Standard Title Page - Report on State Project

<table>
<tr><td>Report No.

VTRC 06-R23</td><td>Report Date

June 2006</td><td>No. Pages

46</td><td>Type Report:
Final
Period Covered:
December 2004 – February 2006</td><td>Project No.:
75852</td></tr>
<tr><td colspan="4"></td><td>Contract No.</td></tr>
<tr><td colspan="4">Title:
Implementation of the Rock Slope Management Project at the Virginia Department of Transportation</td><td rowspan="3">Key Words:
Rock slope management, rockslide, rockfall, geotechnical asset, asset management, RHRS.</td></tr>
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Abstract

The Virginia Department of Transportation (VDOT) is currently developing an asset management system, identifying various transportation assets for inclusion in the system. Rock slopes along Virginia's highways can be viewed as assets that need to be managed proactively in order to maintain a safe and effective transportation network. The benefits of rock slope management are expected to be similar to those derived from bridge and pavement management systems, including inventory, condition, and estimate of maintenance needs. An established rock slope management tool designed to facilitate proactive management of rock slopes is available by way of the Rockfall Hazard Rating System (RHRS), initially developed for the Federal Highway Administration by the Oregon Department of Transportation. The purpose of the RHRS is to allow agencies to prioritize rock slopes for remediation based on a risk assessment and to facilitate the allocation of funds for needed remediation.

VDOT adopted a modified version of the RHRS, which could serve an important role in a comprehensive rockfall management program. Core elements of such a program, including technical training and setup of a GIS database, were implemented in this study to assist VDOT in identifying potentially hazardous rock slopes and establishing funding priorities for mitigation projects.

FINAL REPORT

IMPLEMENTATION OF THE ROCK SLOPE MANAGEMENT PROJECT AT THE VIRGINIA DEPARTMENT OF TRANSPORTATION

Edward J. Hoppe, Ph.D., P.E.
Senior Research Scientist

Derek H. Whitehouse, C.P.G.
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Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

June 2006
VTRC 06-R23

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ABSTRACT

The Virginia Department of Transportation (VDOT) is currently developing an asset management system, identifying various transportation assets for inclusion in the system. Rock slopes along Virginia's highways can be viewed as assets that need to be managed proactively in order to maintain a safe and effective transportation network. The benefits of rock slope management are expected to be similar to those derived from bridge and pavement management systems, including inventory, condition, and estimate of maintenance needs. An established rock slope management tool designed to facilitate proactive management of rock slopes is available by way of the Rockfall Hazard Rating System (RHRS), initially developed for the Federal Highway Administration by the Oregon Department of Transportation. The purpose of the RHRS is to allow agencies to prioritize rock slopes for remediation based on a risk assessment and to facilitate the allocation of funds for needed remediation.

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INTRODUCTION

Overview

The Virginia Department of Transportation (VDOT) is currently developing an asset management system, identifying various transportation assets for inclusion in the system. Rock slopes along Virginia's highways can be viewed as assets that need to be managed proactively in order to maintain a safe and effective transportation network. The benefits of rock slope management are expected to be similar to those derived from bridge and pavement management systems, including inventory, condition, and estimate of maintenance needs. An established rock slope management tool designed to mitigate the situation shown in Figure 1 is available by way

Figure 1. Rockfall at Route 56 Near Crabtree Falls, Nelson County (February 2001)

of the Rockfall Hazard Rating System (RHRS), initially developed for the Federal Highway Administration (FHWA) by the Oregon Department of Transportation (ODOT).[1] The purpose of the RHRS is to allow agencies to prioritize rock slopes for remediation based on a risk assessment and to facilitate the allocation of funds for needed remediation. Presently, rock slopes are not subject to any structured maintenance plan at VDOT.

Preliminary Rating

In a preliminary rating, rock slopes are quickly evaluated and grouped into three broad classes, labeled as *A, B,* and *C,* with the *A* category considered the most at risk. The preliminary rating is accorded on the basis of the potential for rockfall activity and on the historical record, as provided by maintenance personnel.

Detailed Rating

All of the *A*-rated slopes are subjected to a detailed rating procedure. The *B*-rated slopes are evaluated only if time and funding allow further attention. No further action is taken with respect to *C*-rated slopes.

The following specific categories comprise the detailed rating:

1. slope height
2. ditch effectiveness
3. average vehicle risk (probability of being in a wrong place at a wrong time)
4. sight distance
5. roadway width
6. geologic character of the rock slope (Case I is governed by structural discontinuities; Case II is governed by differential erosion.)
7. block size/volume/event
8. climate (including rainfall)
9. past rockfall incidents: block size/volume/frequency of events.

Each category is numerically rated based on the perceived degree of risk. An exponential scoring system is used, providing a rapid increase in score to highlight at-risk sites. Detailed guidance on various rating categories is provided in the RHRS manual.[1]

Remediation Data

Remediation measures, designed to mitigate the potential rockfall hazard, are based on the detailed ratings. Potential rockfall remediation designs include scaling, wire mesh screening, rock bolts, catch fences, barriers, etc. The proposed remedial design and associated construction costs, as recommended by a geologist, become an integral part of the RHRS database.

PURPOSE AND SCOPE

This study was designed to determine the state of the practice in rockfall management in the United States and adapt it for conditions in Virginia. Technical issues such as training, data collection, data analysis, and presentation of results were addressed. In addition, administrative aspects involving the development of a funding allocation system were investigated. Ultimately, the purpose of the study was to implement the essential components of a rock slope management program at VDOT.

METHODOLOGY

Seven tasks were carried out to achieve the study objectives:

1. determination of the type and format of the data elements required for a VDOT RHRS database

2. selection of a consultant experienced with RHRS database development and agency implementation

3. holding of a scoping meeting, and identification of specific geologic conditions and potential rockfall hazards.

4. provision of training in the use of RHRS to VDOT district geologists

5. development of a customized Access database file for field data collection

6. implementation of the Access database

7. determination of components and funding needed for a VDOT Rock Slope Management Program.

Determination of VDOT Data Needs

The project was initiated following its approval by VDOT's Maintenance Program Leadership Group (MPLG) Committee in December 2004. Staff of VDOT's Asset Management Division were subsequently contacted to determine the type and format of data elements required for inclusion in a VDOT RHRS database.

Consultant Selection

Because an RHRS had already been adopted in a number of other jurisdictions, a search was carried out for a consultant experienced with RHRS database development and agency implementation.

Scoping Meeting and Identification of Geologic Condition and Potential Rockfall Hazards

A scoping meeting between the VDOT district geologists and the consultants was held in March 2005 in Charlottesville. Specific geologic conditions and potential rockfall hazards were identified in various districts. The nine rating categories used in the RHRS were discussed, with a particular emphasis on the applicability to Virginia's conditions. Extensive feedback was provided to the consultants regarding the relative merits of each RHRS rating category as applicable to Virginia.

Training in Use of RHRS and Development of Customized Access Database File

A 2-day training course was provided by the consultants to district geologists in June 2005 at VDOT's Salem District Office. It covered practical aspects of the RHRS operation. Class instructions were followed by a field rating exercise. Additional feedback was provided to the consultants with regard to customization of the ACCESS database used for rating rock slopes.

Subsequently, the consultants developed a customized Access database file for VDOT.

Implementation of Access Database

VDOT geologists were requested to rate 20 to 30 rock slope sites in each district and enter ratings into the Access database. Each geologist personally selected potentially hazardous rock slopes based on his experience with the area and based on discussions conducted with the district maintenance personnel. A total of 113 potential rockfall sites were identified and rated between June and December 2005 in VDOT's western districts (Bristol, Salem, Lynchburg, Staunton, and Culpeper). Selected RHRS ratings and proposed mitigation measures were subsequently evaluated in detail by the consultants.

Determination of Components and Funding Required for a VDOT Rock Slope Management Program

A rock slope management program consists essentially of two major components: rating and remediation. The rating component involves data collection and processing. The remediation process is based on the results of the ratings. Administratively, it is relatively easy to budget for ratings, since the number of sites to rate per year and the average cost per site can be estimated fairly closely. The cost of the remediation component is much more difficult to quantify at the outset of the program, because the extent of the potential risk is unknown until more field inspections are carried out.

Although the FHWA's RHRS manual[1] does not provide guidance for the allocation of funds, it can be argued that a successful remediation program requires a budget that represents some percentage of the already identified needs. Total statewide funding should reflect a demonstrable effort aimed at actively addressing the known hazard.

