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UDOT ROCKFALL HAZARD RATING SYSTEM: FINAL REPORT AND USER'S MANUAL

Prepared For:

Utah Department of Transportation
Research and Development Division

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UDOT RESEARCH & DEVELOPMENT REPORT ABSTRACT

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16. Abstract

The purpose of the Rockfall Hazard Rating System and associated software is to evaluate the relative risk associated with rockfall on highways throughout the State of Utah. The system and software are designed specifically for the Utah Department of Transportation (UDOT) and is a tool for ranking sites relative to one another so as to better prioritize their rehabilitation. This manual provides the user with the necessary information to successfully obtain and understand results from a rockfall hazard rating analysis. Part I introduces preliminary analysis done in 2002 and the detailed analysis completed using three competing hazard rating systems developed in other states. These analyses served as the basis for developing the UDOT system. It provides background as to why the custom developed UDOT system is considered the preferred method for Utah. Part II is a tutorial and users' guide that systematically takes the user through the rockfall analysis and report/map making process.

It is assumed that the user is familiar with geological engineering concepts in general and more specifically the characterization of rock masses. In almost all cases, the software will allow the user to enter any arbitrary value for a given parameter. If the user is unable to provide realistic parameters as inputs to the hazard rating system, then the results of the analysis are unpredictable. It is therefore highly recommended that only those with the appropriate professional background modify parameters within the database.

The database software is implemented in Microsoft Access with custom programming in Visual Basic for Applications (VBA). The data is in a *.mdb file structure used as both Microsoft Access database files and ESRI ArcGIS geodatabase files. MS Access provides a convenient environment for database management, the automatic computation of hazard ratings and the flexibility to produce a variety of custom reports. The ArcGIS environment provides a convenient environment for the generation of custom maps showing the location of the rockfall sites and labels representing key rockfall parameters.

The software requires Microsoft Access 2003 or higher and ESRI ArcGIS 9.0 or higher. The user should be acquainted with the MS Access environment in order to review and update the database as well as generate custom reports. A basic understanding of routing and display functions of ArcGIS will allow the user to quickly view, symbolize and label the rockfall sites and overlay them on a variety of GIS database information.

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UDOT Rockfall Hazard Rating System Final Report and User's Manual

Rockfall Hazard Assessment Report and Software
for Utah Department of Transportation Research Division
Salt Lake City, UT

by

Utah State University
Department of Civil and Environmental Engineering
4110 Old Main Hill, Logan, UT 84322-4110

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Release

Release 1.0 dated January 2006

Distribution

Distribution authorized to personnel of the Utah Department of Transportation or others as determined by the UDOT Research Division. Data and program disk distributed separately to qualified users upon request to the UDOT Research Division, 4501 South 2700 West, PO Box 148410, Salt Lake City, Utah 84114-8410, (801) 965-4568.

Support

Ongoing support of the software is available through the calendar year 2006. User feedback is highly encouraged. Please direct any suggestions, questions, or requests to:

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Synopsis

The purpose of the Rockfall Hazard Rating System and associated software is to evaluate the relative risk associated with rockfall on highways throughout the State of Utah. The system and software are designed specifically for the Utah Department of Transportation (UDOT) and is a tool for ranking sites relative to one another so as to better prioritize their rehabilitation. This manual provides the user with the necessary information to successfully obtain and understand results from a rockfall hazard rating analysis. Part I introduces preliminary analysis done in 2002 and the detailed analysis completed using three competing hazard rating systems developed in other states. These analyses served as the basis for developing the UDOT system. It provides background as to why the custom developed UDOT system is considered the preferred method for Utah. Part II is a tutorial and users' guide that systematically takes the user through the rockfall analysis and report/map making process.

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PART I - UDOT RHRS TECHNICAL REPORT

1.0 INTRODUCTON

The occurrences of rock fall along roadways presents a danger to passing motorists. In order to mitigate the rock fall danger and to alleviate negative impacts, a prioritization program has been developed for the State of Utah.

