**27**
	Major	81	Large Diff. Unfav. Struct.	81	Constant Falls	81

City/County	Route	**Site 3**	Travel Direction	Side of the Road	Speed Limit

	Eagle Rock	220			South		West	55
	Section Start	*Lat*			*Long*			
		37.642006			-79.807572			
	Section End	*Lat*			*Long*			
		37.641278			-79.806907			
	Slope Height	250						
	Ditch Effectiveness	Raw Score	Vehicle Risk		Decision Sight Distance		Road Width	
	Good Catchment	3	ADT	6000	Actual DSD	250	Width	64
	Moderate Catchment	**9**	ADT Year	2019	AASHTO DSD	875	Score	1
	Limited Catchment	27	Slope Length	2000	% DSD	28.6		
	No Catchment	81	AVR%	172.18	DSD Score	100.0		
Case 1	Structural Condition	Raw Score	Rock Friction		Raw Score	Rockfall Characteristics		
	Discontinuous/Favorable	3	Rough/Irregular		3	Block Size (ft)	3	
	Discontinuous/Random	9	Undulating		**9**			
	Discontinuous/Adverse	27	Planar		27	Block Vol (cu. Yds)	2	
	Continuous/Adverse	**81**	Clay Infill/Slicks		81	Final or Adjusted Score		**9**
Case 2	Diff. Erosion Features	Raw Score	Diff. Erosion Rates		Raw Score	Rockfall History		Raw Score
	Few	**3**	Small Difference		**3**	Few Falls		3
	Occasional	9	Moderate Difference		9	Occasional Falls		**9**
	Many	27	Large Diff/ Fav. Struct.		27	Many Falls		27
	Major	81	Large Diff. Unfav. Struct.		81	Constant Falls		81

City/County	Route	**Site 4**	Travel Direction	Side of the Road	Speed Limit

	Augusta	629			South	West	30
	Section Start	*Lat*			*Long*		
		38.227998			-79.3583		
	Section End	*Lat*			*Long*		
		38.227748			-79.358594		
	Slope Height	50					
	Ditch Effectiveness	Raw Score	Vehicle Risk		Decision Sight Distance		Road Width
	Good Catchment	3	ADT	830	Actual DSD	50	18
	Moderate Catchment	9	ADT Year	2019	AASHTO DSD	450	
	Limited Catchment	27	Slope Length	500	% DSD	11.1	.
	No Catchment	**81**	AVR%	10.92	DSD Score	100.0	
Case 1	Structural Condition	Raw Score	Rock Friction		Raw Score	Rockfall Characteristics	
	Discontinuous/ Favorable	3	Rough/Irregular		3	Block Size (ft)	3
	Discontinuous/ Random	9	Undulating		9		
	Discontinuous/ Adverse	27	Planar		27	Block Vol (cu. Yds)	3
	Continuous/Adverse	**81**	Clay Infill/Slicks		**81**	Final or Adjusted Score	
Case 2	Diff. Erosion Features	Raw Score	Diff. Erosion Rates		Raw Score	Rockfall History	Raw Score
	Few	3	Small Difference		3	Few Falls	3
	Occasional	**9**	Moderate Difference		**9**	Occasiona l Falls	9
	Many	27	Large Diff/ Fav. Struct.		27	Many Falls	27
	Major	81	Large Diff. Unfav. Struct.		81	Constant Falls	**81**

City/County	Route		Travel Direction	Side of the Road	Speed Limit
Augusta	629	**Site 5**	South	West	55

Section Start	*Lat*	*Long*
	38.26299	-79.315784
Section End	*Lat*	*Long*
	38.262557	-79.315997

	Slope Height	97.7					
	Ditch Effectiveness	Raw Score	Vehicle Risk		Decision Sight Distance		Road Width
	Good Catchment	**3**	ADT	1000	Actual DSD	160	24
	Moderate Catchment	9	ADT Year	2019	AASHTO DSD	875	
	Limited Catchment	27	Slope Length	545	% DSD	18.3	
	No Catchment	81	AVR%	7.82	DSD Score	100.0	
	Final or Adjusted Score	3	AVR Score	1			
Case 1	Structural Condition	Raw Score	Rock Friction	Raw Score	Rockfall Characteristics		
	Discontinuous/Favorable	3	Rough/Irregular	3	Block Size (ft)	5x3 or better	
	Discontinuous/Random	9	Undulating	9			
	Discontinuous/Adverse	27	Planar	27	Block Vol (cu. Yds)	Block Volume Score	
	Continuous/Adverse	**81**	Clay Infill/Slicks	**81**	Final or Adjusted Score	27	
Case 2	Diff. Erosion Features	Raw Score	Diff. Erosion Rates	Raw Score	Rockfall History	Raw Score	
	Few	**3**	Small Difference	**3**	Few Falls	3	
	Occasional	9	Moderate Difference	9	Occasional Falls	9	
	Many	27	Large Diff/ Fav. Struct.	27	Many Falls	**27**	
	Major	81	Large Diff. Unfav. Struct.	81	Constant Falls	81	