Two possible approaches may be considered for remedial funding allocation, one addressing the severity (fully fund the highest-rated sites first) and the other addressing the multitude of high ratings above a particular threshold. Published studies recommend the second approach, which results in hazard reduction along as many miles as possible, using the available budget.[2]

RESULTS

Determination of VDOT Data Needs

It was deemed essential to provide RHRS data in a format that positively identifies the location of a given rockfall site within VDOT's highway network. The information includes route designation, proper site coordinates (latitude and longitude), and offset distance. VDOT's Asset Management Division was consulted regarding the required format of the location data. The finalized data structure, including all rating components, was subsequently relayed to VDOT's Information Technology Applications Division, with a proposal to incorporate the entire RHRS database structure in the existing web-based GIS Integrator. This proposal was accepted, and the RHRS layer is currently being developed. It will serve as the central storage for all RHRS-related information and a business tool for budget allocation. Work in progress can be viewed at http://bioapp07/website/rhrs_dev/ (VDOT Intranet access only).

Consultant Selection

Following a formal bid process, a consulting contract was awarded to Landslide Technology of Portland, Oregon. Lawrence Pierson, Senior Associate of Landslide, was assigned to the project, together with Darren Beckstrand, the Project Engineering Geologist. Pierson is one of the original developers of the RHRS.[1]

Development of Customized Access Database File

The consultants developed and delivered a customized Access database file to VDOT. This file has been made available to VDOT's Asset Management Division and Information Technology Applications Division.

A major modification of the original RHRS database structure involved removing the "Climate" category from the detailed ratings. It was recognized that the amount of annual rainfall at a particular site in Virginia was difficult to determine in an objective manner. In addition, the presence of water on a slope cannot always be ascertained. A decision was made to rate only those elements that are directly and objectively measurable at a given location at the time of the rating.

Implementation of Access Database

The RHRS ratings collected from the 113 sites are posted on the Internet (VDOT access only) at http://matrix.vtrc.virginia.edu/rhrs/. This website will serve as an intermediate storage location for the rockfall data (excluding the GIS functionality) until the official GIS Integrator RHRS web page is finalized.

Figures 2 through 7 show typical data collected in the field and entered into the Access file. The information includes a description of the site location (with GPS coordinates), preliminary ratings, detailed ratings, photos (including GPS location and orientation of the camera), maintenance data, and proposed mitigation measures. The final results are summarized in terms of a single rating number and a cost of the proposed remedial action. Figure 8 shows an example of a final report, generated to display a detailed rating summary.

The consultants conducted a review of rockfall ratings, concentrating on the five highest-scoring sites from each district. Their report is provided in Appendix A. The consultants concluded that "VDOT now has the tools and training required to approach the State's rockfall hazards in a comprehensive fashion."