UDOT began with an preliminary survey in 2001, referred to as Phase I, to classify sections of roadway into three categories associated with a grade A, B, or C according to apparent severity of the hazard and grouped by "Shed", an area maintained by local Department of Transportation personnel and equipment. Category A sites are perceived as the most hazardous and C sites the least. This survey, based on a preliminary rating system used by the Oregon Department of Transportation (referred to as ODOT I), was completed in 2001 (ODOT, 2001). A total of 1099 sites were identified. UDOT Research Report UT 03.01 dated April 2002 presents the results of Phase I (Pack and Boie, 2002).

UDOT has completed detailed rockfall investigations as a part of Phase II. This was completed for sites categorized in Phase I as either A, A-, or B+. Since a definitive system for conducting detailed investigations did not exist in Utah at the start of the study, site parameters required for three candidate systems used in other states – two developed in Oregon, and one in New York - were included in the data collection to enable comparison of results. This study would determine the strengths and weaknesses of each system in the Utah context and would enable the modification of evaluation parameters to better suit the site conditions of the Utah survey. Data collection for Phase II was initiated during the summer of 2002 when 318 sites were surveyed, and investigation of the remaining 189 sites was completed in the summer of 2003.

Given the results of Phase II, a detailed hazard rating system has been developed that is appropriate for the State of Utah based on the New York System. This rating system has been used to evaluate potential rockfall at each site and enables the prioritization of those sites where mitigation efforts may be centered. It can also be updated when site conditions change. This report presents the results of Phase II and encompasses the Phase I results previously reported.

2.0 UTAH GEOLOGIC SETTING

The State of Utah is located near the continental divide providing an array of exposed geologic formations. It is divided into four major physiographic provinces, the Colorado Plateau, Middle Rocky Mountains, Basin and Range, and Colorado Plateau/Basin-Range Transition.

The Colorado Plateau is a sparsely vegetated landscape of plateaus, mesas, deep canyons, sloping pediments, imposing linear cliffs, and barren badlands that closely reflect the attitudes and differential erosion of predominantly sandstone and shale. A few intrusive mountains of Middle Tertiary age dot the rugged landscape. Although sandstone dominates the southern Utah landscape, local variations in stratigraphy expose fractured layers to erosion and lead to the development of hazards where road cuts expose the rock. In the region served by the St. George Shed, columnar basalt calving from the top of an existing sandstone exposure, itself generating overhung shale and sandstone boulders, is an example of a rockfall site. This is in contrast to the overhung wall near newspaper rock, in the Monticello Shed jurisdiction, where the hazard is not due to erosion of the slope face, but to loose material that may wash down from above as a result of intense storm events. Site locations east of Bluff in the southeastern corner of the state are almost completely mudstone and show signs of rapid erosion that may only occur during storm events (which, in themselves, are rare but intense). The red hue to the sandstone and mudstone formations in the south and central portions of the state is characteristic of the oxidized iron content of these rocks and prolific over large areas.

The Middle Rocky Mountains Province is represented by the dissimilar Uinta Mountains and Wasatch Range. The Uinta Mountains trend east-west, are a superficially anticlinal in structure, and are practically devoid of igneous rocks. They are Precambrian at their core surrounded by successively younger rock layers arranged in a radial pattern. The Wasatch Range trends north-south, is essentially a tilted fault block, and is an assemblage of sedimentary, igneous, and metamorphic rocks. The surveyed portions of the northern region of the state contain many rock formations with a variety of compositions. Many outcroppings are of resistant Paleozoic carbonates, sandstones, and quartzite. Tertiary conglomerates and older sedimentary beds occur along the Wasatch front.

The Basin and Range Province consists of approximately 35 north-south-trending "ranges" and an equal number of alluvial valleys. The basic structure is that of alternating horsts and grabens. In the present state of geomorphic evolution, about equal areas of bedrock and alluvium make up the surface. Rockfall is less common in this Province when compared to the rest of the state.

The Basin and Range/Colorado Plateau Transition Province is a broad belt in which geologic features grade between the two provinces. Dominantly north-south structural alignments are evident in the High Plateaus and typical Colorado Plateau stratigraphic units extend well into the Basin and Range.

The wide variety of rock types described illustrates the complex geological makeup of the state and hints at the difficulties associated with implementing an unmodified system of evaluating geology-influenced rockfall hazards. It is for this reason that a custom system for UDOT has been developed.