City/County	Route		Travel Direction	Side of the Road	Speed Limit
Covington	18	**Site 6**	South	West	45

Section Start		*Lat*		*Long*		
		37.758822		-80.022725		
Section End		*Lat*		*Long*		
		37.758555		-80.023312		
Slope Height	200			Slope Angle		35
Ditch Effectiveness	Raw Score	Vehicle Risk		Decision Sight Distance		Road Width
Good Catchment	3	ADT	1600	Actual DSD	240	22
Moderate Catchment	**9**	ADT Year	2019	AASHTO DSD	675	
Limited Catchment	27	Slope Length	1000	% DSD	35.6	
No Catchment	81	AVR%	28.06	DSD Score	12.0	

Case 1	Structural Condition	Raw Score	Rock Friction	Raw Score	Rockfall Characteristics	
	Discontinuous/Favorable	3	Rough/Irregular	3	Block Size (ft)	3
	Discontinuous/Random	9	Undulating	**9**		
	Discontinuous/Adverse	27	Planar	27	Block Vol (cu. Yds)	3
	Continuous/Adverse	**81**	Clay Infill/Slicks	81	Final or Adjusted Score	9
Case 2	Diff. Erosion Features	Raw Score	Diff. Erosion Rates	Raw Score	Rockfall History	Raw Score
	Few	3	Small Difference	3	Few Falls	3
	Occasional	**9**	Moderate Difference	**9**	Occasional Falls	9
	Many	27	Large Diff/ Fav. Struct.	27	Many Falls	**27**
	Major	81	Large Diff. Unfav. Struct.	81	Constant Falls	81

City/County	Route		Travel Direction	Side of the Road	Speed Limit
Bath	39	**Site 7**	South	West	55
Section Start	*Lat*		*Long*		

	37.924924	-79.717697
Section End	*Lat*	*Long*
	37.924864	-79.718029

Slope Height	59			Slope Angle		80
Ditch Effectiveness	Raw Score	Vehicle Risk		Decision Sight Distance		Road Width
Good Catchment	3	ADT	750	Actual DSD	150	18
Moderate Catchment	9	ADT Year	2019	AASHTO DSD	875	
Limited Catchment	**27**	Slope Length	300	% DSD	17.1	
No Catchment	81	AVR %	1.00	DSD Score	100.0	

Case 1	Structural Condition	Raw Score	Rock Friction	Raw Score	Rockfall Characteristics		
	Discontinuous/ Favorable	3	Rough/Irregular	3	Block Size (ft)		3
	Discontinuous/ Random	9	Undulating	**9**			
	Discontinuous/ Adverse	27	Planar	27	Block Vol (cu. Yds)		3
	Continuous/Adverse	**81**	Clay Infill/Slicks	81	Final or Adjusted Score	27	
Case 2	Diff. Erosion Features	Raw Score	Diff. Erosion Rates	Raw Score	Rockfall History	Raw Score	
	Few	**3**	Small Difference	**3**	Few Falls	3	
	Occasional	9	Moderate Difference	9	Occasional Falls	**9**	
	Many	27	Large Diff/ Fav. Struct.	27	Many Falls	27	
	Major	81	Large Diff. Unfav. Struct.	81	Constant Falls	81	

City/County	Route			Travel Direction		Side of the Road		Speed Limit
Amherst	130	**Site 9**		N		E		55
Section Start	*Lat*				*Long*			

