ROCK SLOPE INVESTIGATION ALONG US 340 NEAR HARPER'S FERRY, WEST VIRGINIA

Harper's Ferry, Jefferson County, WV

18th Annual Technical Forum for Geohazards Impacting Transportation In the Appalachian Region

August 7th – 9th, 2018

Baltimore, MD

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SCOPE OF WORK

SCOPE OF WORK OVERVIEW:

Phase 1 (Preliminary Engineering):

- Perform Lower and Upper Slope Investigations
- Evaluate Feasible Rockfall Protection and Stabilization Options
- Perform Preliminary Design of Options
- Develop Preliminary Cost Estimates

Phase 2 (Final Design):

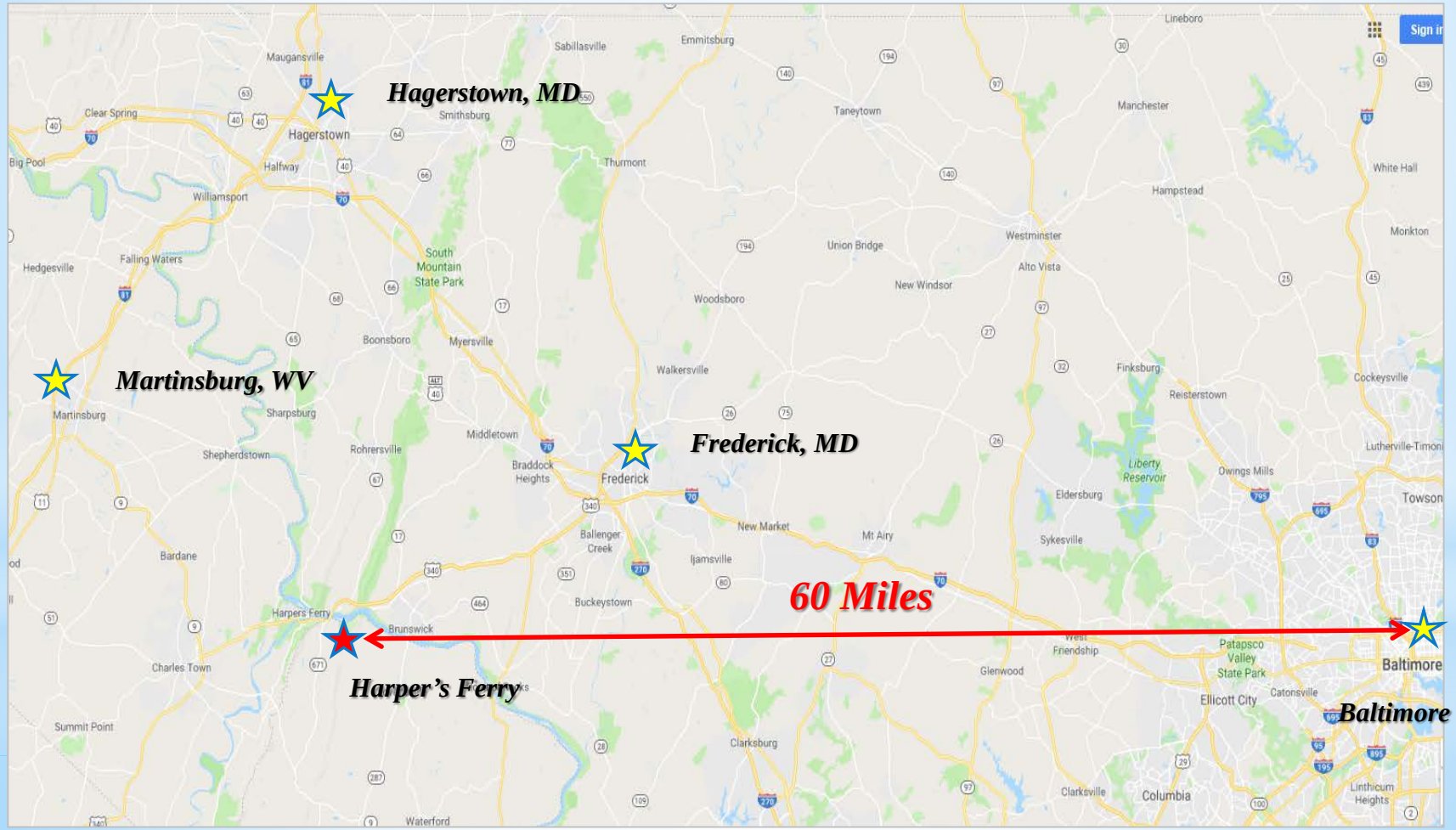
- Perform Final Design of Selected Options
- Prepare Slope Remediation Plans for Construction

PHASE I DETAILED SCOPE OF WORK:

- Complete Aerial and Mobile LiDAR Mapping
- Review of Existing Geologic Information
- Complete Road-Level Field Investigation
- Complete Upper-Slope Field Investigation, Including 22-Mile Detour
- Complete Rockfall (CRSP), Kinematic, and Global Stability Analyses
- Perform Relative Risk Analyses
- Evaluate and Develop Preliminary Designs for Three (3) Feasible Rock Slope Remediation Options
- Prepare Preliminary Construction Cost Estimates (30% Design)
- Reporting

PROJECT LOCATION

PROJECT LOCATION MAP:



PROJECT VICINITY MAP:

PROJECT PHYSIOGRAPHY AND GEOLOGY

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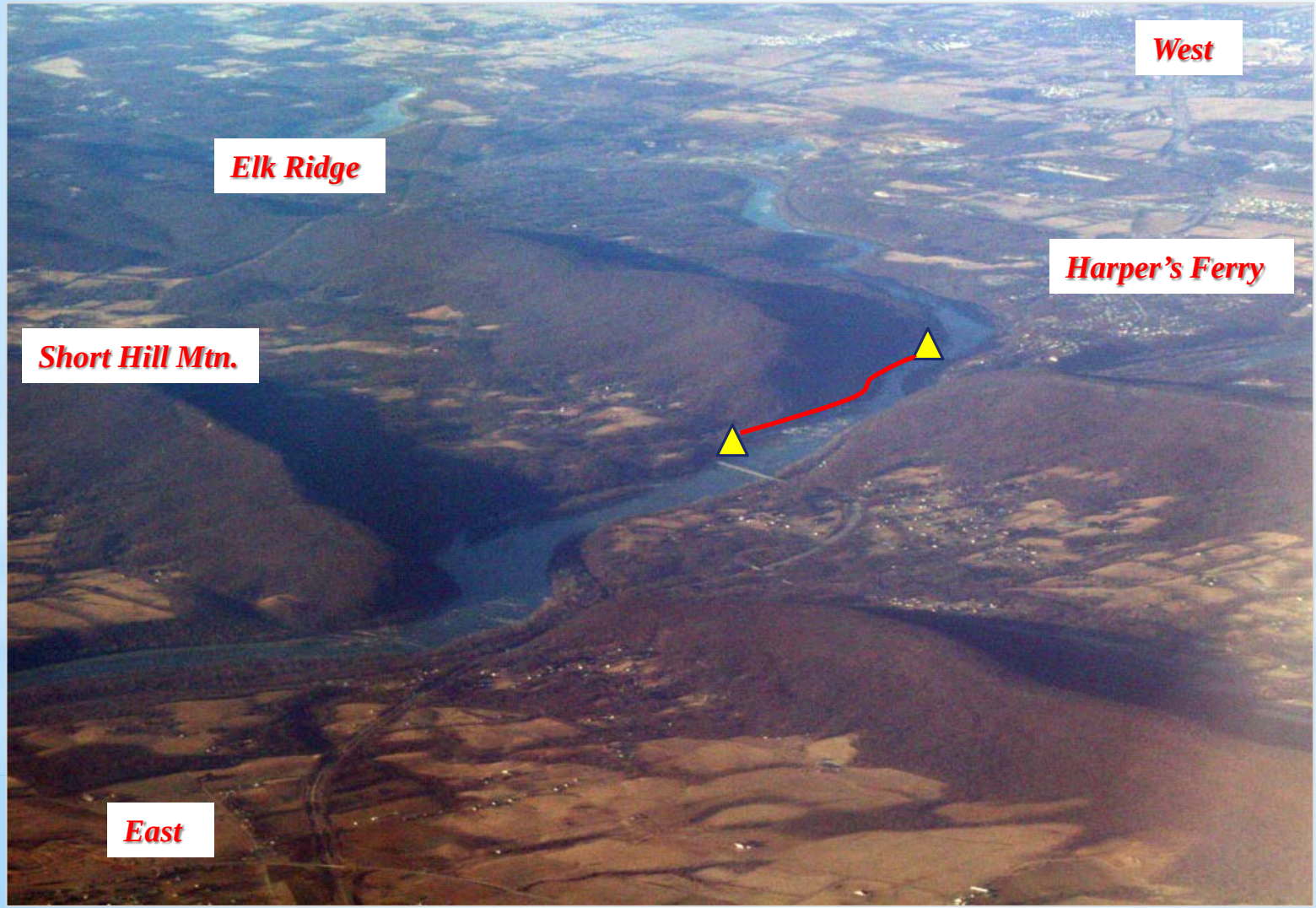