3.0 PRELIMINARY ROCKFALL STUDY (PHASE I)

3.1 Overview

At the beginning of the summer of 2001, existing sources of information on rockfall hazard rating systems were reviewed with particular focus on systems previously developed by other state departments of transportation. It was recognized at the beginning that the existing models would likely need to be modified to fit the needs of Utah's rockfall areas. After this review, it was decided that the preliminary rockfall hazard assessment work should follow methods developed by the Oregon Department of Transportation. This system was originally developed during the mid 1980's by Lawrence Pierson and had been adopted by several states at the time of the start of this study (Pierson et al., 1990). Mr. Pierson served as an advisor to UDOT at this stage in the study and, after some review, the ODOT system was deemed adequate as a starting point for developing a rockfall inventory in Utah.

Beginning in May 2001, all maintenance stations ("sheds") across the State of Utah were systematically contacted and key individuals interviewed by phone to determine the nature of the rockfall hazard (if any) in their jurisdiction. If no significant rockfall hazard was identified by these personnel, the maintenance station was erased from the inventory schedule and not considered further. If any hazards were identified, an estimate of the number of sites requiring visits was used to partition off a block of time in the inventory schedule. An appointment was then made with the Station Forman or his identified employee to meet and visit the sites. Each site was visited in the company of a UDOT employee so as to obtain an estimate of rockfall frequencies, rockfall quantities, and cleanout frequencies. Other site data were also gathered while at the rockfall location. Many of the sessions involved driving more than 100 miles in one day to cover the territory. In virtually all cases UDOT personnel were extremely helpful and provided valuable insight into the nature of their rockfall problems.

The information obtained from the interviews, site verification, and classification with the maintenance foreman was then used to create a preliminary (Phase I) rockfall hazard database. This database contains information on rockfall areas throughout the state of Utah and served as the basis for developing an appropriate detailed hazard rating system through more detailed inventories.

UDOT Research Report UT 03.01 "Utah Rockfall Hazards Inventory, Phase I" dated April 2002 provides detail on the Phase I study procedures and contains a preliminary ranking of rockfall sites across the state. The rankings were divided into three categories in order to prioritize them for future study. A total of 1099 rockfall sites were inspected in the field. Of these, 479 sites were given a rating of A (immediate potential for rockfall danger), 569 sites were classified as B (moderate rockfall potential), and 51 sites were ultimately rated as C (low potential for rockfall) based on the ODOT Rockfall Hazard Rating System (RHRS) criteria. It was clear from the beginning that C-rated sites would not likely be further assessed during Phase II. "C"-sites were chosen at random to be included in the field survey so as to round out the data pool and provide examples of slopes that are not deemed worthy of further analysis. Following the completion of these field ratings, a GIS database was constructed for all A & B-rated sites and some C-rated sites statewide. The database includes basic descriptions, locations, and photographs of the sites. This rockfall database was implemented immediately for some aspects of state transportation improvement planning, and formed the foundation of the Phase II study.

3.2 ODOT RHRS System

3.2.1 Classification Criteria

The ODOT system for performing preliminary rockfall inventories classifies rockfall sites into three broad, manageably sized categories labeled as A, B, or C. The purpose was to eliminate some sites from the overall inventory based on their inherent lack of risk and to target those sites that warranted future detailed investigation under Phase II. This rating is a subjective evaluation of rockfall potential that requires experienced, insightful personnel to make valid judgments.

The criteria associated with the ODOT rating system are given in Table 1 and are based on estimated potential for rockfall on the roadway and historical rockfall activity. The ODOT system is primarily aimed at assessing the rockfall potential at a site. This rockfall potential is the controlling element of the preliminary rating. For example, if a rock slope contains a large block with evidence of active displacement and no ditch is present to catch it if it falls, it would receive an A-rating, regardless of past rockfall activity. The historical rockfall activity criterion supplements the primary rating where clarification is needed.

Table 1. Preliminary Rating System.