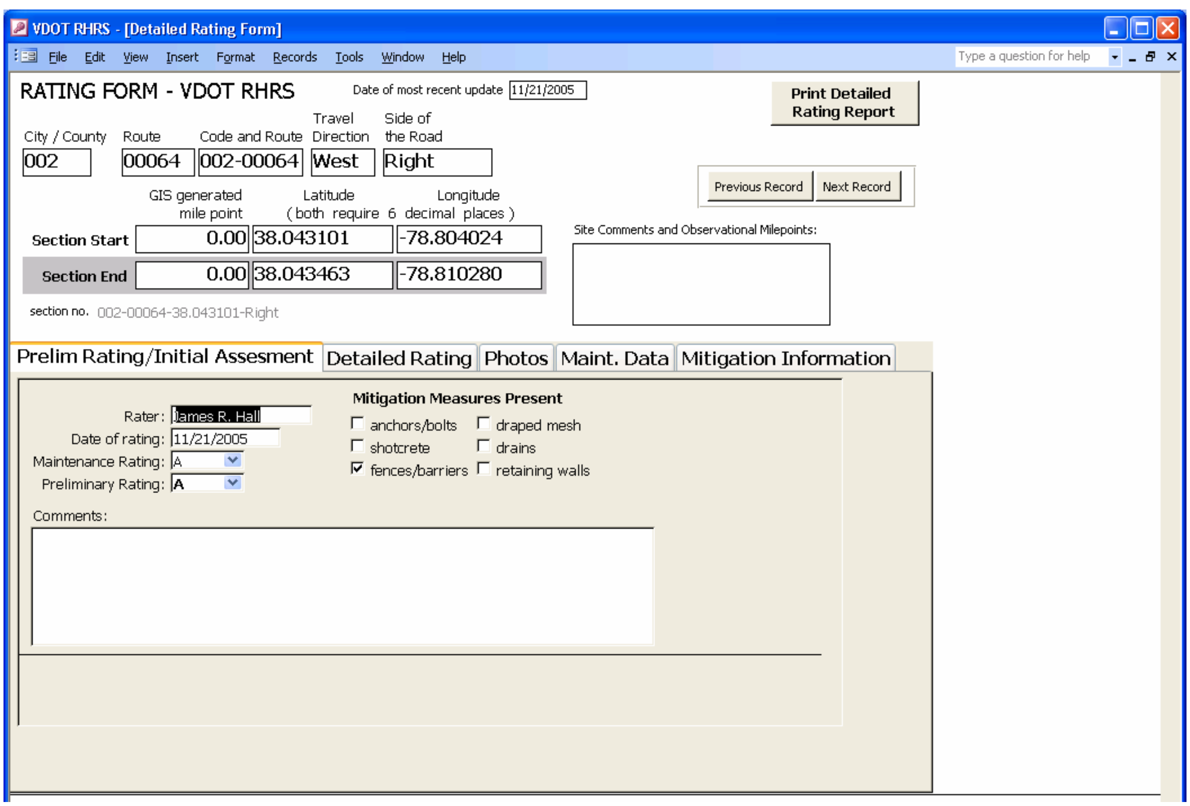

Figure 2. Preliminary Rating Data

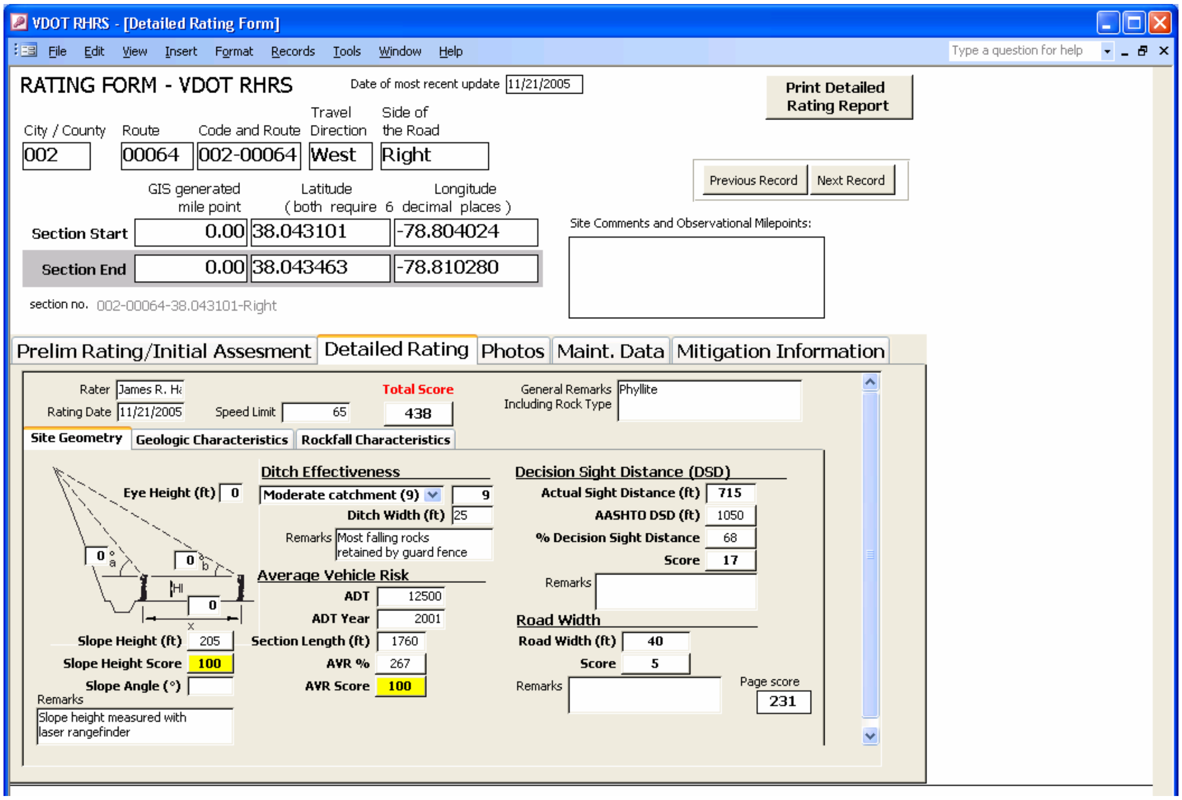

Figure 3. Detailed Rating Data

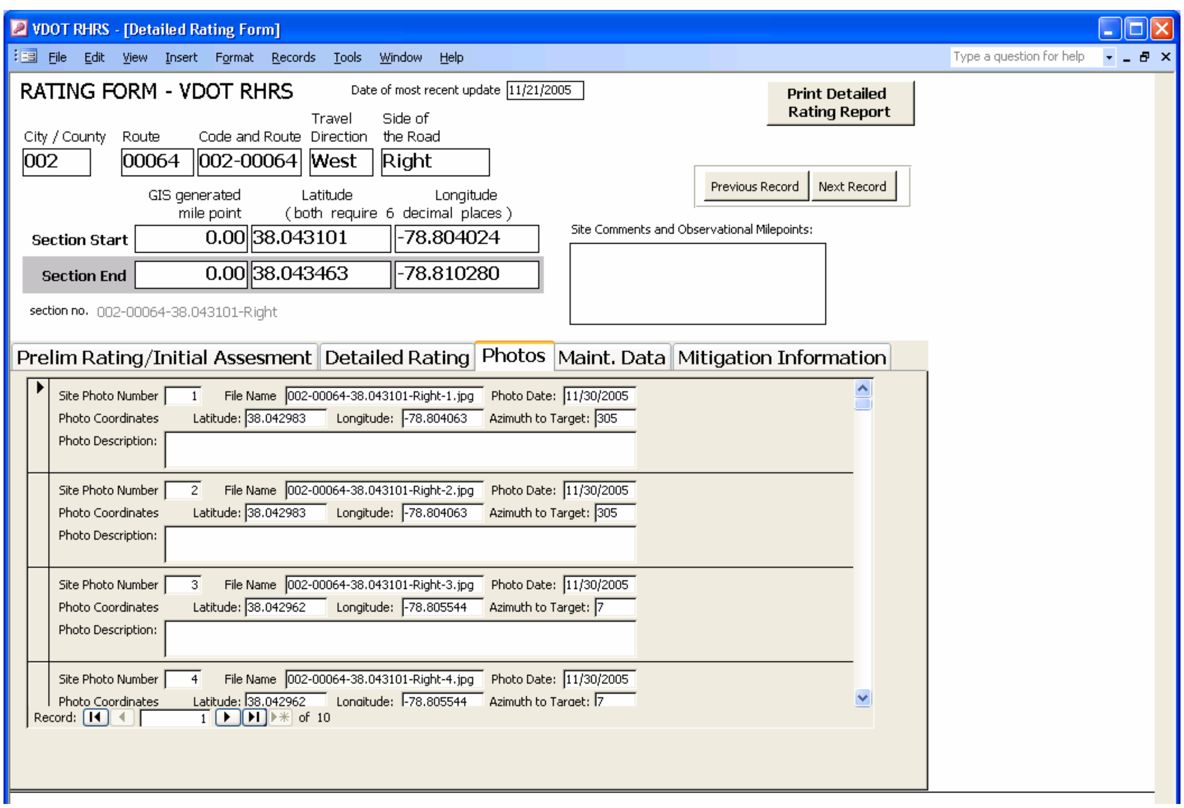

Figure 4. Site Photo Location Data

Figure 5. Example of Referenced Photo

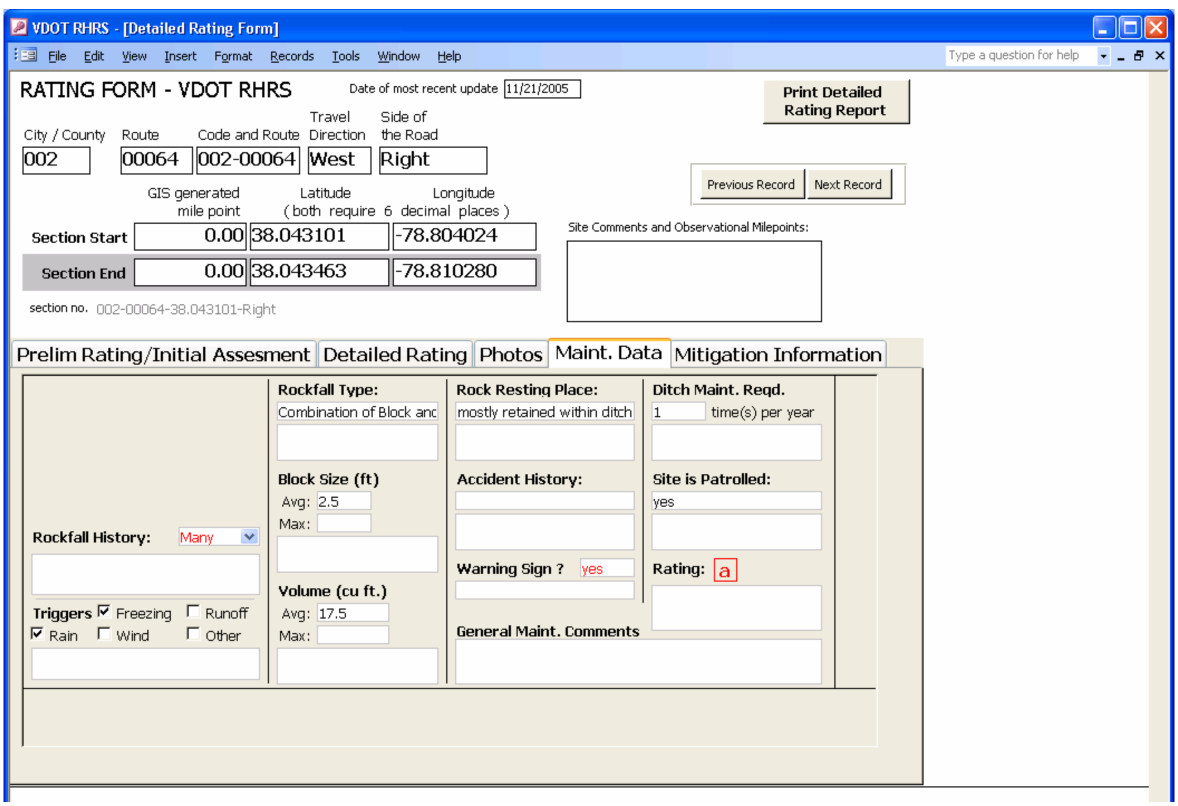

Figure 6. Maintenance Data

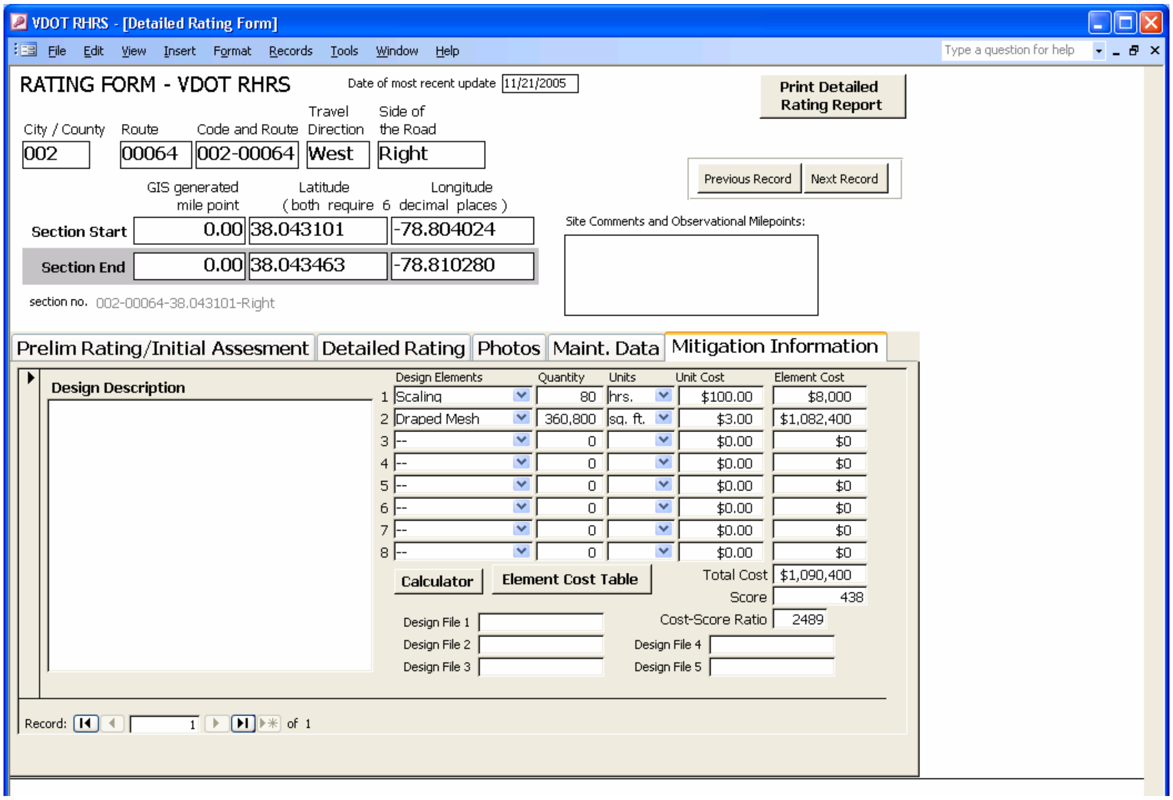

Figure 7. Mitigation Data

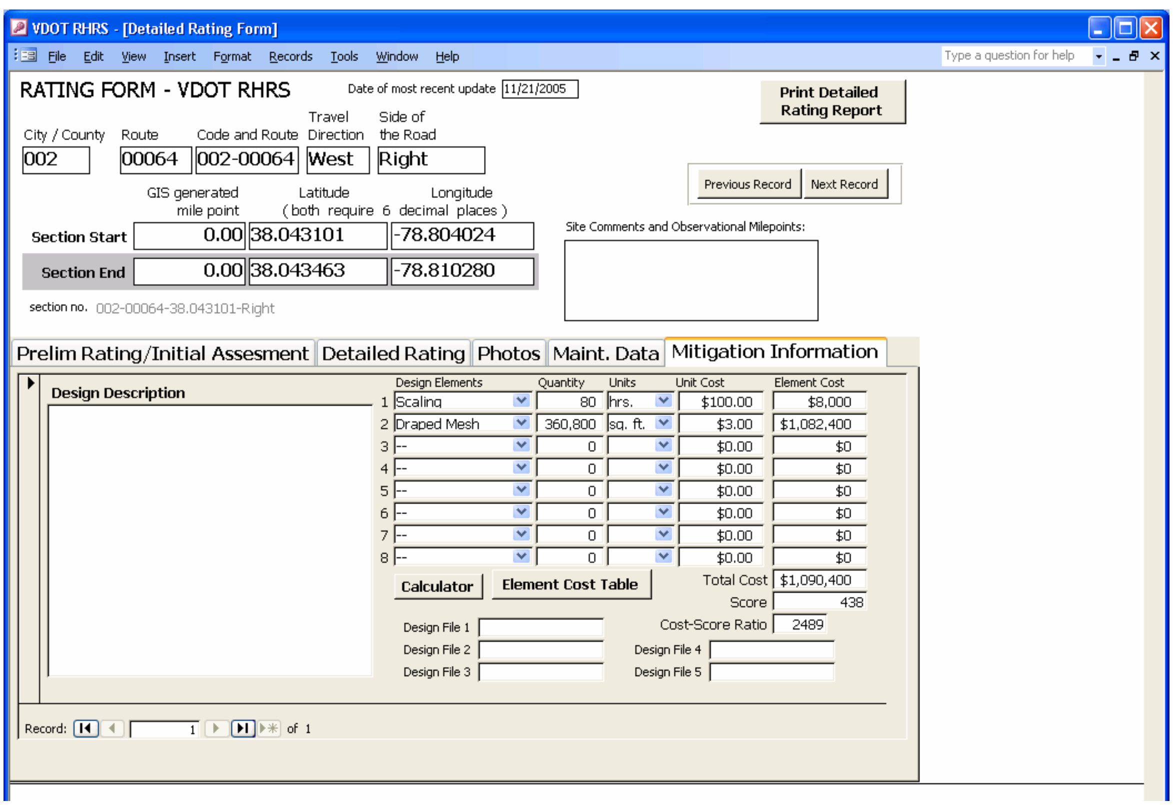

Figure 8. Example of Output Report

Presently, it is difficult to develop a statewide picture of the potential extent of the rock slope risk until more field inspections are carried out. A preliminary estimate of slopes that need to be assessed, provided by district geologists, is as follows:

- Staunton, approximately 100
- Lynchburg, approximately 100
- Bristol, more than 100
- Salem, more than 100.

Proposed VDOT Rock Slope Management Program

VDOT's Rock Slope Management Program should come under VDOT's Asset Management Division. It will require continuous administrative and technical support. The technical oversight should be provided by VDOT's Chief Transportation Geologist, who should be held accountable for the overall quality of the program.

Data for the GIS Integrator RHRS website will be fed from individual Access database rating files supplied by district geologists. It is recommended that all final ratings be approved by a professional geologist experienced in the use of RHRS prior to them being posted on the website. Having a licensed professional review and take responsibility for the ratings is likely to result in a more transparent and uniform system.

The GIS Integrator website will display locations of rock slopes rated 300 and above as red triangles to indicate the most hazardous sites. Slopes rated below 300 will be denoted as light blue triangles. The proposed cutoff score of 300 is consistent with the level established in other states (typically in the 300 to 350 range). In Virginia, many rock slopes are encountered on relatively low-volume roads. This situation results in the average vehicle risk (AVR) rating component scoring low and consequently depressing the overall rating. Having a threshold of 300 is likely to flag many of these rock slopes. It is proposed that the needs for budget development be quantified based on the number of sites rated 300 and above. This functionality will be provided on the GIS Integrator RHRS website.

Further, it is proposed that the total funding for the VDOT Rock Slope Management Program consist of two components: rating and remediation. Appendix B provides the rating budget recommendations for various districts, based on estimated needs, degree of effort required, and feedback from rating work done to date. Overall, it is estimated that when VDOT personnel and resources are used, approximately $80,000 per fiscal year will be needed to cover the entire rating program.

The magnitude of the required remediation funding component will depend on the discovery of at-risk slopes, as identified by site ratings above 300. It is proposed that the initial annual remediation budget allocation per district be based on the following formula:

[District number of "+300-rated" slopes/Statewide number of "+300-rated" slopes]
x (Statewide remediation budget)

The total statewide remediation budget should reflect a percentage of the needs already identified. As of December 31, 2005, approximately $10 million worth of rock slope remedial measures was identified by district geologists. These conceptual estimates do not include full contract costs associated with incidentals, such as traffic control, mobilization, etc. It is recommended that the remediation funding be determined at the end of a given calendar year for possible inclusion in the following fiscal year budget by VDOT's Asset Management Division. For the first operational year of the program, it is recommended that approximately $5 million be allocated.[3]