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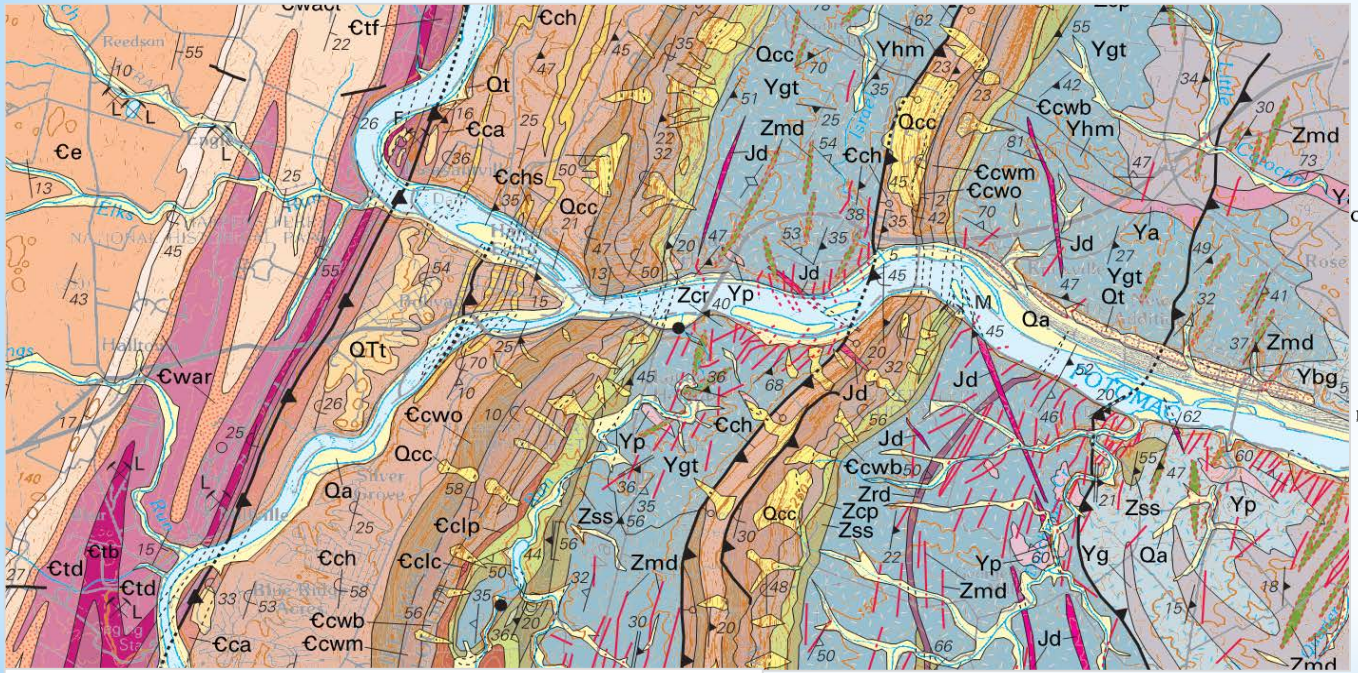
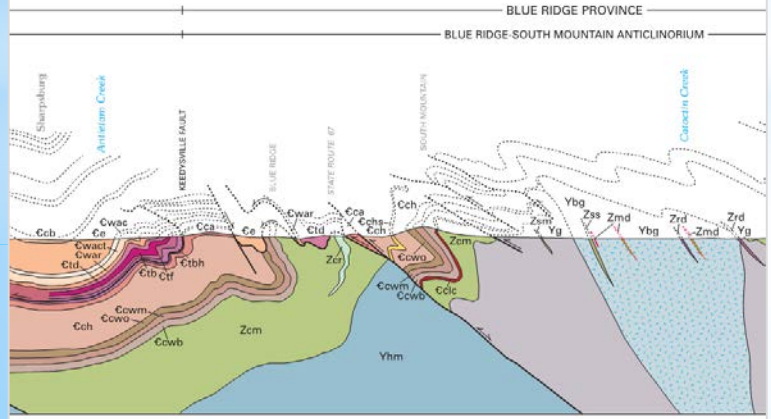




Weverton Formation:

€cwo – Owen's Creek Memb. - Quartzite and MetaSiltstone
€cwm – Maryland Heights Memb. - Quartzite and MetaSiltstone
€cwm – Buzzard Knob Memb. - Quartzite and Sandy MetaSiltstone

USGS science for a changing world

GEOLOGIC MAP OF THE FREDERICK 30' x 60' QUADRANGLE, MARYLAND, VIRGINIA, AND WEST VIRGINIA

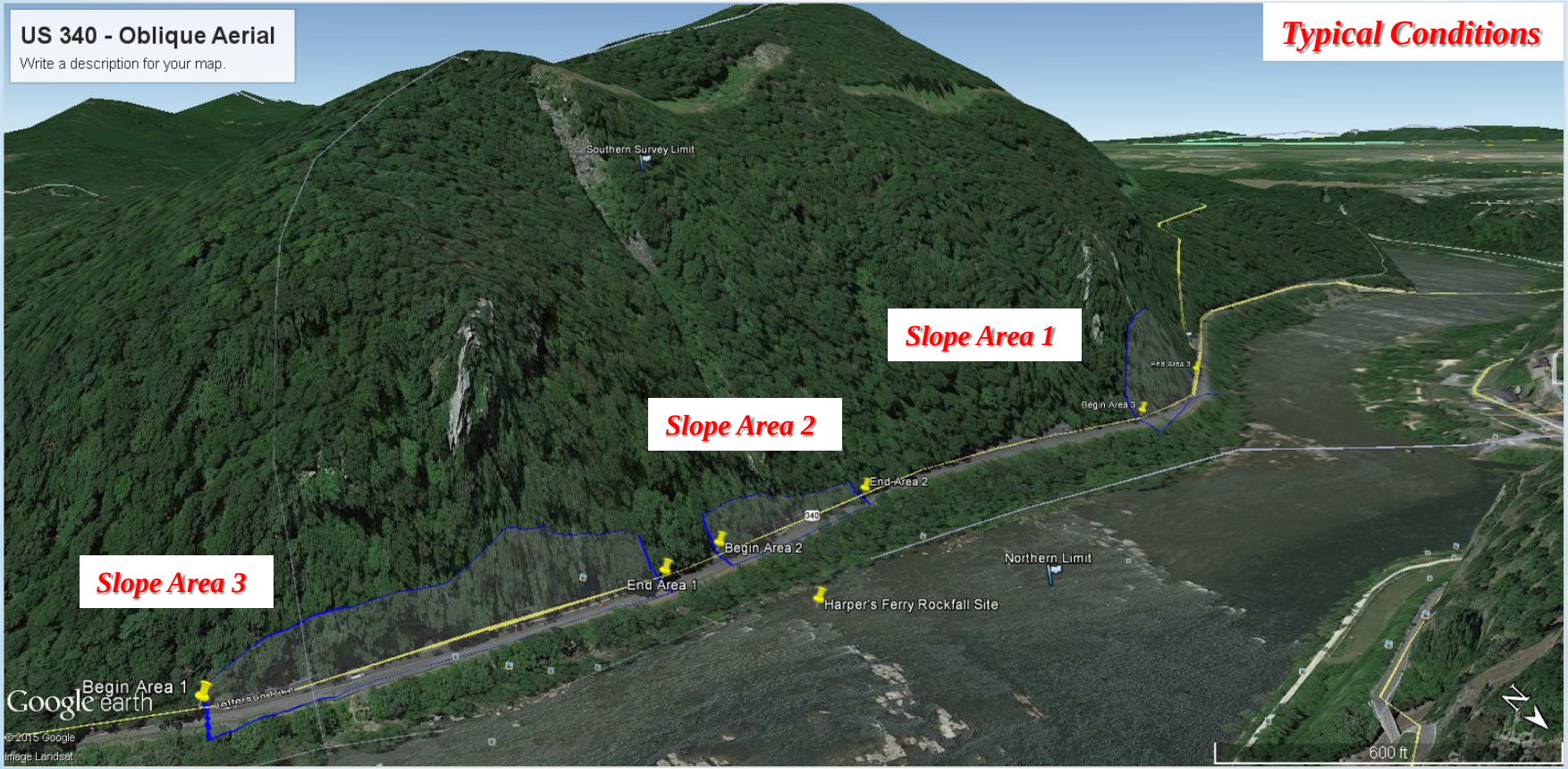
By

Scott Southworth,[1] David K. Brezinski,[2] Avery Ala Drake, Jr.,[3] William C. Burton,[1] Randall C. Orndorff,[1] Albert J. Froelich,[4] James E. Reddy,[5] Danielle Denenny,[1] and David L. Daniels[3]

[1]U.S. Geological Survey, Reston, Va. [2]Maryland Geological Survey, Baltimore, Md. [3]U.S. Geological Survey, Retired. [4]Deceased.

2007

PROJECT PHYSIOGRAPHY AND GEOLOGY:



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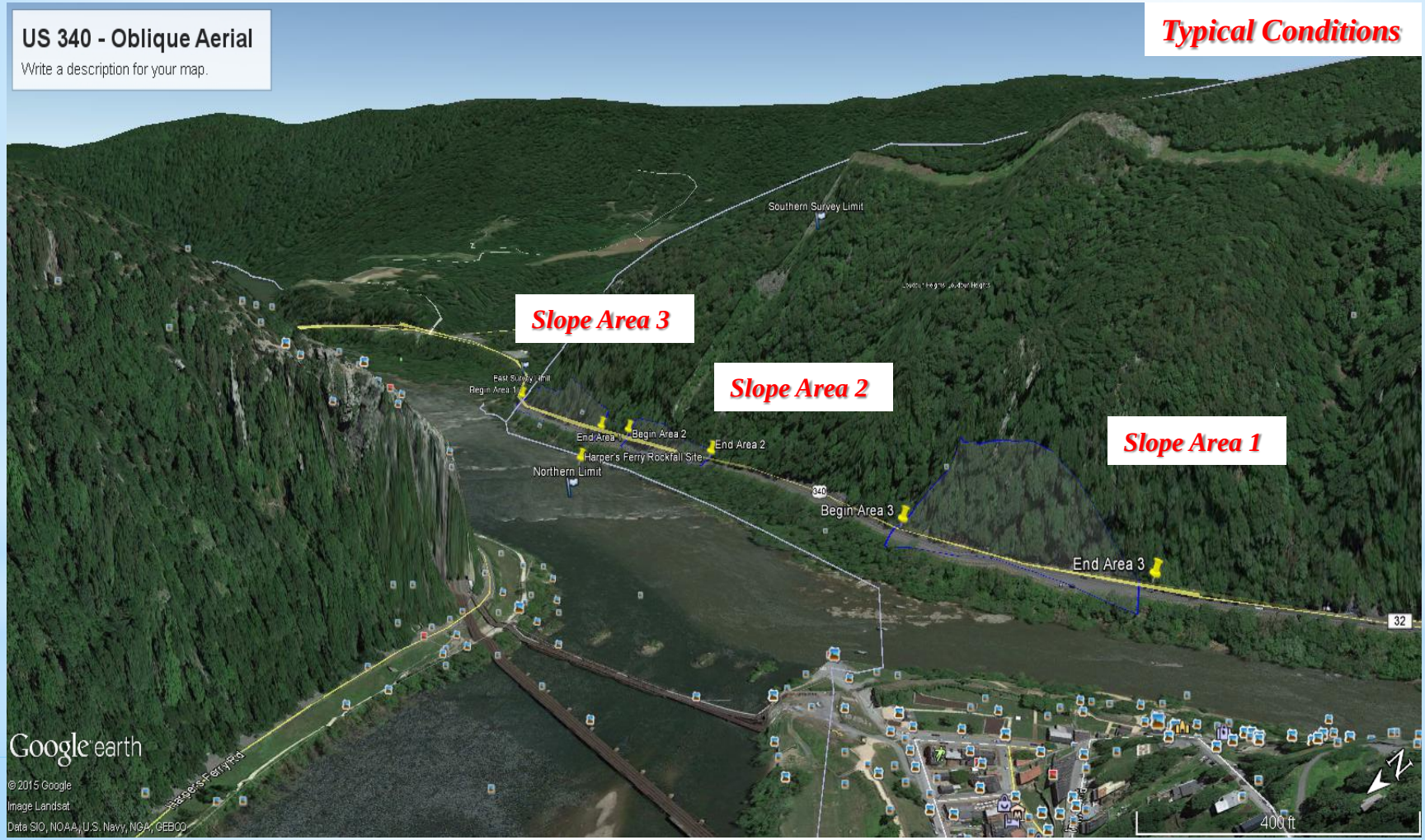


PROJECT PHYSIOGRAPHY AND GEOLOGY:

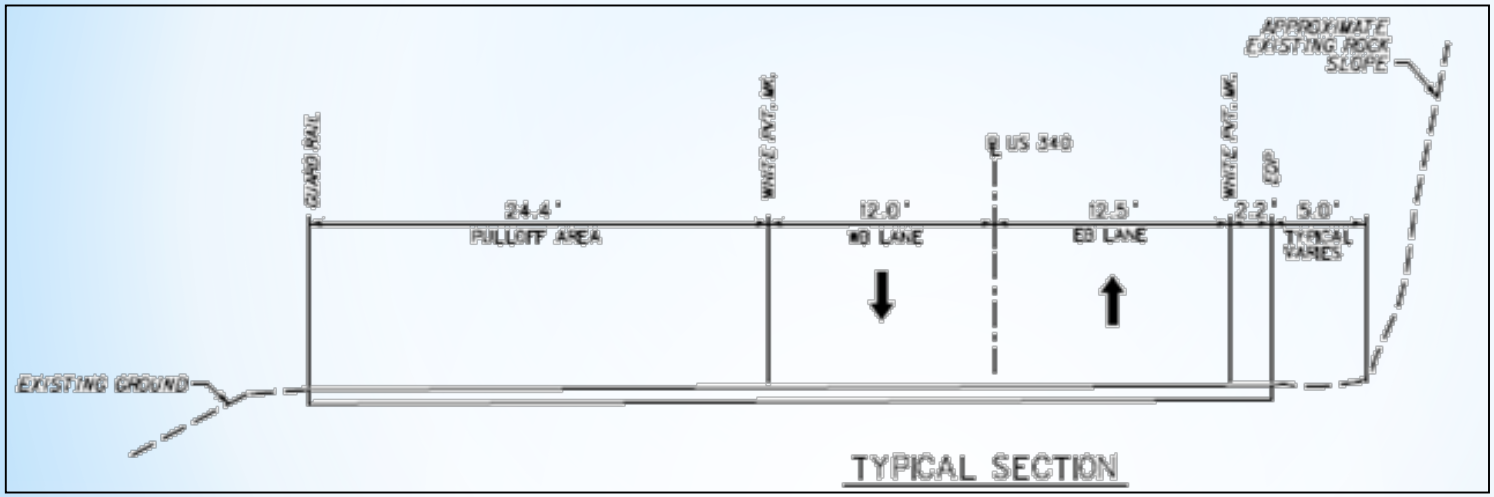
Traffic Data:

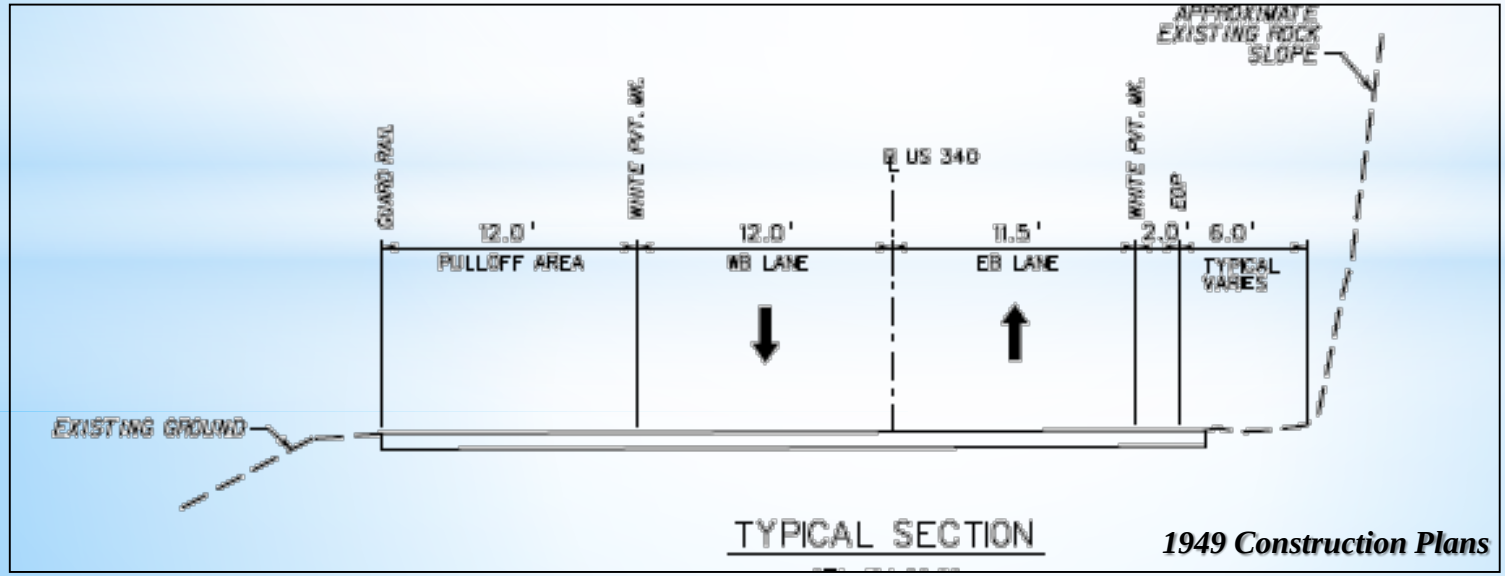
Table 1: 2014 Average Annual Daily Traffic within Project Limits

Route[1]	State	Begin Location	End Location	2014 AADT	Source
US-340	WV	Chestnut Hill Road (WV 32)	VA/WV State Line	30,946[2]	WVDOH: http://www.transportation.wv.gov/highways/programplanning/preliminary_engineering/traffic_analysis/trafficvolume/Pages/default.aspx
US-340	MD	Jefferson Pike (MD 180)	Washington Co. Line	23,856	MDSHA:http://www.sha.state.md.us/OPPEN/AADT_AAWDT_Truck_Percentage.pdf
US-340	VA	MD State Line (S. Bank Potomac R.)	WV/VA State Line	23,000	VDOT:http://www.virginiadot.org/info/2014_traffic_data.asp
Chestnut Hill Road (WV 32)	WV	NA	US-340	1,524	WVDOH:http://www.transportation.wv.gov/highways/programplanning/preliminary_engineering/traffic_analysis/trafficvolume/Pages/default.aspx

1. Traffic counts for Harper's Ferry Road (VA-671) was not readily discernible from the referenced VDOT source.
2. Traffic volume shown (30,946 vpd) is the traffic on US 340 through the study area.

PROJECT PHYSIOGRAPHY AND GEOLOGY:





1949 Construction Plans

PROJECT PHYSIOGRAPHY AND GEOLOGY:

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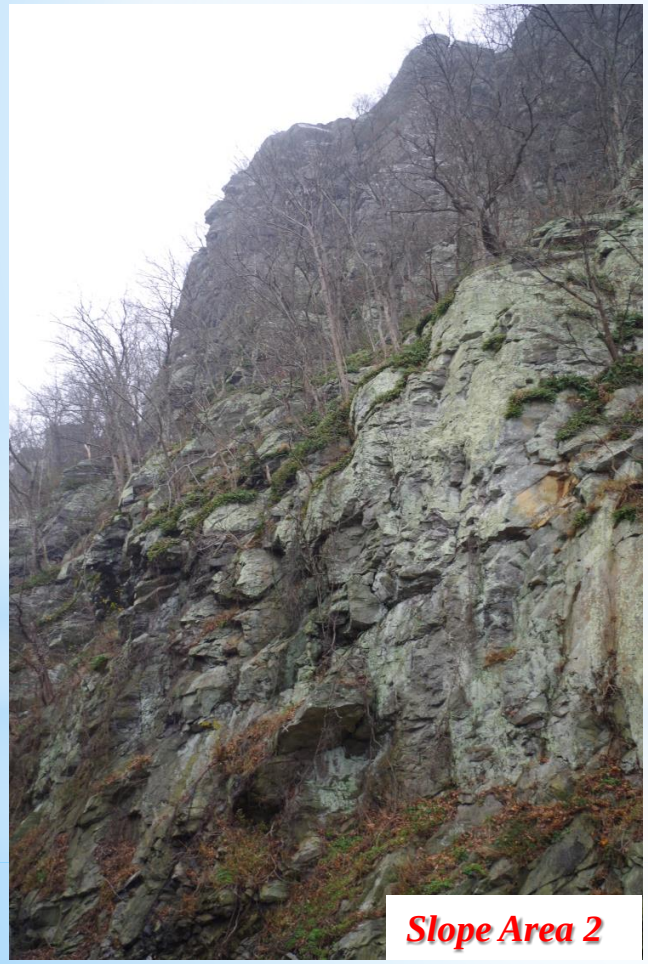


PROJECT PHYSIOGRAPHY AND GEOLOGY:

Slope Area 2 (Boulder Field)

PROJECT PHYSIOGRAPHY AND GEOLOGY:

PROJECT PHYSIOGRAPHY AND GEOLOGY:

Slope Area 3

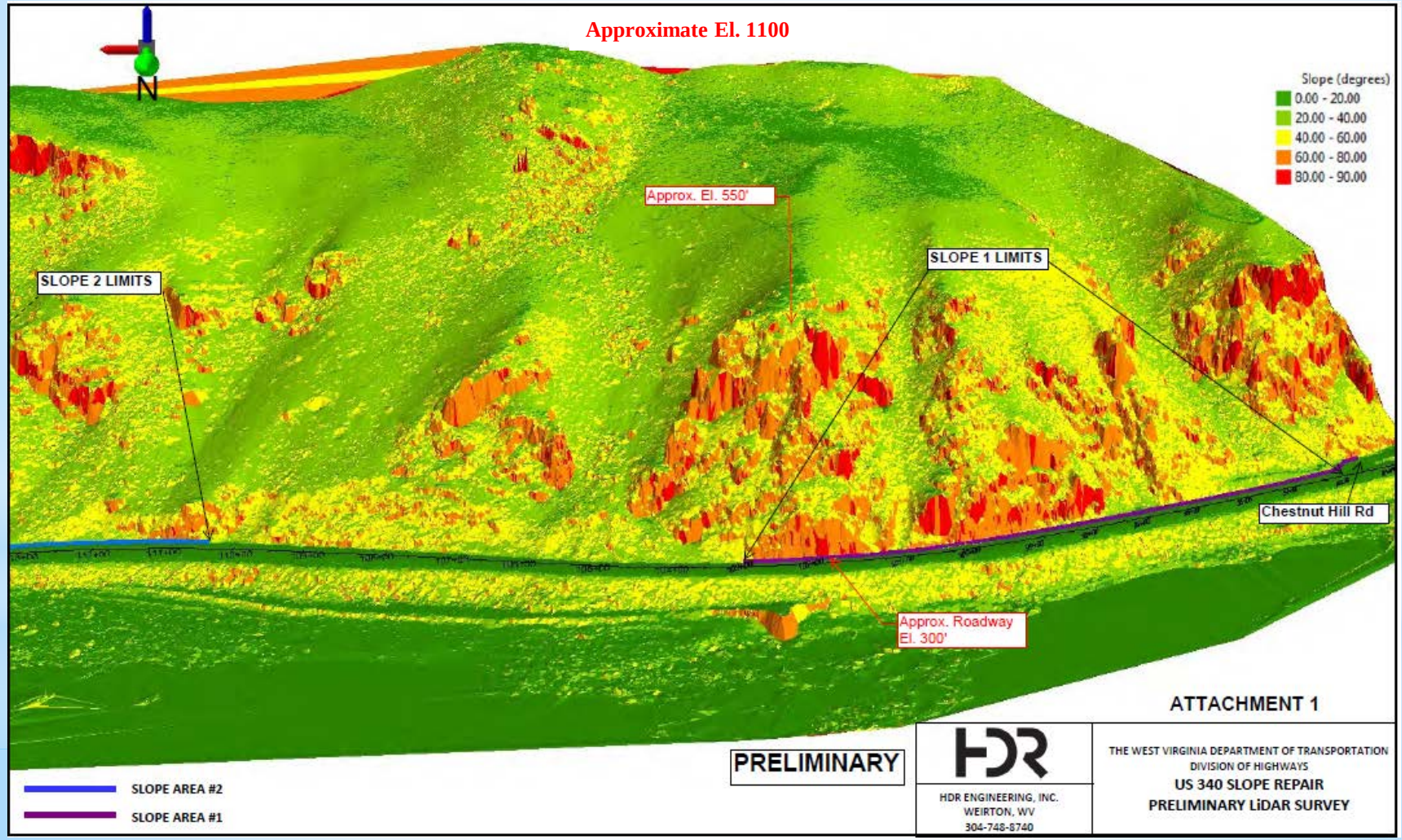
PROJECT PHYSIOGRAPHY AND GEOLOGY:

PROJECT PHYSIOGRAPHY AND GEOLOGY:

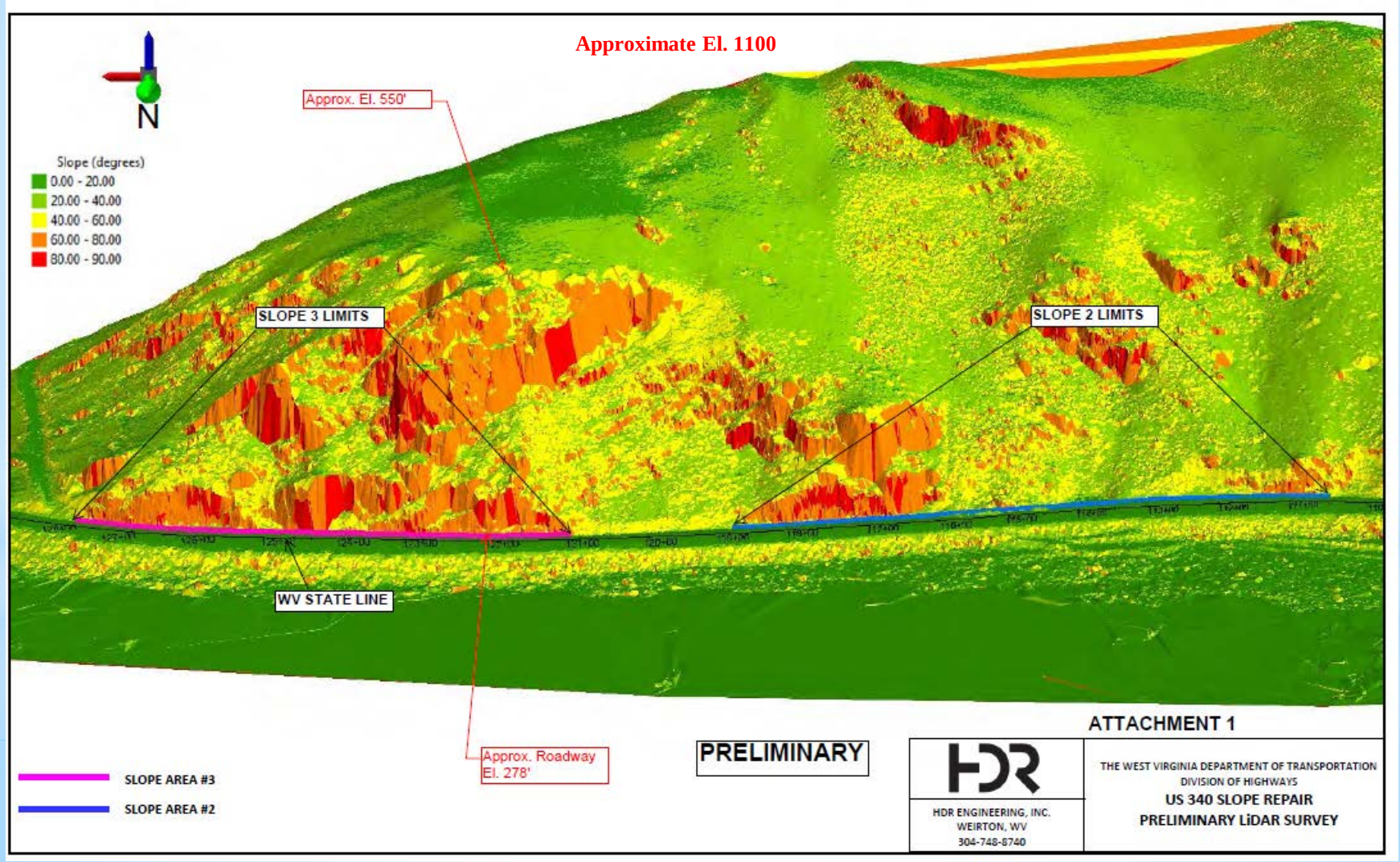
Slope Area 3

PROJECT DEVELOPMENT

LiDAR MAPPING AND PLAN DEVELOPMENT:



LiDAR MAPPING AND PLAN DEVELOPMENT:



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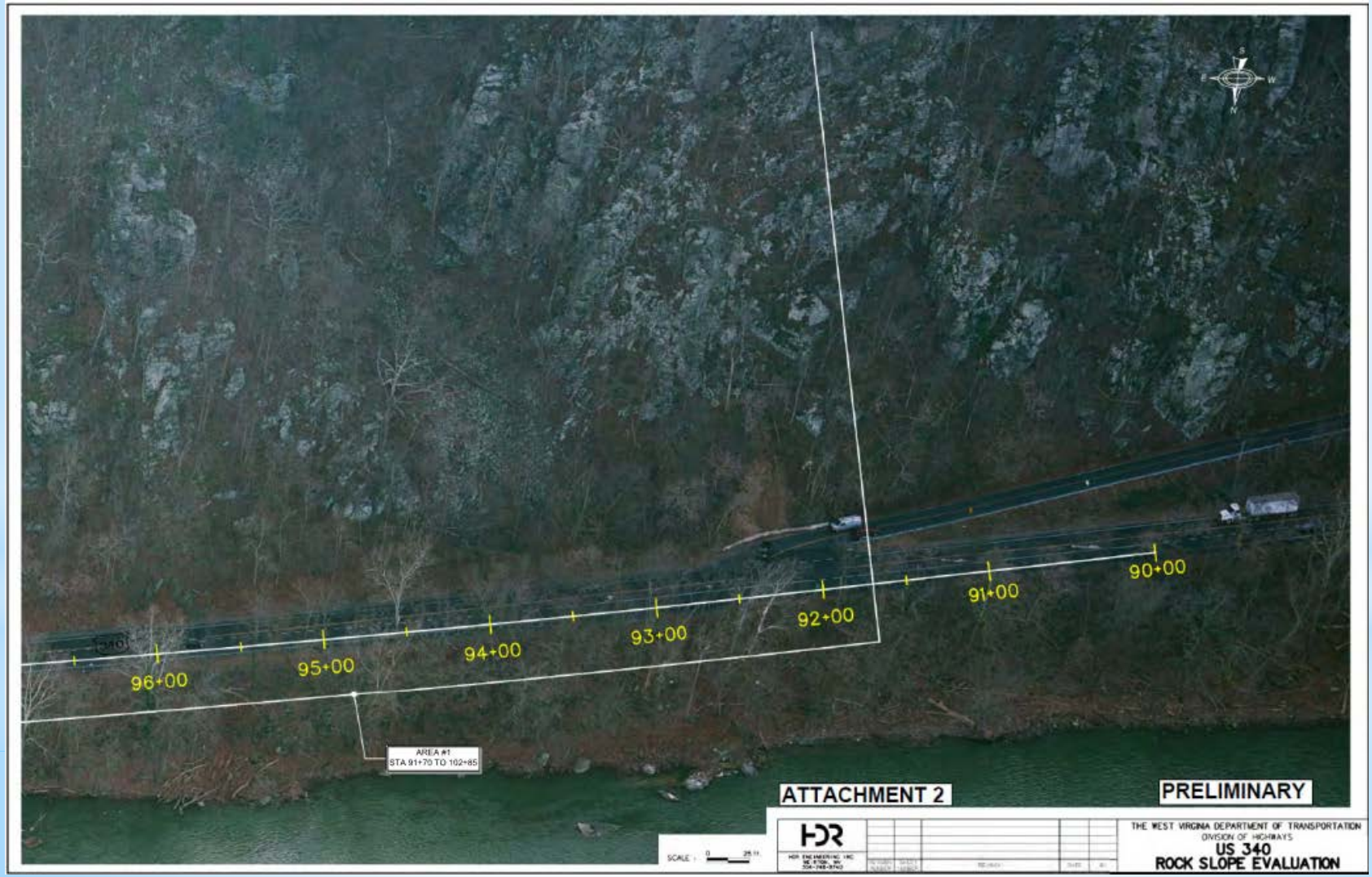