Criteria / Class	A	B	C
Estimated Potential for Rockfall on the Highway	HIGH	MODERATE	LOW
Historical Rockfall Activity	HIGH	MODERATE	LOW

The following factors have been considered when estimating rockfall potential on the highway: (1) estimated size of material in the rock cut; (2) estimated quantity of material; (3) amount available; and (4) ditch effectiveness. In addition, the following factors were considered with respect to the historical rockfall activity: (1) frequency of rockfall on highway; (2) quantity of material; (3) size of material; and (4) frequency of clean-out. The A-B-C rating system is based on the following criteria:

- A-Rating. The risk ranges from moderate to high. In these cases the source of rockfall must be obvious. If this situation is combined with small roadside ditches and a history or frequent rock on the roadway, it is clearly an A-rating.
- B-Rating. The risk ranges from low to moderate. Although rockfall from a slope is possible, the frequency is low enough or the roadside ditch is large enough to restrict nearly all of the rockfall from reaching the highway.
- C-Rating. It is unlikely that a rock will fall at a given site, or that, if a fall should occur; it is unlikely to reach the roadway. In other words, the risk is nonexistent to low. The RHRS Participant's Manual (Pierson and Van Vickle, 1993) suggests that "it is not worthwhile to clutter a database with information on slopes of this nature".

A sample of the Phase I field-rating sheet is given as Figure 1 and includes fields for both location and estimates of rockfall magnitude and history. A detailed description of each blank in the form is given in the Phase I Report (Pack and Boie, 2002). The rockfall magnitude and historical frequency data are based on somewhat subjective recollections of past events or on the physical characteristics of the site. For this reason it was important that a UDOT maintenance station foreman or a maintenance employee familiar with the site participate in the estimation.

In this study, it was often difficult to decide whether a slope with a moderate risk should fall into the "A" rating or "B" rating. For this reason, it was found to be advantageous to adopt a finer scale where "B" rated slopes that had a clearly moderate risk would be given a "B+". Similarly, if an "A" rated slope was more at the moderate end of the risk scale, it would be given a rating of "A-".

3.2.2 Field Work

The Phase I field work was accomplished in a three-month period from June through August of 2001. Most of the work (75%) was done by one worker (Jamie Farrell) with a second worker (Bob Pack) performing the remaining 25%.

Efforts were also made by the raters to search for potential rockfall problems that may have escaped UDOT's notice. Such new discoveries turned out to be non-existent. Only slopes relatively close to the roadway such as rock cuts were included in the inventory. Potential sources of rockfall from natural slopes further upslope were not included.

The rating process itself progressed quickly and took a few minutes per site as UDOT personnel under the tutelage of the USU raters became "practiced" over the first hour or so of each session. At each site the site data sheet was filled out, GPS coordinates recorded, and one or more photographs taken (see Figure 1). Once the data and associated classification was recorded, this information was entered into an ArcView v.3.3 geographic information system (GIS) database at the end of the day or week. Because geographic coordinates of the beginning and end of each road section were taken with a GPS receiver, the two coordinates could be used to estimate the road section length and mark the site location in the GIS.

The A, B, C rating itself is mainly subjective but as stated before, raters become fairly adept at these judgments within a short period of time. The two raters spent considerable time together to harmonize class definitions and rating criteria. The key factor in preliminary ratings is the concept of "risk", which refers to the likelihood of rockfall material reaching the roadway (Kliche, 1999). The emphasis was on fall material actually reaching the highway. A vertical and imposing slope does not always warrant an "A" rating.

3.3 Phase I Results

A statistical summary of Phase I results is given in two tables found in Appendix A. Table A1 shows the number of rockfall sites per shed classified by the A, B, and C ratings. The number classified as A is 479, as B is 569, and as C is 51 for a total of 1099 rockfall sites. Table A2 shows the total length of road section falling into each classification summarized for each maintenance station. The number of kilometers of roadside slopes classified as A is 134.8, as B is 155.3, and as C is 7.5 for a total of 297.7 kilometers (185 miles). It should be noted that sites classified as C are a very small subsample of sites in this category as they are essentially excluded from the inventory. As stated in the Section on methodology, "C" rated slopes are considered low-risk and would add un-needed clutter to the database. However, a few have been included in order to get a feel for their nature and how they are distinguished from the "A" rated and "B" rated sites. Figure 2 shows the distribution of "A" and "B" rockfall sites throughout Utah.