In many cases, remedial measures can be carried out by state forces. More elaborate solutions will likely require procurement of experienced contractors. It is recommended that the statewide remediation budget be used only for "+300-rated" sites with an estimated remedial cost less than $200,000. Contract maintenance funds should be considered for sites above this cost threshold.[3]

DISCUSSION

VDOT, as a transportation agency, is responsible for providing and maintaining a safe roadway network to the traveling public. The risk of rockfalls is inherent and unavoidable along many highways. A sensible way to approach this challenge is to treat rock slopes as roadside geotechnical assets that need to be managed in a proactive fashion.[4] The primary justification for such an approach is to reduce lifecycle costs associated with construction and maintenance of assets at a systemwide level. It is also a prudent business practice. In the past, the U.S. courts have indicated that it is unreasonable to expect an agency to have enough funds at its disposal to deal with all possible safety issues at any given time. However, a formal system should be set up that identifies and rectifies "problem" areas as funding becomes available. Having a federally recognized, state-of-the-art, structured process for dealing with at-risk rock slopes is a positive step that VDOT can take to improve the asset management program.

This pilot project resulted in the implementation of the core components required for a sustainable VDOT Rock Slope Management Program. It provided for technical training of field personnel, adoption of a standardized rating system suited to Virginia, and development of specialized software for data entry and analysis. When completed by VDOT's Information Technology Applications Division, the GIS Integrator RHRS website will consolidate all statewide rockfall-related data and provide a decision-making tool for managing identified rock slopes.

CONCLUSIONS

- *The purpose of VDOT's Rock Slope Management Program is to provide risk assessment and to determine cost-effective mitigation measures. It should be viewed as a business tool for identifying high-priority maintenance areas and for prioritizing funding.*

- *The essential components of a rock slope management program were implemented at VDOT through this pilot project. Continued operation will depend on the availability of funding.*

- *Similar programs, based on the RHRS methodology, have been implemented at many other state DOTs. This approach has been promoted by the FHWA.*

RECOMMENDATIONS

1. *VDOT should formally implement a VDOT Rock Slope Management Program.*
2. *The program should be administered by VDOT's Asset Management Division.*
3. *Annual funding should consist of two components: rating and remediation.*
4. *Technical oversight should be provided by VDOT's Chief Transportation Geologist.*

COSTS AND BENEFITS ASSESSMENT

The unique nature of this program does not easily lend itself to a numerical characterization based strictly on a cost and benefit assessment. The principal benefit is safety of the traveling public. A proactive rock slope management program will prioritize available funding to remediate the potentially most hazardous sites. Having no structured program in place is likely to be less cost-effective in the long run.