		37.592				-79.38			
Section End		*Lat*				*Long*			
		37.593				-79.38			
Slope Height			35			Slope Angle		80	
Ditch Effectiveness			Raw Score	Vehicle Risk		Decision Sight Distance		Road Width	
Good Catchment			3	ADT	1300	Actual DSD	300	18	
Moderate Catchment			9	ADT Year	2019	AASHTO DSD	875		
Limited Catchment			27	Slope Length	500	% DSD	34.3		
No Catchment			**81**	AVR%	9.33	DSD Score	100.0		
Case 1	Structural Condition		Raw Score	Rock Friction		Raw Score	Rockfall Characteristics		
	Discontinuous/ Favorable		3	Rough/ Irregular		3	Block Size (ft)	1.5	
	Discontinuous/Random		**9**	Undulating		**9**			
	Discontinuous/Adverse		27	Planar		27	Block Vol (cu. Yds)	3	
	Continuous/Adverse		81	Clay Infill/Slicks		81			
Case 2	Diff. Erosion Features		Raw Score	Diff. Erosion Rates		Raw Score	Rockfall History		Raw Score
	Few		3	Small Difference		3	Few Falls		3
	Occasional		**9**	Moderate Difference		**9**	Occasional Falls		**9**
	Many		27	Large Diff/ Fav. Struct.		27	Many Falls		27
	Major		81	Large Diff. Unfav. Struct.		81	Constant Falls		81

City/County	Route		Travel Direction	Side of the Road	Speed Limit
Nelson	64	**Site 12**	W	N	65
Section Start	*Lat*		*Long*		
	38.033146		-78.854561		

Section End	*Lat*				*Long*			
	38.132705				-78.858619			
Slope Height		100				Slope Angle	45	
Ditch Effectiveness		Raw Score	Vehicle Risk		Decision Sight Distance		Road Width	
Good Catchment		**3**	ADT	18000	Actual DSD	500	Width	36
Moderate Catchment		9	ADT Year	2019	AASHTO DSD	1015	Score	9
Limited Catchment		27	Slope Length	1000	% DSD	49.0		
No Catchment		81	AVR%	218.53	DSD Score	3.6		
Case 1	Structural Condition	Raw Score	Rock Friction		Raw Score	Rockfall Characteristics		
	Discontinuous/ Favorable	3	Rough/Irregular		3	Block Size (ft)	3	
	Discontinuous/ Random	9	Undulating		**9**			
	Discontinuous/ Adverse	27	Planar		27	Block Vol (cu. Yds)	6	
	Continuous/ Adverse	**81**	Clay Infill/Slicks		81	Final or Adjusted Score		27
Case 2	Diff. Erosion Features	Raw Score	Diff. Erosion Rates		Raw Score	Rockfall History		Raw Score
	Few	**3**	Small Difference		**3**	Few Falls		3
	Occasional	9	Moderate Difference		9	Occasional Falls		**9**
	Many	27	Large Diff/ Fav. Struct.		27	Many Falls		27
	Major	81	Large Diff. Unfav. Struct.		81	Constant Falls		81

City/County	Route		Travel Direction	Side of the Road	Speed Limit
Rockingham	33	**Site 13**	W	N	25
Section Start	*Lat*		*Long*		
	38.580828		-79.129338		

Section End		*Lat*			*Long*		
		38.579712			-79.132316		
Slope Height		25			Slope Angle		45-80
Ditch Effectiveness		Raw Score	Vehicle Risk		Decision Sight Distance		Road Width
Good Catchment		3	ADT	1900	Actual DSD	150	21
Moderate Catchment		9	ADT Year	2019	AASHTO DSD	375	
Limited Catchment		27	Slope Length	700	% DSD	40.0	
No Catchment		**81**	AVR%	41.98	DSD Score	81.0	
Case 1	Structural Condition	Raw Score	Rock Friction		Raw Score	Rockfall Characteristics	
	Discontinuous/Favorable	3	Rough/Irregular		3	Block Size (ft)	3
	Discontinuous/Random	9	Undulating		9		
	Discontinuous/Adverse	27	Planar		27	Block Vol (cu. Yds)	6
	Continuous/Adverse	**81**	Clay Infill/Slicks		**81**		
Case 2	Diff. Erosion Features	Raw Score	Diff. Erosion Rates		Raw Score	Rockfall History	Raw Score
	Few	3	Small Difference		3	Few Falls	3
	Occasional	9	Moderate Difference		9	Occasional Falls	9
	Many	27	Large Diff/ Fav. Struct.		27	Many Falls	**27**
	Major	**81**	Large Diff. Unfav. Struct.		**81**	Constant Falls	81