Data Sheet for RHRS, Summer of 2001

Section # ____	Highway ____	GRADE
Waypoint Start ____	Shed (#) ____	
Waypoint End ____	Mileage ____	

Estimated Potential for Rockfall on Roadway:

Avg. Size of Material		< 6 in.	6-12 in.	1- 3 ft.	> 3 ft.	____
Max. Size of Material		< 1 ft.	1-2 ft.	2-5 ft.	> 5 ft.	____
Estimated Quantity of Material						
" " Event						
Amount Available		Limited	Limited +	Plentiful -	Plentiful	
Ditch Effectiveness		Poor	Fair	Good	V. Good	

Historical Rockfall Activity:

Frequency of Rockfall on Highway	< 1/yr.	1-2/yr.	3-6/yr.	7-10/yr.	>10	____
Frequency of Clean-out	< 1/yr.	1-2/yr.	3-6/yr.	7-10/yr.	>10	____
Quantity of Material						____

COMMENTS:

Figure 1. Rockfall Hazard Rating System, Phase I data entry form.

Figures 3 through 6 are photographs of representative slopes in categories A through C. The "C" slope given in Figure 3 is located in the jurisdiction of the Emery Maintenance Station in central Utah. The slope angle for this site is relatively low and is cut through a sedimentary rock unit (shale or mudstone) that is subject to moderate weathering. The upslope portion of this rockfall site has evident rounded boulders likely from an upslope alluvial or conglomerate source. The lower portion of the slope poses no risk to the roadway, save for small soft sediment sloughs where the upslope material might represent a low risk. However, because of the large roadside ditch and the low slope angle, this slope was given a "C" rating.

Two "B" rated slopes have been included as examples. Figure 4 is from the Huntington Maintenance Station while Figure 5 is from the Colton Maintenance Station. These two photos were chosen because they illustrate two very different "B" rated slopes. The site in Figure 4 is what might be envisioned as a typical "B" slope. This cut is surrounded by heavy forest and has abundant plant cover on the slope itself. The presence of rock slabs on the slope surface indicates some possibility for rock sliding despite the plant cover and relatively low slope angle. In the background, it is apparent that there is a relatively modest ditch area. This slope was given a "B" rating because of the small ditch area combined with the presence of slabs that could potentially slide on the slope face and reach the roadway. Figure 5 also shows a "B" rated slope. This slope has both vertical and laid-back rock faces cut through multiple sedimentary rock-types. Differential weathering is apparent in two of the three layers shown. On first glance, this slope might seem to warrant an "A" rating but on closer inspection, the width of the ditch area indicates very effective catchments for debris (both slough and boulders evident in the ditch). This is also borne out by the modest amount of rockfall reported on the road over the years. This slope demonstrates the effect of well sized catchments on this preliminary rating system. This slope may have significant cleaning requirements to maintain its "B" status.