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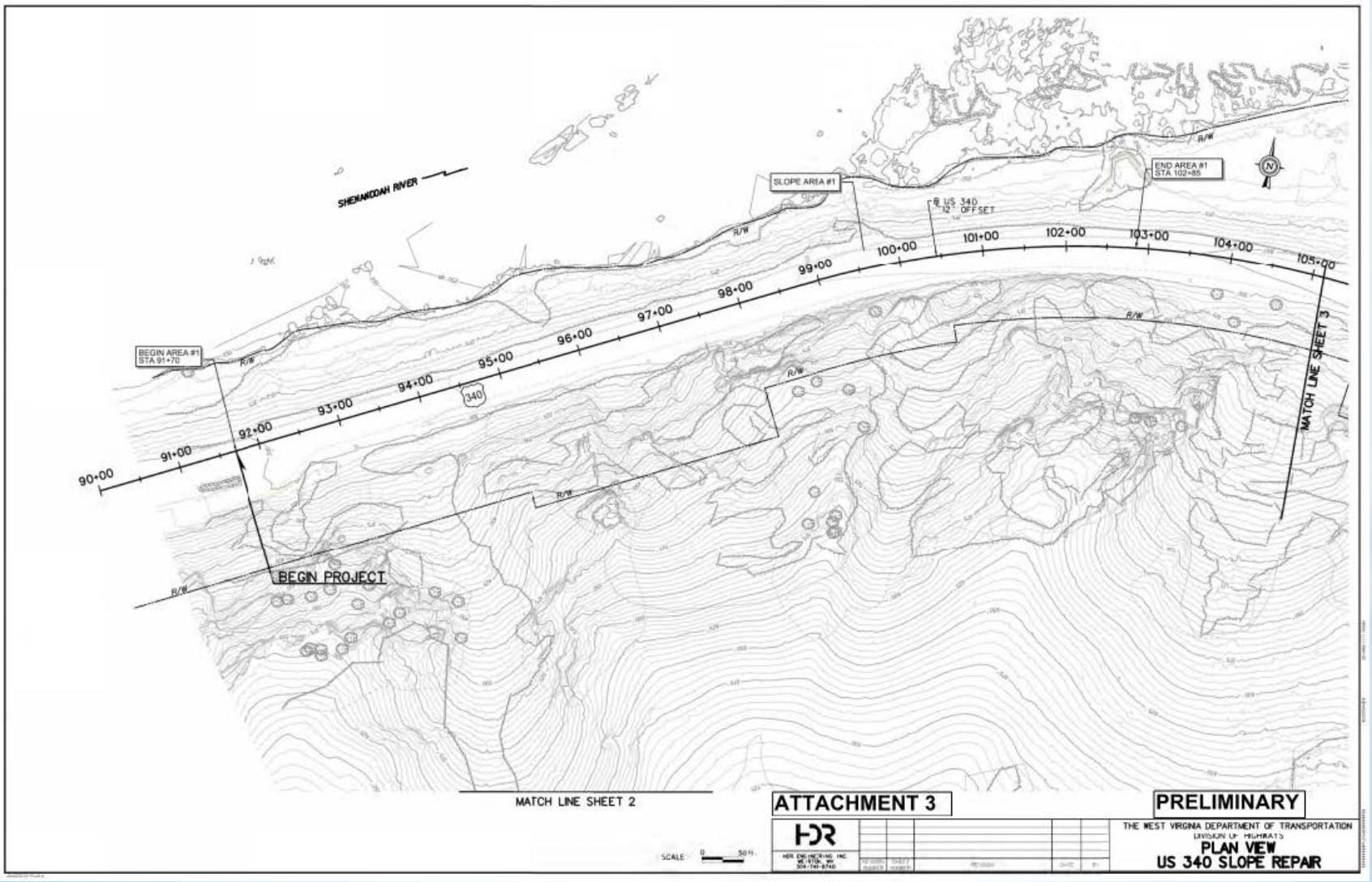
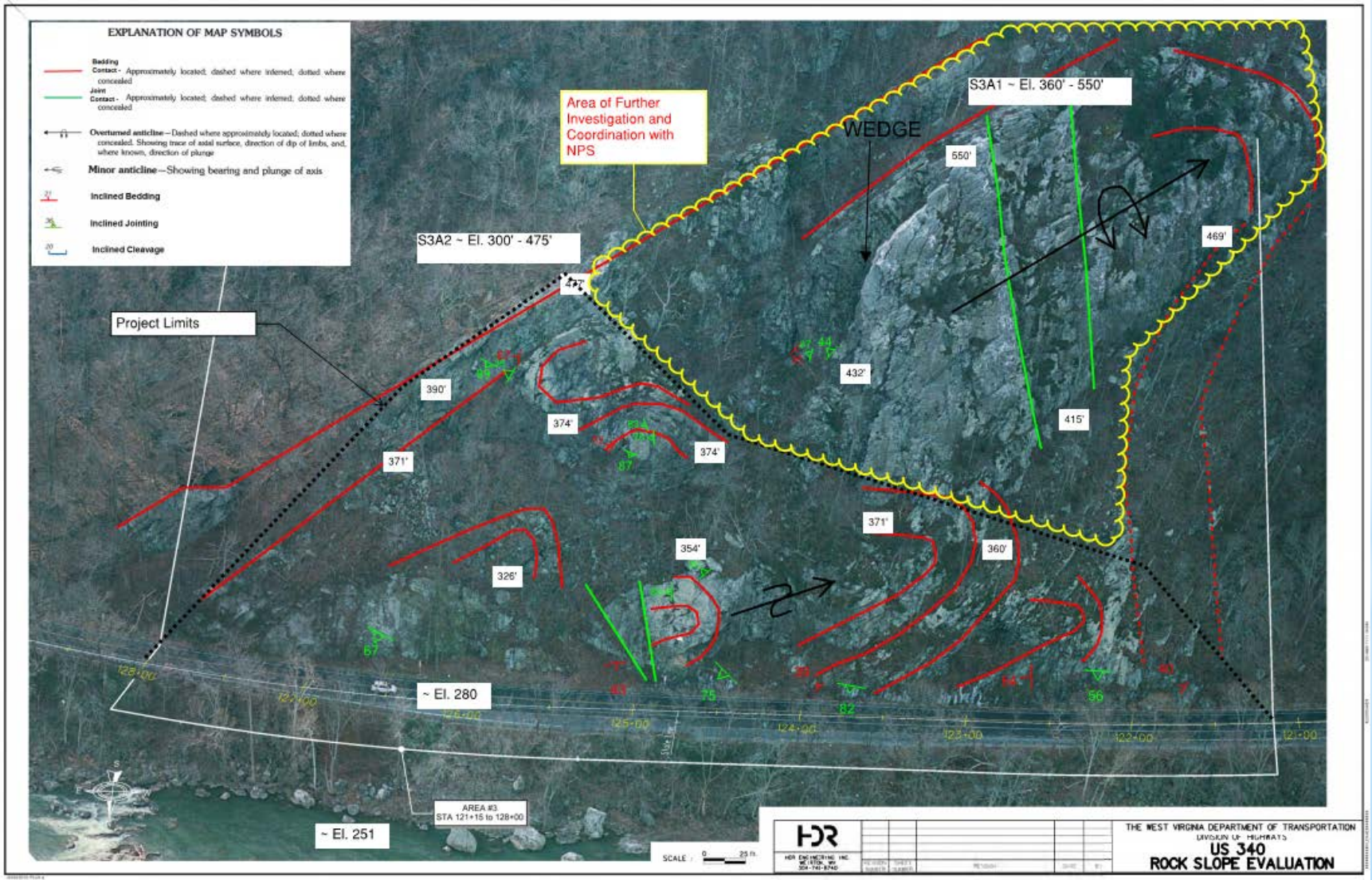


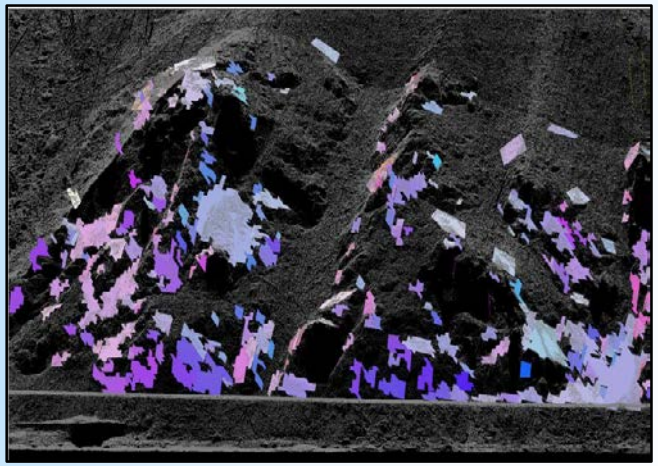
ROAD LEVEL INVESTIGATION

FIELD "TRUTHING" OF GEOLOGIC CONDITIONS:

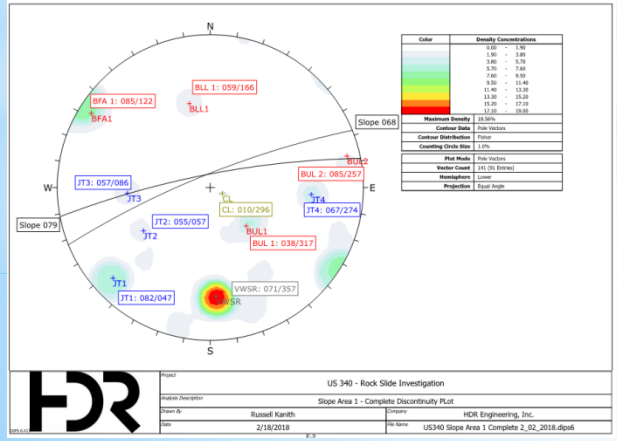


PRELIMINARY ROCK SLOPE ANALYSIS:

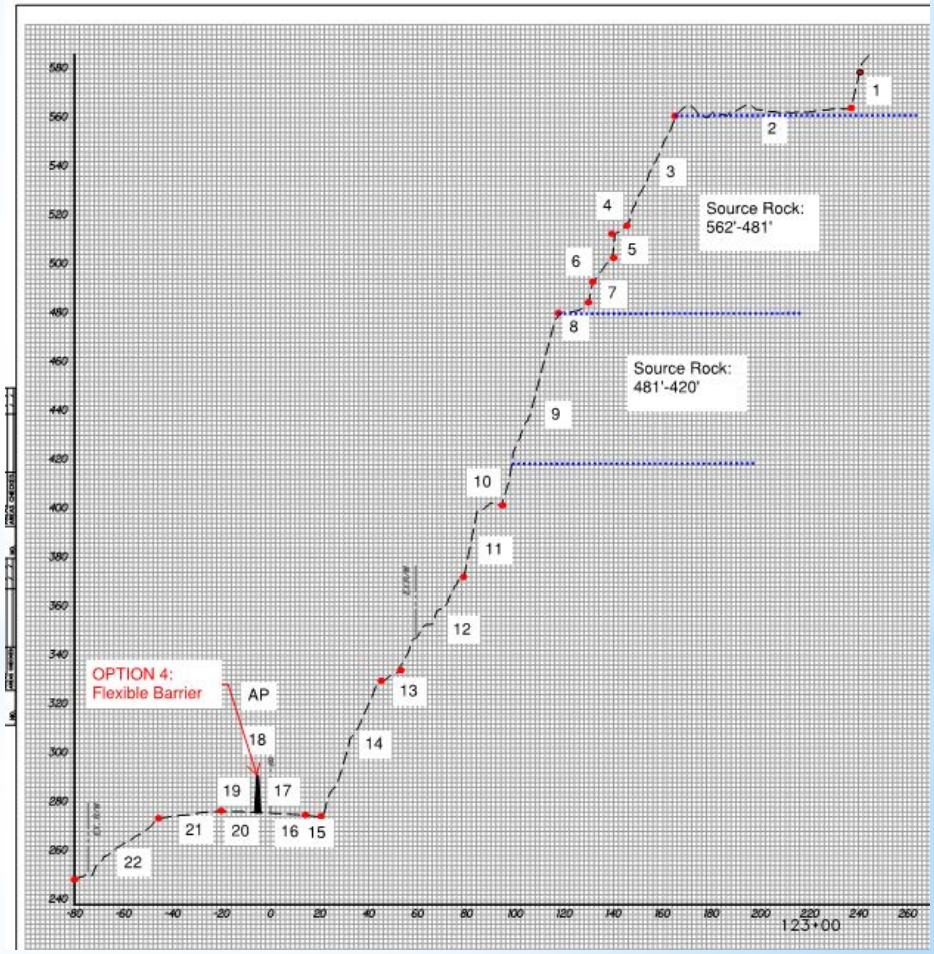
LiDAR Mapping Integrated with SplitFx



Preliminary Kinematic Analysis



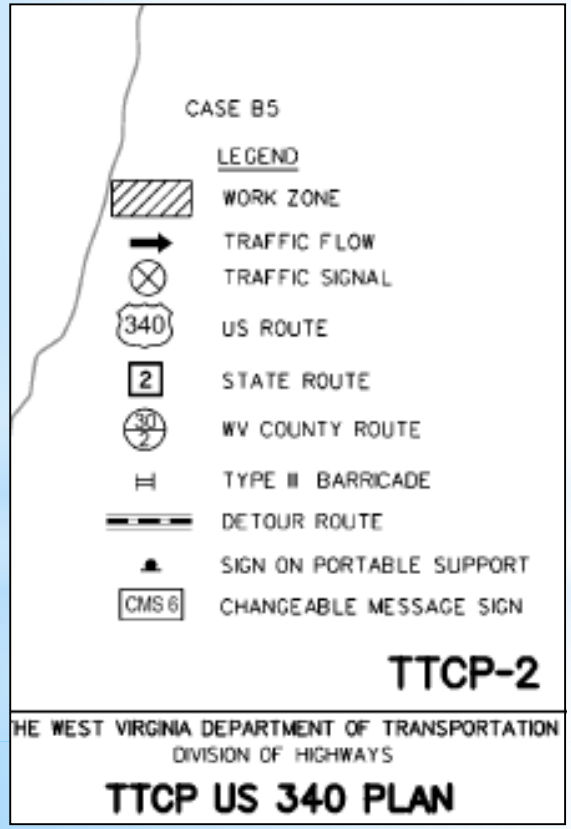
Preliminary CRSP Analysis

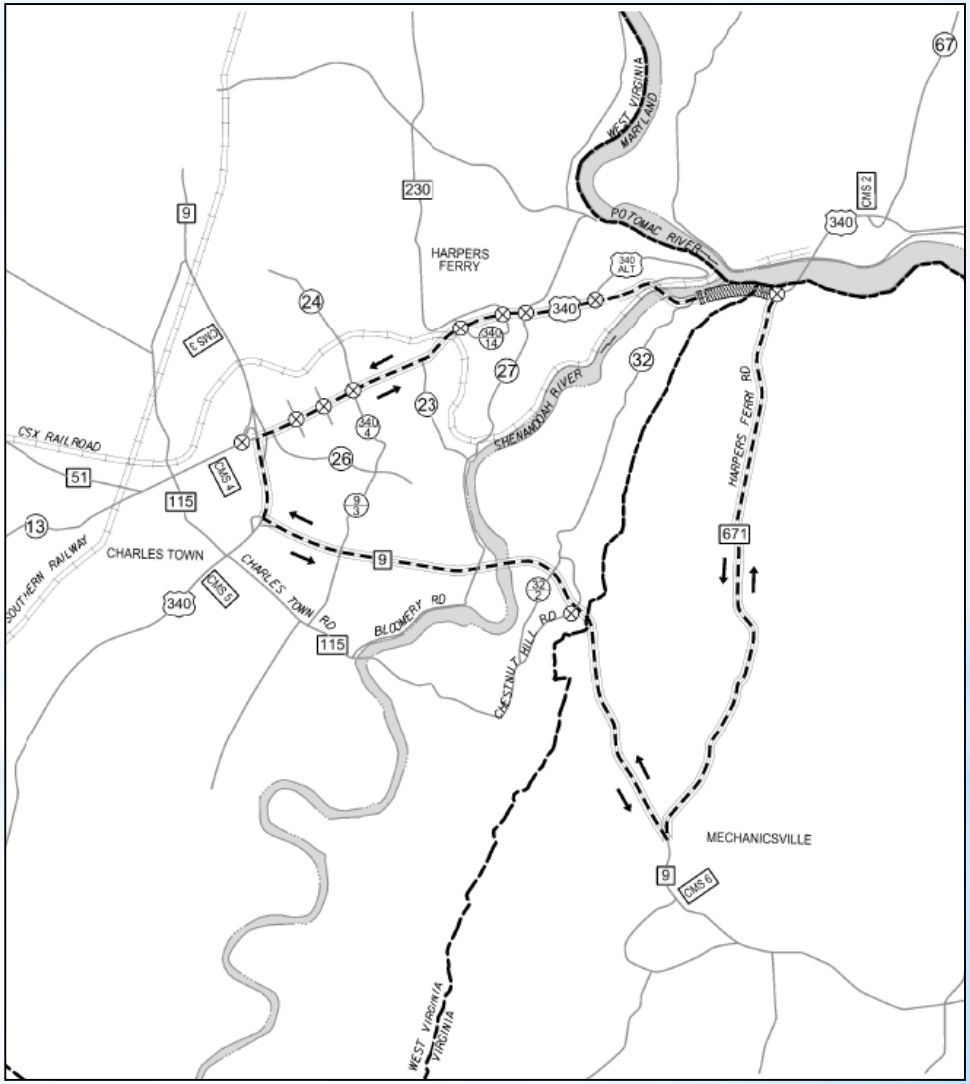


UPPER-SLOPE INVESTIGATION

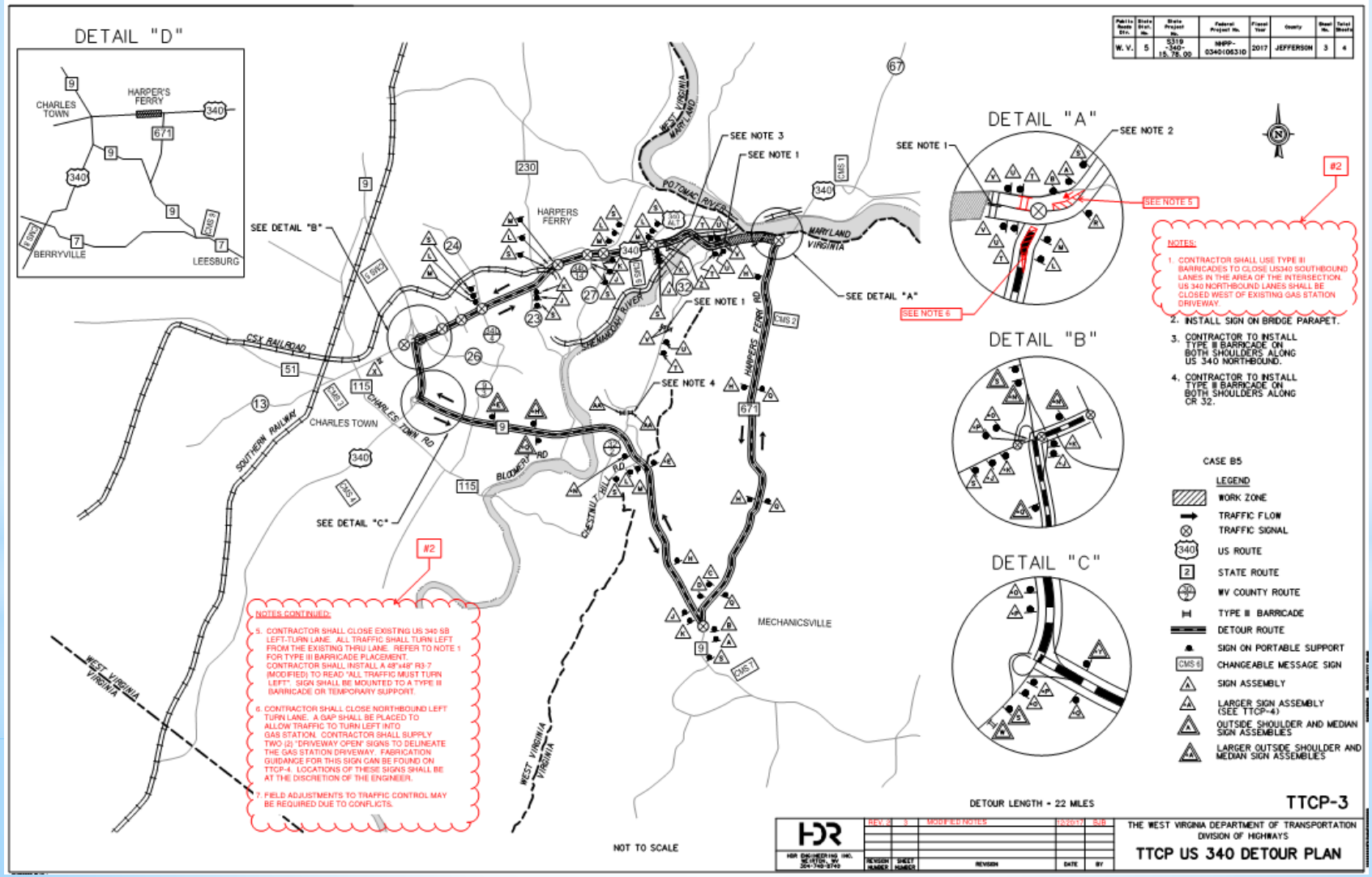
PRELIMINARY TTCP DEVELOPMENT:

Detour:





FINAL TTCP DEVELOPMENT:



A CLOSER LOOK WITH UAV:

UAV and Research Team from Radford University

SLOPE RAPPELLING:

Slope Area 1

SLOPE RAPPELLING:

Slope Area 2

SLOPE RAPPELLING:

Slope Area 3

SLOPE RAPPELLING:

Conditions on Upper Slope Areas

SLOPE RAPPELLING:

Conditions on Upper Slope Areas

SLOPE RAPPELLING:

Conditions on Upper Slope Areas

SLOPE RAPPELLING:

Conditions on Upper Slope Areas

SLOPE RAPPELLING:

Slope Area 1 Safety Scaling

SLOPE RAPPELLING:

Rockfall Cleanup

RELATIVE RISK ASSESSMENT

RELATIVE RISK ASSESSMENT:

Table 1: Relative Rockfall Risk Assessment

Slope Condition		Rockfall Risk[2]			
		Road Cuts and Natural Rock Slopes		Debris Channels	
Slope	Slope Location / Height of Rockfall Generator [1]	Subglobal Rockfall[3]	Global Rockfall[3]	Subglobal Rockfall[3]	Global Rockfall[3]
1	Within DOH ROW	High	High	High	High
	Within Project Limits	High	High	High	High
	Above Project Limits	High[4]	High[4]	Moderate[4]	Moderate[4]
2	Within DOH ROW	High	Moderate	Low	Low
	Within Project Limits	High	Moderate	Low	Low
	Above Project Limits	Low[5]	Low [5]	Low[5]	Low[5]
3	Within DOH ROW	High	High	High	High
	Within Project Limits	High	High	High	High
	Above Project Limits	High[4]	High[4]	Moderate[4]	Moderate[4]

[1] **Slope / Rockfall Generator Location:**
- Within DOH ROW – based on 1949 plans varies from elevation 325 to 450 feet
- Within Project Limits – within ROW and up to approximate elevation 475 feet – blue clouded area on orthophotographs (DOH and NPS ROW)
- Above Project Limits – Outside ROW and Project Limits – yellow clouded area on orthophotographs (NPS ROW)

[2] **Rockfall Risk** - Likelihood of rockfall to reach roadway
- High: 68-100% Likelihood Rockfall will reach the roadway
- Moderate: 34-67%
- Low: 0-33%

[3] **Rockfall Failure Mechanisms:**
- Subglobal Rockfall – 0.5' to 5.0' rockfall diameter
- Global Rockfall – greater than 5.0' diameter rockfall typically discontinuity controlled failures (planar, wedge, etc.)