ACKNOWLEDGMENTS

The authors express their gratitude to all VDOT district geology personnel who actively participated in this project and provided essential feedback. Thanks are also extended to Dan Widner and Jim Hopkins of VDOT's Information Technology Applications Division for their helpful support with creating the GIS Integrator RHRS website and to Stanley Hite of VDOT's Materials Division for his technical advice. The authors also acknowledge Randy Combs, Ed Deasy, and Linda Evans of VTRC for their assistance with the graphics and the editorial process.

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1. Pierson, L.A., and Vickle, R.V. *Rockfall Hazard Rating System: Participant's Manual*. FHWA SA-93-057. Federal Highway Administration, Washington, D.C., 1993.

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3. Hite, S.L. Personal communication, 2006.

4. Bernhardt, K.L.S., Loehr, J.E., and Huaco, D. Asset Management Framework for Geotechnical Infrastructure. *Journal of Infrastructure Systems*, Vol. 9, No. 3, 2003, pp. 107-116.

APPENDIX A

Consultant Report

LANDSLIDE
TECHNOLOGY

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Phone 503-452-1200 Fax 503-452-1528

January 11, 2006
Dr. Edward Hoppe
Virginia Transportation Research Council
530 Edgemont Rd.
Charlottesville, Virginia 22903

Rockfall Hazard Rating System Pilot Implementation Review
VDOT Rockfall Hazard Rating System (1667)

Dear Dr. Hoppe:

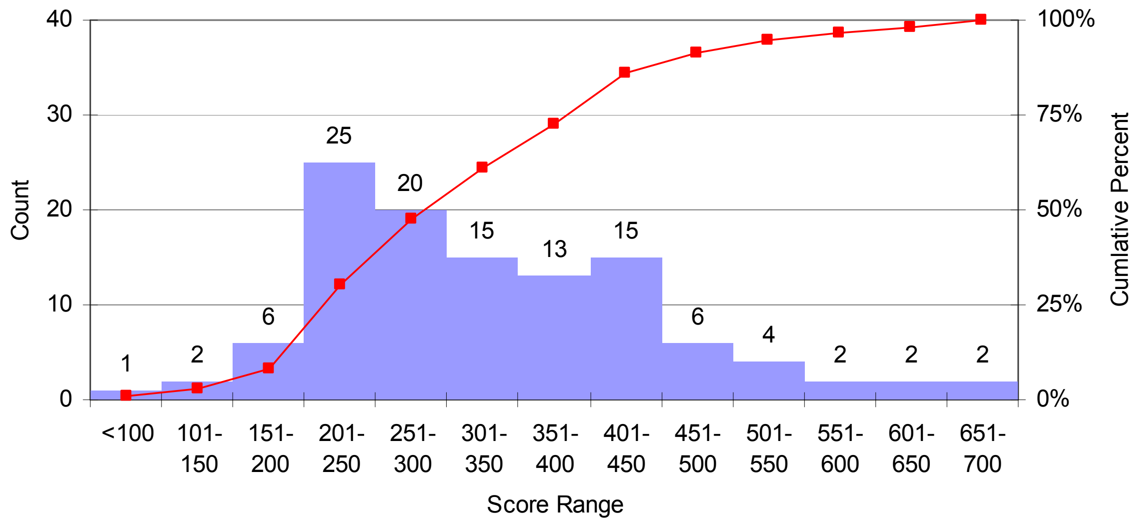
Following the Virginia Department of Transportation's (VDOT) authorization, we have completed our review of VDOT's pilot implementation of the Rockfall Hazard Rating System (RHRS) and all contract required tasks. This letter-report summarizes our review of the completed RHRS ratings and the conceptual design and cost estimates for the five highest rated sites from the four reporting Districts.

Background
The State's key objectives for our services during the project included training, development of a database system amenable to electronic data recording and use in the field that is compatible with VDOT's GIS Integrator, and review of the Department's results. The goals of the RHRS training were to provide VDOT personnel with the ability to: (i) thoroughly understand the RHRS methodology and consistently inspect, evaluate, and rate potentially hazardous rockfall sites, and (ii) efficiently utilize a customized RHRS database to manage VDOT's rock slope assets.

A Senior Associate and Project Engineering Geologist from Landslide Technology attended a scoping meeting in spring, 2005 and later presented a two-day workshop to Department personnel to introduce the RHRS and the use of the customized Microsoft Access RHRS database.

RHRS Rating Review
The pilot implementation performed by geotechnical staff from the Lynchburg, Salem, Bristol, and Culpeper Districts resulted in Detailed Ratings for 113 separate sites. The RHRS scores ranged from 82 to 675. The score distribution is shown on the graph below.

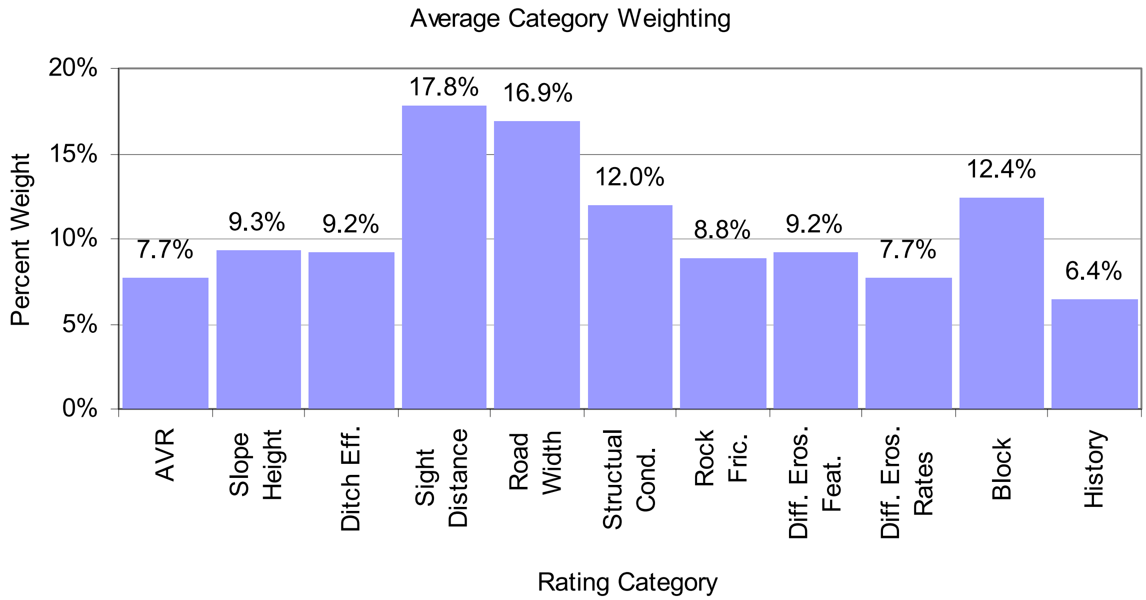
The exhibited trends are consistent with our implementation experience with other states. The distribution indicates that the 50^{th} percentile is a score of 306, which is near or below the arbitrary "B" cutoff score established by other states (300 for Oregon, 350 for Montana). If Virginia determines that the use of a similar score is appropriate, then those sites that fall below the cutoff would not be considered for further mitigation evaluations. The purpose of the cutoff score is to finalize the preliminary rating designations and in most cases reduce the number of "A" sites. For a pilot implementation program a cutoff score can be beneficial for calibrating the personnel performing the Preliminary Ratings. More accurate Preliminary Ratings can mean improved efficiency for the Detailed Rating phase.



Descriptive statistics of the category scores are found in the table below. Note that some categories, such as Average Vehicle Risk, have a significant difference between the mean and median. This results from many scores in the category being low (generally due to low ADTs) but having a few sites with high AVR scores due to high ADTs and/or long section lengths.

	Avg. Vehicle Risk	Slope Height	Ditch Effect.	Sight Distance	Roadway Width	Structural Cond.	Rock Friction	Diff. Eros. Feat.	Diff. Eros. Rates	Block/Vol.	History	Total Score
Mean	25	32	31	59	52	38	27	27	24	44	22	332
Median	2	14	27	69	54	27	27	20	9	27	9	306

The categories can also be evaluated based on their relative contribution to the overall score. The figure below displays a histogram of the average percentage represented by each category in the Detailed Ratings. This reveals that the two highest contributing categories on average are Sight Distance and Roadway Width, while the Rockfall History contributes the least. For the breakdown below, when both Geologic Character categories were rated (both Case 1, Structural Condition and Case 2, Differential Erosion), the case that provided the highest score combination was used for the score breakdown. See the National Highway Institute RHRS manual for additional explanation of rating Geologic Character.