[4] Slopes were not investigated for rockfall hazards. Relative rating is based on observations from lower elevations from HDR engineering geologists and potentially unknown slope conditions within NPS.

[5] Slope 2 is significantly shorter with less exposed natural rock slopes compared to Slopes 1 and 3. Relative rating is based on observations from HDR engineering geologists

RELATIVE RISK ASSESSMENT :

Table 2: HDR Importance Factors

Driver	Importance Factor
Construction Cost	9
Effectiveness within Project Limits	10
Effectiveness above Project Limits	5
Construction Complexity	5
Traffic Impacts	9
Aesthetics	2
Rockfall Maintenance	5
System Maintenance	8

10 = Most Important **1 = Least Important**

RELATIVE RISK ASSESSMENT :

Table 3: Driver, Driver Description, Score, and Relative Assessment Rating

Driver	Description	Score	Relative Assessment
Construction Cost	Construction costs includes all items necessary to install rockfall protection or mitigation measure. Items include traffic control, safety scaling, equipment, materials, utility maintenance, protection of utilities, etc.	5	Low Cost
		3	Moderate Cost
		1	High Cost
Effectiveness (within Project Limits)	Effectiveness refers to the ability of rockfall protection or mitigation measure to perform for the service life (50 to 75 years) of the project within the project limits. For example scaling would have a lower effectiveness over the service life as compared to a rockfall barrier. The scaling effectiveness can be related to how fast a rock slope weathers or how fractured a slope is, which can reduce the service life of a scaling alternative. Scaling service life is typically 5 to 20 years, but is highly dependent on the site and geologic conditions.	5	High Effectiveness
		3	Moderate Effectiveness
		1	Low Effectiveness
Effectiveness (NPS ROW)	Effectiveness refers to the ability of rockfall protection or mitigation measure to perform for the service life (50 to 75 years) of the project from higher rockfall generators outside of the project limits. Rockfall generators exist outside the project limits which if a rockfall occurs from the higher elevation will impact the effectiveness of the designed system based on the slopes within the project. Rockfall could still impact the roadway with the system in place. However, some systems will offer some improved protection from the higher rockfall generators over other options.	5	High Effectiveness
		3	Moderate Effectiveness
		1	Low Effectiveness
Construction Complexity	Construction complexity refers to constructability of a rockfall protection or mitigation measure relative to site constraints and access. The measure may require a specialty contractor.	5	Low Complexity
		3	Moderate Complexity
		1	High Complexity
Traffic Impacts	Traffic impacts include all impacts to SB and/or NB traffic during construction of a rockfall protection or mitigation measure such as shoulder closure, lane closure, detour, slow roll during blasting, etc.	5	Low Impact
		3	Moderate Impact
		1	High Impact
Aesthetics	Aesthetics refers to any potential impact to the natural/existing scenery and historical setting.	5	Low Impact
		3	Moderate Impact
		1	High Impact
Rockfall Maintenance	Rockfall Maintenance refers to relative cost, traffic impact, and overall complexity involved in long-term clean-up of rockfall activity associated with a particular rockfall protection or mitigation measure to maintain its effectiveness. For example, periodic catchment ditch clean-out behind rockfall barrier or removal of any accumulated material suspended in a mesh or on the slope.	5	Low Maintenance
		3	Moderate Maintenance
		1	High Maintenance
System Maintenance	System Maintenance refers to relative cost, traffic impact, and overall complexity involved in repair or replacement of damaged rockfall protection or mitigation measure due to rockfall activity to maintain its effectiveness. For example, repair or replacement of rockfall barrier or mesh due to rockfall activity.	5	Low Maintenance
		3	Moderate Maintenance
		1	High Maintenance

RELATIVE RISK ASSESSMENT :

Table 4: Feasible Options for Subglobal Rockfall and Global Rockfall for Natural Rock Slopes and Roadway Cuts

		Subglobal Rockfall								Global Rockfall							
Driver	Importance Factor (Weight)	Maintenance Scaling	Maintenance Scaling Score	Rock Slope Drape	Rock Slope Drape Score	Attenuator Drape	Attenuator Drape Score	Flexible Rockfall Barrier	Flexible Rockfall Barrier Score	Maintenance Scaling	Maintenance Scaling Score	Rock Bolts	Rock Bolts Score	Attenuator Drape	Attenuator Drape Score	Rockfall Barrier	Rockfall Barrier Score
Construction Cost	9	5	45	3	27	2	18	1	9	5	45	5	45	2	18	1	9
Effectiveness (within project)	10	3	30	5	50	5	50	5	50	3	30	5	50	3	30	3	30
Effectiveness (NPS)	5	0	0	0	0	4	20	4	20	0	0	0	0	3	15	2	10
Construction Complexity	5	2	10	3	15	2	10	4	20	2	10	3	15	1	5	4	20
Traffic Impacts	9	5	45	4	36	3	27	1	9	5	45	3	27	3	27	1	9
Aesthetics	2	5	10	1	2	1	2	1	2	5	10	3	6	1	2	2	4
Rockfall Maintenance	5	1	5	3	15	3	15	3	15	2	10	3	15	3	15	3	15
System Maintenance	8	5	40	1	8	1	8	3	24	5	40	4	32	3	24	2	16
Total			**185**		**153**		**150**		**149**		**190**		**190**		**136**		**113**

Slope 1 and 3:

- Maintenance Scaling - 185
- Attenuator Barrier – 150 [1]
- Localize Road Shift - Flexible Rockfall Barrier – 149 [1]
- Rock Bolting - 190

Slope 2:

- Maintenance Scaling - 185
- Rock Bolting – 190
- Rock Slope Drape – 153 [1]

1. Slope 2 has lower rockfall generators and less exposed rock face in close proximity to the roadway and a lower likelihood of rockfall from above the project limits. Therefore, the attenuator barrier and localized road shift were not considered for Slope 2.

PROBABLE CONSTRUCTION COST ESTIMATE:

Table 1-1: Slope 1 Cost Summary of Remediation Options

Slope 1 Remediation Cost Summary Options:			Rockfall Remediation Cost			Estimated Traffic Detour Cost			Total		
OPTION	OPTION DESCRIPTION	SLOPE CONDITION	DOH ROW	NPS ROW within Project Limits	Project Limits	DOH ROW	NPS ROW within Project Limits	Project Limits	DOH ROW	NPS ROW within Project Limits	Project Limits
1	Maintenance Scaling	Natural Rock Slope and Roadway Cut	$923,855	$379,387	$1,303,242	$253,125	$84,375	$337,500	$1,176,980	$463,762	$1,640,742
3	Attenuator Barrier with Drape	Natural Rock Slope and Roadway Cut	$1,593,177	$31,646	$1,624,823	$590,625	$196,875	$787,500	$2,183,802	$228,521	$2,412,323
4	Localized Roadway Shift with Rockfall Barrier	Natural Rock Slope and Roadway Cut, and Debris Channel / Boulder Field	$2,820,377	$0	$0	$2,250,000	$0	$0	$5,070,377	$0	$5,070,377
5	Pinned Rock Berm	Debris Channel / Boulder Field	$67,500	$0	$67,500	$0	$0	$0	$67,500	$0	$67,500
6	Attenuator Barrier	Debris Channel / Boulder Field	$292,500	$0	$292,500	$0	$0	$0	$292,500	$0	$292,500
Options 1+5+6			$1,021,355	$379,387	$1,081,355	$379,387	$1,460,742	$253,125	$84,375	$337,500	$1,334,480
Options 3+5+6			$1,690,677	$31,646	$1,750,677	$31,646	$1,782,323	$590,625	$196,875	$787,500	$2,341,302
Option 4			$2,820,377	0	$2,820,377	$0	$0	$2,250,000	$0	$2,250,000	$5,070,377

Table 1-2: Slope 2 Cost Summary of Remediation Options

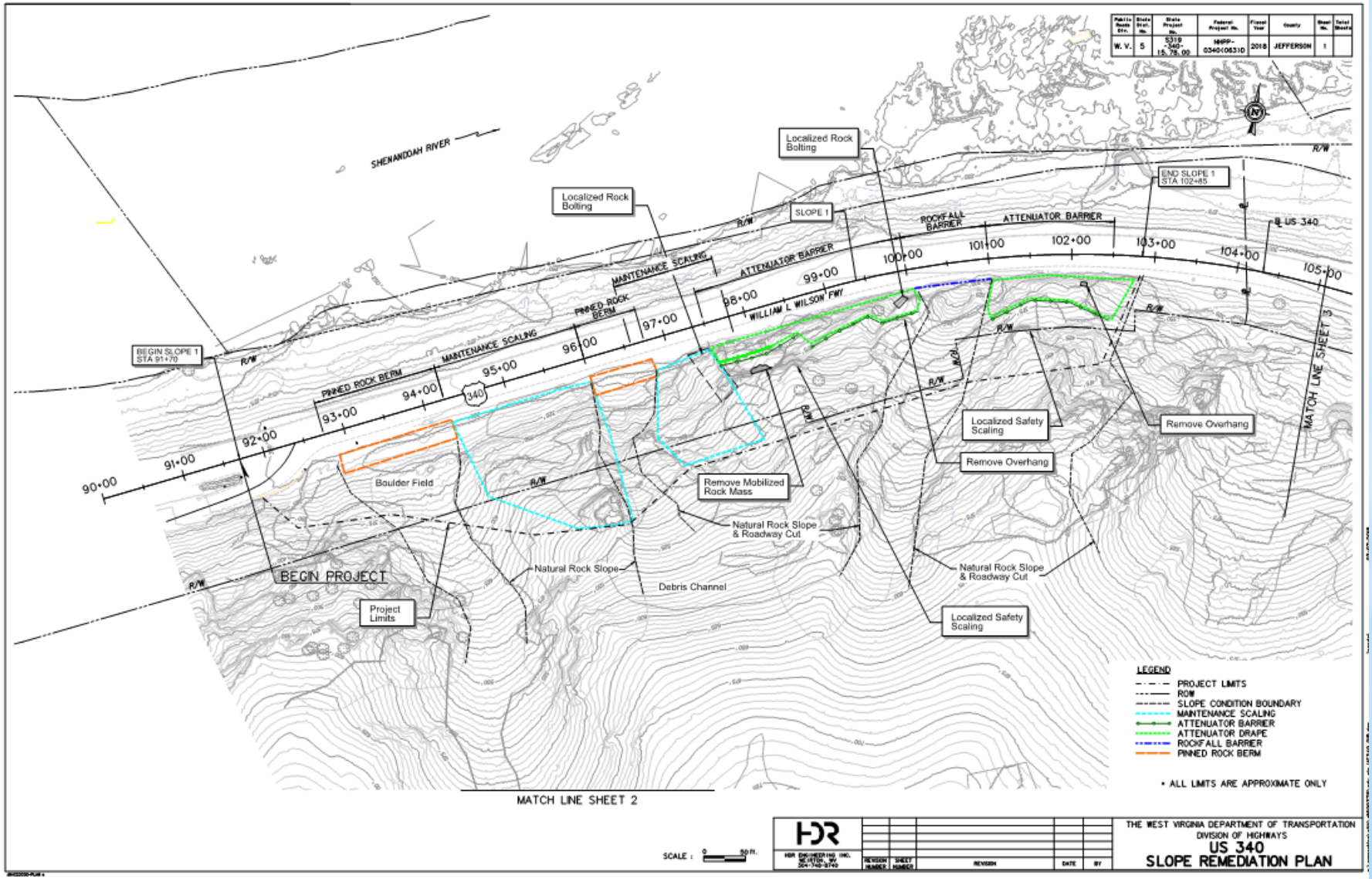
Slope 2 Remediation Cost Summary Options:			Rockfall Remediation Cost			Estimated Traffic Detour Cost			Total		
OPTION	OPTION DESCRIPTION	SLOPE CONDITION	DOH ROW	NPS ROW within Project Limits	Project Limits	DOH ROW	NPS ROW within Project Limits	Project Limits	DOH ROW	NPS ROW within Project Limits	Project Limits
1	Maintenance Scaling	Natural Rock Slope and Roadway Cut	$246,591	$219,710	$466,301	$183,750	$183,750	$367,500	$430,341	$403,460	$833,801
2	Rock Slope Drape	Natural Rock Slope and Roadway Cut	$305,209	$325,737	$630,947	$183,750	$183,750	$367,500	$488,959	$509,487	$998,447
5	Pinned Rock Berm	Debris Channel / Boulder Field	$34,220	$0	$34,220	$0	$0	$0	$34,220	$0	$34,220
7	Gabion Barrier	Debris Channel / Boulder Field	$37,167	$0	$37,167	$0	$0	$0	$37,167	$0	$37,167
Slope 2: Options 1+7			$280,811	$219,710	$280,811	$219,710	$503,467	$183,750	$183,750	$367,500	$464,561
Slope 2: Options 2+7			$342,376	$325,737	$342,376	$325,737	$668,113	$183,750	$183,750	$367,500	$526,126