In evaluating the implementation of the RHRS based on the content of the Access Database, these observations are provided:

- Overall, the RHRS appears to have been implemented without significant errors or misunderstandings of the rating system.
- In some cases, the Preliminary Ratings did not reflect the RHRS score. In some examples of this, a "B" rating was assigned to slopes that later received a Detailed Rating score in the 300- and 400-point range. During full scale implementation, the Preliminary Ratings are performed first with the Detailed Ratings performed in a following phase. For efficiency sake, the more resource-demanding Detailed Ratings are only performed on those sites that received an "A" rating. It is better to be conservative by applying an "A" Preliminary Rating if there is some doubt about a site being either and "A" or "B" site. This will guard against slopes that could be rated in the 300- to 400-point range from being excluded.
- At a few sites, the Rockfall History category rating was not consistent with the comments. When this occurred, the comments indicated a higher level of activity than the history score reflected. All sites should have a thorough history recorded with input from maintenance personnel who observe the slope on a regular basis. This input should be reflected in the history score.

Conceptual Design and Cost Estimate Review

Twenty conceptual design and cost estimates were reviewed that included the top five rated sites from each District's database. The four Districts submitting a database were the Lynchburg, Salem, Bristol, and Culpeper Districts. The photographic database was also reviewed to compare the appropriateness of proposed concepts with the documented conditions. Landslide Technology staff did not visit the sites and the alternatives and/or recommendations proposed by Landslide Technology are conceptual in nature. A thorough site investigation by personnel with a strong background in rock slope design is recommended for final design purposes. General comments on proposed conceptual designs are listed below. Specific concept review comment and additional options for each of the 20 sites are found in Attachment A.

Overall, the conceptual designs provided by VDOT exhibit an understanding of the site specific rockfall causative factors, proposed mitigation measures and their general limitations, and specification of appropriate quantities. The following are general comments regarding the conceptual designs.

- Some sites were addressed with measures more suited for short- to mid-term design lives. In general, scaling of loose rock will achieve a decreased frequency of rockfall for one to seven years. Beyond this period, the rockfall frequency can revert to pre-mitigation levels and another round of scaling may be needed.
- Draped mesh is generally a proper mitigation measure for slopes that are not expected to produce rockfalls greater than roughly two feet in diameter. Following scaling, if blocks larger than this and susceptible to falling are still present, consideration should be given to mechanically securing the blocks to the slope using tensioned rock bolts. Often, groups of blocks can be secured by bolting a key block to the slope. Identifying key blocks

requires the ability to evaluate the 3-dimensional configuration of the blocks that comprise the slope, which improves with experience. Other methods of securing blocks or slabs to the slope are rock dowels and cable lashing.

- Many highly rated sites had minimal ditch width, limiting the options for roadside mitigation measures. While a new rock cut to create or expand ditch width can be a higher cost mitigation option, it should be considered where conditions, such as very poor sight distance, high traffic loads or critical roadways, may warrant the expenditure.
- In some instances, a mitigation measure was proposed that adequately addressed the rockfall problems, but it may have been more costly than an equally suitable option. As an example, slopes with large areas and rock sizes less than 2 feet, draped mesh would control most rockfall, but the cost of this measure can be relatively high if large areas are to be covered. In these cases, options such as a catch fence with draped mesh below could be considered because even though their unit cost may be higher, the required quantity may be much less. Catch fences can also be constructed using heavy duty ring or cable nets to intercept larger rocks with a backing of gabion mesh to control the smaller rocks. When designing a catch fence, careful consideration should be paid to launch features on the slope so that rocks do not bounce over the fence.

Conclusions

The Rockfall Hazard Rating System (RHRS) is intended to assist an agency as a tool in prioritizing the funding of rockfall mitigation projects. The RHRS is a state-of-the-practice methodology promoted by the FHWA that has been implemented by many other State DOT's. Based on this pilot implementation program, VDOT now has the tools and training required to approach the State's rockfall hazards in a comprehensive fashion.

Several reasonable techniques have been used to prioritize rockfall projects based on the RHRS information. These include using the site scores, score to cost ratios, or on selected RHRS categories. While no rating system can predict the next hazardous rockfall event, the RHRS is a valuable part of a proactive geotechnical asset management program. This proactive approach is integral in strategic planning and efficient management of maintenance and construction investments. It has the added benefit of reducing the potential liability exposure that would be faced if a more reactive approach to rockfall management were followed.

We appreciate the opportunity to be of assistance to the Virginia Department of Transportation. If there are any questions, do not hesitate to contact Lawrence Pierson or Darren Beckstrand at (503) 452-1200.

District: Lynchburg
City / County Code: 062   Route Number: 00056   Side: Right
Beginning Latitude and Longitude: 37.854382, -79.039404
RHRS Score: 599

Conceptual Mitigation Design

This slope is approximately 160 feet long with a maximum height of about 100 feet. The VDOT conceptual design indicated the ideal option of a Brugg Fence coupled with ditch improvement and scaling with a lower cost option of a concrete barrier placed instead of the Brugg Fence. These design concepts appear appropriate for the rockfall modes present. However, vegetation present on the slope will likely limit the kinetic energy of a falling rock, allowing the application of the lower cost option of a draped mesh with a catch fence. Following computer simulation for verification, install a seven-foot tall fence with a 15-foot drape installed in location such that the mesh ends three to five feet from the ditch line.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Draped Mesh with Catch Fence	3,500 sq ft	5	17,500
	Total Cost:	$17,500	
	Cost /Score Ratio:	29	

District: Lynchburg
City / County Code: 005 Route Number: 00685 Side: Right
Beginning Latitude and Longitude: 37.419971, -79.138277
RHRS Score: 502

Conceptual Mitigation Design
This slope is approximately 340 feet long with a maximum height of about 180 feet. Individual rock blocks detach from the outcrop near the top of the slope and proceed down the slope to the roadway.

The mitigation measures presented provided a temporary solution and included scaling and ditch improvement. A long term mitigation measure for this site would involve reducing the likelihood of rockfall and improving the catchment area capabilities with barriers.

The history of 10-foot blocks and the height they have fallen justify high capacity protective measures. Scaling followed by rock bolting of problematic rock blocks along the crest of the slope would reduce the rockfall potential. For estimation purposes, assume one 10-foot and one 15-foot bolt for every 10 feet of the crest. This quantity would need to be adjusted based on final design investigation. A high capacity Brugg Fence could be considered, with the ditch improved to facilitate cleanout and a concrete barrier placed to control errant drivers from hitting the Brugg fence. If the area from which rockfall originates is less than the 340 foot section length, the Brugg Fence and concrete barrier could be shortened accordingly.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 100 hrs	100	10,000	
Brugg Fence	340 ln ft	425	144,500
Ditch Improvement	200 cu yds	25	5,000
Rock Bolts	850 ln ft	80	68,000
Concrete Barrier	340 ln ft	25	8,500
	Total Cost:	$236,000	
	Cost /Score Ratio:	470	

District: Lynchburg
City / County Code: 005   Route Number: 00685   Side: Right
Beginning Latitude and Longitude: 37.420887, -79.138494
RHRS Score: 462

Conceptual Mitigation Design
The VDOT conceptual design suggested scaling and ditch improvement to mitigate immediate rockfall hazard. Based on the photos, the rockfall hazards appear to originate from highly fractured outcrops scattered across the slope. To extend the design life, scale back all outcrops so that only tight joints are observed. Following scaling, place a concrete barrier the length of the slope to prevent any small rock from entering the roadway.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 120 hrs	100	12,000	
Concrete Barrier	600 ln ft	25	15,000
	Total Cost:	$27,000	
	Cost /Score Ratio:	58	

District: Lynchburg
City / County Code: 005 Route Number: 00130 Side: Right
Beginning Latitude and Longitude: 37.589159, -79.379250
RHRS Score: 441

Conceptual Mitigation Design

This section is approximately 900 feet long and up to about 125 high. The slope consists of a rockfall chute, large rock overhangs, and fractured bedrock. Rock blocks up to 6 feet have fallen from the slope. The conceptual design provided by VDOT included a Brugg fence, blast scaling, scaling, and ditch improvement. These measures are appropriate for a short- to mid-term mitigation effort. For long-term mitigation, increase the scaling hours, include rock bolt installation, and install a concrete barrier with fence extension. If possible, consider shifting the centerline to the left to increase fallout area. To facilitate a centerline shift, constructing a 5- to 15-foot MSE wall may be beneficial.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 550 hrs	100	55,000	
Blast Scaling	500 cu yds	100	50,000
Rock Bolts	600 ln ft	80	48,000
Ditch Improvement	200 cu yds	15	3,000
Brugg Fence	100 ln ft	300	30,000
Concrete Barrier w/ Fence Extension	900 ln ft	25	36,000
	Total Cost:	$222,000	
	Cost /Score Ratio:	503	

District: Lynchburg
City / County Code: 005   Route Number: 00685   Side: Right
Beginning Latitude and Longitude: 37.423347, -79.139036
RHRS Score: 440

Conceptual Mitigation Design

This section is approximately 775 feet long and up to 125 feet high. In 2004, a parked car was partially buried by a rockfall incident. The conceptual design provided by VDOT appeared to focus on short-term mitigation and included scaling and ditch improvement. Long term mitigation efforts should include scaling and rock bolting of the various outcrops that comprise the slope. Loose blocks should be scaled. Following scaling, rock bolts should be installed in problematic and key blocks. Assume fifty 10-foot bolts.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 250 hrs	100	25,000	
Rock Bolts	500 ln ft	80	40,000
	Total Cost:		$65,000
	Cost /Score Ratio:		148

District: Salem
City / County Code: 035   Route Number: 00460   Side: Right
Ending Latitude and Longitude: 37.371483, -80.819031
RHRS Score: 675

Conceptual Mitigation Design
This section is approximately 1,940 feet long and up to 85 feet high. Surface area was estimated by VDOT to be approximately 83,000 square feet, which indicates and average height of about 43 feet over the length of the slope. The mitigation options provided by VDOT essentially describe a scaling and draped mesh application. The large blocks described that are produced by the slope would likely overwhelm and destroy the draped mesh without additional mitigation. Creating a catchment area using presplit blasting techniques would provide an ideal rockfall mitigation but would likely cost over 1 million dollars. Measures in addition to the scaling and draped mesh include applying shotcrete to protect erodible seams, such as the one shown above and the possibility of rock bolt placement in problematic rock blocks. For estimation purposes and assuming approximately 5% of the surface area would require shotcrete, use 4,200 square feet of shotcrete, 800 feet of rock bolts, 83,000 sq ft of draped mesh and a 200 sq ft per hour scaling production rate. The total cost for this concept would be on the order of $650,000.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 400 hrs	100	40,000	
Shotcrete	4,200 sq ft	55	231,000
Draped Mesh	83,000 sq ft	3	249,000
Rock Bolts	800 ln ft	100	80,000
	Total Cost:	$643,000	
	Cost /Score Ratio:	952	

District: Salem
City / County Code: 035   Route Number: 00460   Side: Right
Starting Latitude and Longitude: 37.347103, -80.807250
RHRS Score: 651

Conceptual Mitigation Design
Mitigative measures were performed at this site in the late 1990's and appeared to primarily consist of scaling activities. The rockfall section is approximately 2,350 feet long and is up to about 100 feet high. The rockfall activity is reported as often containing about 24 tons of rock in an average event. Draped mesh was identified by VDOT in this study for placement. The draped mesh would contain the common small rockfalls that occur, but it could be damaged or destroyed by the 24-ton events that have been described.
If this area continues to be an on-going problem, constructing a 20-foot wide fallout area with a 0.5H:1V cut slope could be considered. At approximately $20 per cubic yard, the cost would be on the order of two to three million. Placing draped mesh over slope would be approximately $700,000, but may be damaged by the large volumes reported.

District: Salem
City / County Code: 011   Route Number: 00043   Side: Right
Starting Latitude and Longitude: 37.508425, -79.664297
RHRS Score: 632

Conceptual Mitigation Design
This slope is approximately 600 feet long and up to 40 feet high and contains many open, adversely oriented discontinuities. The surface area estimated by VDOT is about 12,000 square feet. The mitigation concepts from VDOT include scaling, draped mesh, shotcrete, and ditch improvement. Due to the large rock blocks present at the site (4½ feet), the planned draped mesh could be damaged on occasion. Following scaling, rock blocks larger than 2½ feet that serve as key blocks should be rock bolted to improve slope stability and reduce the potential for damage to the draped mesh. Assume one 10-foot rock bolt for every 300 square feet of slope and a scaling production rates of 100 square feet per hour.
As an alternative, a new 20-foot wide fallout area with a 0.5H:1V cut slope could be constructed for roughly $450,000.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 120 hrs	100	120,000	
Draped Mesh	12,000 sq ft	3	36,000
Rock Bolts	400 ln ft	80	32,000
Ditch Improvement	1 ls	6,000	6,000
	Total Cost:	$202,000	
	Cost /Score Ratio:	320	

District: Salem
City / County Code: 009   Route Number: 00501   Side: Right
Starting Latitude and Longitude: 37.516575, -79.342603
RHRS Score: 604

Conceptual Mitigation Design

This section is approximately 1,050 feet long with a natural hillside above the cut slope up to 100 feet high and appears to be the source of rockfall. The hillside above the cut consists of talus and colluvial boulders. The conceptual mitigation elements provided by VDOT include scaling, draped mesh, and a Brugg fence or a chain link fence.

The size of rock found on this slope would make a chain link fence inadequate for stopping the majority of rolling rocks. A modified catch fence, similar to draped mesh with a catch fence but using heavy duty Brugg nets with a backing of gabion mesh to restrict smaller rocks, could be placed at the top of the cutslope, assuming that a relatively continuous line of elevation is available for fence placement. The Brugg panels would drape down the face to within three feet of the ditch line and would be self-cleaning. Scaling production on the hillside should be 100 square feet per hour.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 520 hrs	100	52,000	
Modified Catch Fence	27,000 sq ft	20	540,000
	Total Cost:	$592,000	
	Cost /Score Ratio:	980	

District: Salem
City / County Code: 060 Route Number: 00081 Side: Right
Starting Latitude and Longitude: 37.099375, -80.556489
RHRS Score: 519

Conceptual Mitigation Design
The section is about 350 feet long and 30 feet high with approximately 5,200 square feet of face. The mitigation options provided include scaling, draped mesh, double guard rail, Brugg fence, and ditch improvement. Rock block size is up to 4½ feet. Based on the 30-foot slope height and reverse ditch shape, the Brugg Fence does not appear to be needed. Following scaling, key blocks should be bolted to secure blocks larger than 2 feet to the slope to prevent damage to the draped mesh. Assume one 10-foot bolt will be required for every 200 square feet of face, or about 26 rock bolts.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 52 hrs	100	5,200	
Draped Mesh	5,200 sq ft	3	15,600
Rock Bolts	260 ln ft	80	20,800
	Total Cost:	$41,600	
	Cost /Score Ratio:	80	

District: Culpeper
City / County Code: 032   Route Number: 00656   Side: Right
Starting Latitude and Longitude: 37.712661, -80.556489
RHRS Score: 597

Conceptual Mitigation Design

The rockfall section is approximately 650 feet long and 105 feet high and appears to be a natural outcrop adjacent to the roadway. Maintenance personnel state that rockfall has not fallen and reached the road in 20+ years. However, the presence of continuous, steeply dipping joints poses a threat of rockfall. VDOT's conceptual design involved signage, scaling, and draped mesh.

The lack of historical rockfall activity suggests that this outcrop is at least marginally stable. However, if rocks do dislodge from the slope, the lack of a catchment area means that rock would likely reach the roadway. The size of blocks and slope irregularity reduces the effectiveness of draped mesh as proposed. Following scaling, installation of rock bolts perpendicular to the primary, steeply dipping joint set would combine and support the rock slabs, increasing long-term stability. Rock bolting of key rock blocks lower on the slope would improve support to the upper outcrop. Assume scaling on this irregular slope would take approximately one week for a 3 person crew and eight 30-foot bolts and twenty 10-foot bolts would be required.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 120 hrs	100	12,000	
Rock Bolts	440 ln ft	80	35,200
	Total Cost:	$47,200	
	Cost /Score Ratio:	79	

District: Culpeper
City / County Code: 002   Route Number: 00064   Side: Right
Starting Latitude and Longitude: 38.043101, -78.804024
RHRS Score: 438

Conceptual Mitigation Design
The rockfall section is nearly 1,800 feet long and up to 205 feet high. The fallout area is 25 feet wide. A guard fence is in place and retains most rockfalls. Based on the photos, the guard fence appears to be in good condition and does not appear to have sustained repeated damage. The conceptual design from VDOT included scaling and applying draped mesh to the entire slope.
Based on the success of the guard fence preventing most rockfalls from reaching the roadway, but because rock blocks up to a maximum of 4 feet has been observed, a Brugg fence is preferable to and less expensive than the draped mesh concept, and only minor scaling would be required. For the cost estimate, a low capacity Brugg fence has been used, but final design should include rockfall modeling to determine the required design capacity.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 120 hrs	100	12,000	
Brugg Fence	1,800 ln ft	300	540,000
	Total Cost:	$552,000	
	Cost /Score Ratio:	1,260	

District: Lynchburg (in Culpeper District's RHRS Database)
City / County Code: 062   Route Number: 00064   Side: Right
Starting Latitude and Longitude: 38.033077, -78.854862
RHRS Score: 425