Table 1-3: Slope 3 Cost Summary of Remediation Options

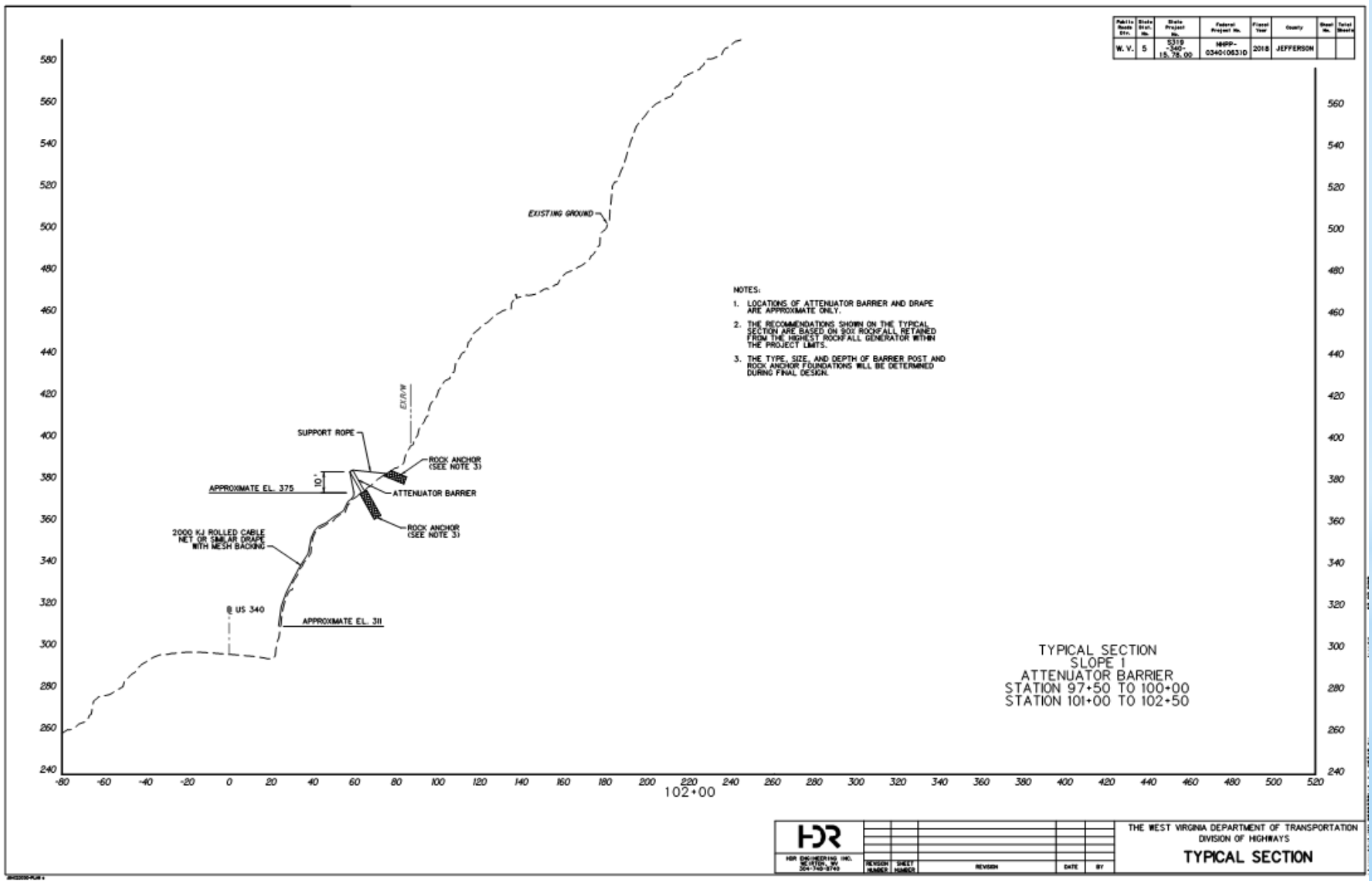
Slope 3 Remediation Cost Summary Options:			Rockfall Remediation Cost			Estimated Traffic Detour Cost			Total		
OPTION	OPTION DESCRIPTION	SLOPE CONDITION	DOH ROW	NPS ROW within Project Limits	Project Limits	DOH ROW	NPS ROW within Project Limits	Project Limits	DOH ROW	NPS ROW within Project Limits	Project Limits
1	Maintenance Scaling	Natural Rock Slope and Roadway Cut	$558,259	$474,753	$1,033,013	$275,625	$91,875	$367,500	$833,884	$566,628	$1,400,513
3	Attenuator Barrier with Drape	Natural Rock Slope and Roadway Cut	$1,104,256	$231,617	$1,335,873	$408,750	$408,750	$817,500	$1,513,006	$640,367	$2,153,373
4	Localized Roadway Shift with Rockfall Barrier	Natural Rock Slopes and Roadway Cut	$886,463	$0	$0	$1,132,500	$0	$0	$2,018,963	$0	$2,018,963

PRELIMINARY SLOPE REMEDIATION PLANS

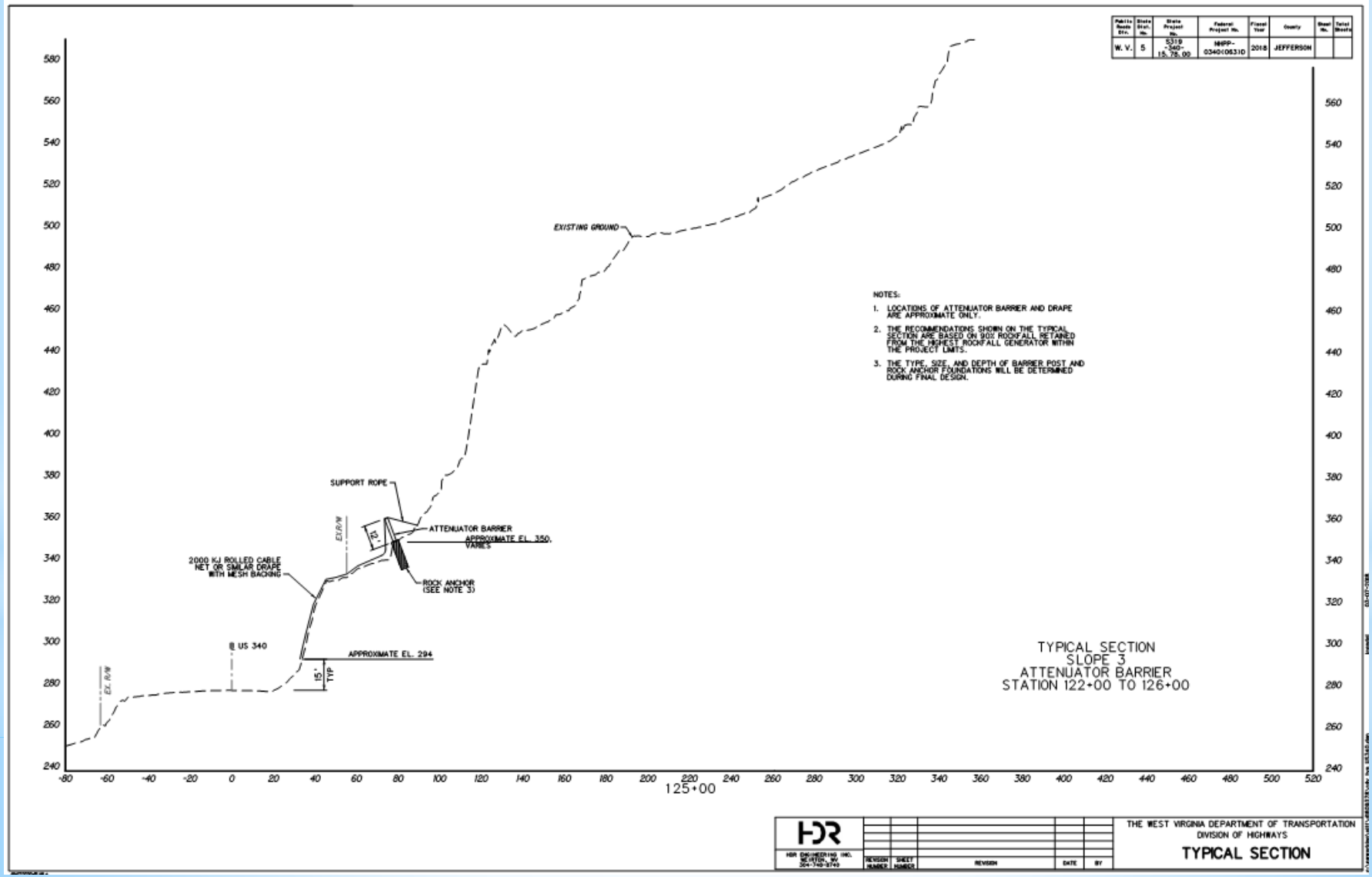
PRELIMINARY SLOPE REMEDIATION PLANS:



PRELIMINARY SLOPE REMEDIATION PLANS:



PRELIMINARY SLOPE REMEDIATION PLANS:



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