Conceptual Mitigation Design
The rockfall section is about 1,150 feet long and up to 150 feet high. A guard fence has been installed and retains most of the rockfall. Based on the photos, the guard fence appears to be in good condition and does not appear to have sustained repeated damage. The conceptual design from VDOT included scaling and applying draped mesh to the entire slope.
Based on the guard fence preventing most rockfalls from reaching the roadway, but because rock blocks up to a maximum of 3 feet has been observed, a Brugg fence is preferable to and less expensive than draped mesh, and only minor scaling would be required. For estimate purposes, a low capacity Brugg fence has been used, but final design should include rockfall modeling to determine the required design capacity.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 120 hrs	100	12,000	
Brugg Fence	1,050 ln ft	300	315,000
	Total Cost:	$327,000	
	Cost /Score Ratio:	769	

District: Lynchburg (in Culpeper District's RHRS Database)
City / County Code: 062   Route Number: 00064   Side: Right
Starting Latitude and Longitude: 38.038777, -78.837411
RHRS Score: 375

Conceptual Mitigation Design

This rockfall section is about 1,050 feet long and up to about 160 feet high. Numerous daylighting joints intersect the cut slope creating large slabs that dip out of the slope roughly perpendicular to the cut. The conceptual design from VDOT recommended draped mesh. The size of slabs that have formed are such that draped mesh could be damaged or destroyed should a slab detach.

Following the scaling of loose rock blocks, untensioned rock bolts, or dowels, can be installed at key locations to prevent slabs from mobilizing. For estimate purposes, approximately one hundred 3-foot dowels were estimated.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 240 hrs	100	24,000	
Dowels 300 ln ft	50	15,000	
	Total Cost:	$39,000	
	Cost /Score Ratio:	104	

District: Culpeper
City / County Code: 032   Route Number: 00006   Side: Right
Starting Latitude and Longitude: 37.750308, -78.158318
RHRS Score: 356

Conceptual Mitigation Design
This rockfall section is about 750 feet long and up to about 45 feet high. A portion of the section consists of an outcrop with low angle surfaces and discontinuities dipping out of the slope. For the portion of the slope with the highest potential for rockfall, scaling the slope of loose rock blocks, as VDOT recommended, would reduce the potential for rockfall. Strategically placed dowels would also improve stability. Final design efforts should evaluate the benefits of installing rock bolts to support key blocks and rock slabs,

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 80 hrs	100	8,000	
Rock Dowels	200 ln ft	50	10,000
	Total Cost:	$18,000	
	Cost /Score Ratio:	51	

District: Bristol
City / County Code: 010   Route Number: 00612   Side: Left
Starting Latitude and Longitude: 37.138073, -81.130267
RHRS Score: 495

Conceptual Mitigation Design
This slope is approximately 1,230 feet long and up to about 225 feet high. VDOT's conceptual design included draping mesh over the entire slope. This approach is appropriate for the one-foot rock size present, but can be cost prohibitive due to the large surface area. Installation of a 7-foot tall, self-cleaning, draped mesh catch fence the length of the slope with a 15-foot drape is a less costly alternative. Minor scaling prior to the installation of the fence may be appropriate. This design requires careful consideration of fence placement so that it is not placed directly below any potential launch features.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 240 hrs	100	24,000	
Draped Mesh with catch fence	18,450 sq ft	5	92,250
	Total Cost:	$116,250	
	Cost /Score Ratio:	235	

District: Bristol
City / County Code: 010   Route Number: 00052   Side: Right
Starting Latitude and Longitude: 37.137379, -81.132545
RHRS Score: 450

Conceptual Mitigation Design

This slope is approximately 750 feet long and up to about 160 feet high. VDOT's conceptual design included draping mesh over the entire slope. This approach is appropriate for the one-foot rock size present, but is cost prohibitive. Installation of a 7-foot tall, self-cleaning, draped mesh catch fence the length of the slope with a 15-foot drape is a less costly alternative. Minor scaling prior to the installation of the fence may be appropriate. This design requires careful consideration of fence placement so that it is not placed directly below any potential launch features.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 200 hrs	100	20,000	
Draped Mesh with Catch Fence	11,250 sq ft	5	56,250
	Total Cost:	$76,250	
	Cost /Score Ratio:	169	

District: Bristol
City / County Code: 010   Route Number: 00612   Side: Left
Starting Latitude and Longitude: 37.140318, -81.124929
RHRS Score: 437

Conceptual Mitigation Design
This slope is approximately 770 feet long and up to about 85 feet high. VDOT's conceptual design included draping mesh over the entire slope. This approach is appropriate for the one-foot rock size present, but it represents a more costly alternative. Based on the photograph, most rockfall produced by this slope is very small ant there are few launch features on the slope. The small rock size, expected modest bounce heights, and well-shaped catchment ditch suggest that a concrete barrier at the ditch edge would contain a high percentage of rockfall. If rockfall modeling shows the potential for bounce heights greater than the concrete barrier could intercept, a fence extension on the barrier could be added.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Concrete Barrier	770 ln ft	25	19,250
	Total Cost:	$19,250	
	Cost /Score Ratio:	44	

District: Bristol
City / County Code: 092   Route Number: 00016   Side: Left
Starting Latitude and Longitude: 37.040474, -81.518791
RHRS Score: 392

Conceptual Mitigation Design

This slope is approximately 250 feet long and up to about 35 feet high. The conceptual design provided by VDOT involved excavating about six feet of rock along the dip slope to create a modest rockfall catchment area, which is a reasonable approach. Due to the occasional nature of rockfall and the steeply dipping planar features, scaling followed by installation of rock bolts to tie the potential rock slabs together and keep them from detaching from the slope would be a less costly option. Assume ten-foot bolts installed on ten-foot centers wherever the rock slabs are not supported at the ditch grade, as in the photo above.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 24 hrs	100	2,400	
Rock Dowels	200 ln ft	80	16,000
	Total Cost:	$18,400	
	Cost /Score Ratio:	47	

District: Bristol
City / County Code: 013   Route Number: 00460   Side: Left
Starting Latitude and Longitude: 37.214957, -82.006997
RHRS Score: 376

Conceptual Mitigation Design

This slope is approximately 680 feet long and up to about 80 feet high. VDOT indicates that the rockfall problem is generated from above the sandstone face. The conceptual design included a draped mesh catch fence installed along the top of the sandstone cut following scaling. This design appears to adequately address the rockfall issues described except that the three-foot maximum block size could overwhelm a mesh catch fence. Consider replacing the gabion mesh with ring or cable nets backed by the gabion mesh to catch smaller rock. To reduce quantities, evaluate draping 20 to 25 feet of cable nets from the top of the posts. The nets would not drape to the ditch. Make sure no launch features are present lower on the slope below the end of the mesh. Construct a reverse shaped ditch and install a concrete barrier at the side of the road for the length of the section.

Mitigation Cost Estimate

Design Element	Quantity / Units	Unit Cost ($)	Element Cost ($)
Scaling 360 hrs	100	36,000	
Modified Catch Fence w/ 20-ft Drape	13,600 sq ft	20	272,000
Ditch Improvement	1,000 cu yds	30	30,000
Concrete Barrier	680 ln ft	25	17,000
	Total Cost:	$355,000	
	Cost /Score Ratio:	906	

APPENDIX B

Estimate of Rating Funds

RHRS ESTIMATE

DISTRICT	BRISTOL	SALEM	STAUNTON	LYNCHB'G	CULPEPER	NOVA	TOTAL
CREW SIZE	2	2	2	3	1	1	
CREW/DAY	$700	$700	$700	$1,050	$300	$400	
EST'D DAYS	10	10	10	8	10	2	
CREW COST	$7,000	$7,000	$7,000	$8,400	$3,000	$800	
POTENTIAL TRAFFIC CONTROL	30%* (3DAYS)	30%* (3DAYS)	30%* (3DAYS	30%* (3DAYS)	60% (6DAYS)	100% (2DAYS)	
COST/DAY	$450	$450	$450	$450	$450	$450	
COST	$1,350	$1,350	$1,350	$1,350	$2,700	$900	
DISTRICT COST	$8,350	$8,350	$8,350	$9,750	$5,700	$1,700	**$42,200**

OVERVIEW (CO/VTRC TEAM - 2 MEN)

15 DAYS	12600	
30 OVERNIGHTS	3800	
MIE	2250	
TRAFFIC	4000	
CONSULTANT	5000	**$27,650**

MITIGATION STUDIES (DISTRICT GEOLOGIST + CO/VTRC STAFFER)

ALLOW 12 SITES @ 1/DAY

STAFF	8350	
HOTELS	1350	
MIE	900	**$10,600**

GLOBAL (ORDER OF MAGNITUDE) **$80,450**