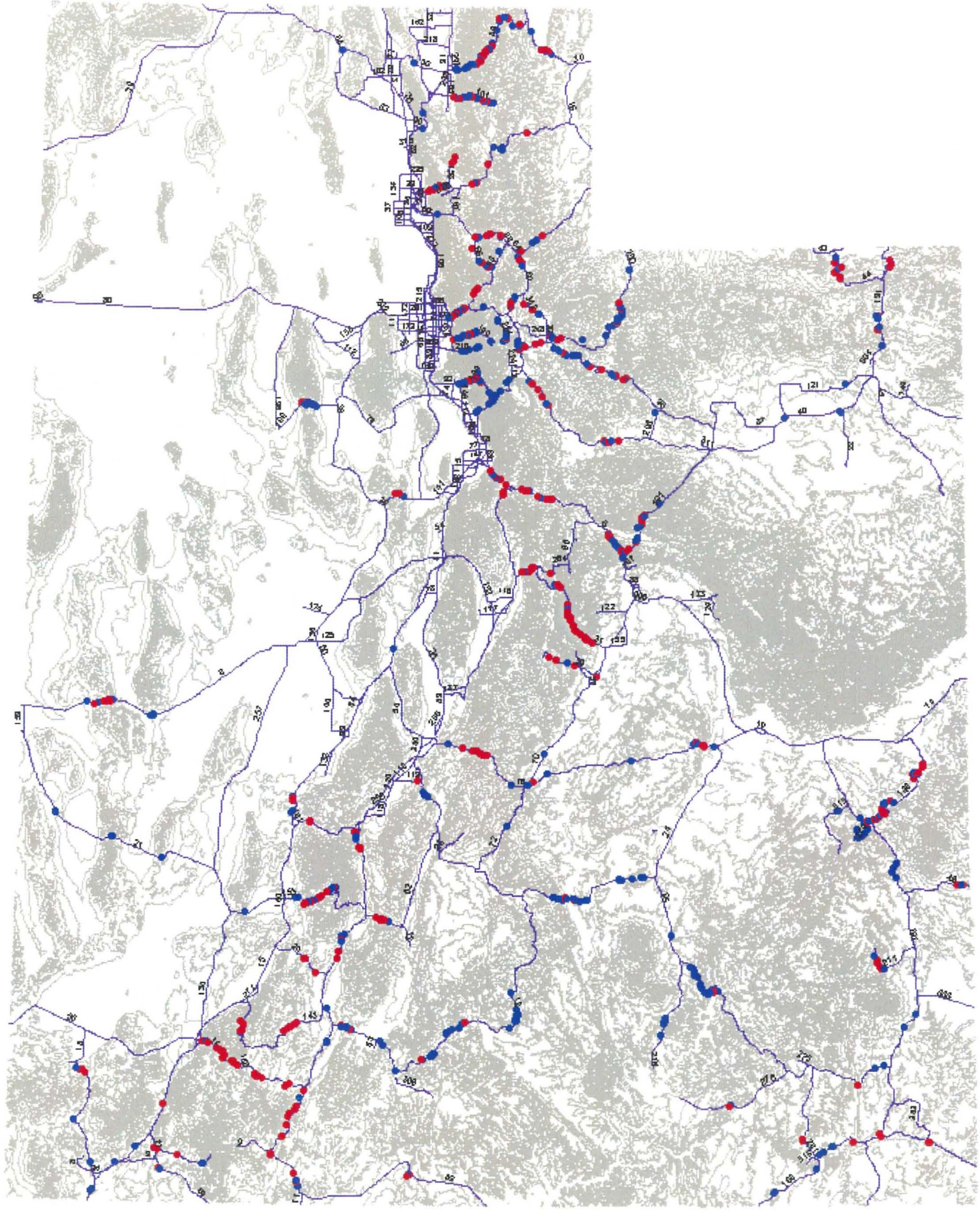


Figure 2. Distribution of rockfall sites classified as A (red dots) and B (blue dots).

Figure 6 is a typical "A" rated slope. This cut located in the Beaver Maintenance Station jurisdiction is a representative "A" rated slope for several reasons. The catchment ditch area is inadequate in both width and depth to catch the size of material weathered from the rock face. While the face itself is not extremely high and has good cover on top, the sizes of the blocks that are weathering from the cliff face are large and easily capable of reaching the road surface. Significant factors contributing to instability on this face are (1) the potential effects of saturation due relatively high rainfall and (2) the potential effects of seasonal freeze-thaw action during the spring thaw.

Figure 3. "C" rated slope near Emery, Utah.

Figure 4. "B" rated slope near Huntington, Utah.

Figure 5. "B" rated slope near Colton, Utah.

Figure 6. Near-vertical "A" rated rock cut in the Beaver Maintenance Station.

3.4 Phase I Database

The culmination of the Phase I inventory was the creation of an interactive database that linked the field data spatially to the Utah state road grid. The database was built to be compatible with the ArcView GIS software package in use at Utah State University and at UDOT. The database was compiled in a dBASE (*.dbf) file format and contained 1100 lines corresponding a heading line, 1099 sites (one line per site) and 27 columns, which include specific site information. The sites themselves were grouped by the state DOT maintenance station jurisdiction in which they lie. The field descriptions are found in Section 2.4.6 of Part II.

The Phase I database delivered to UDOT was linked to a map of the State of Utah containing the state-wide road grid with each site entry displayed as a colored dot with the color determined by rating (A – C). The GIS user could double click on any given site symbol and display, in table form, the data for that site as shown in Figure 7. A color photo could also be automatically queried as shown in Figure 8 using a "hot-link" button in ArcGIS. The culmination of Phase I was the production of this interactive database.

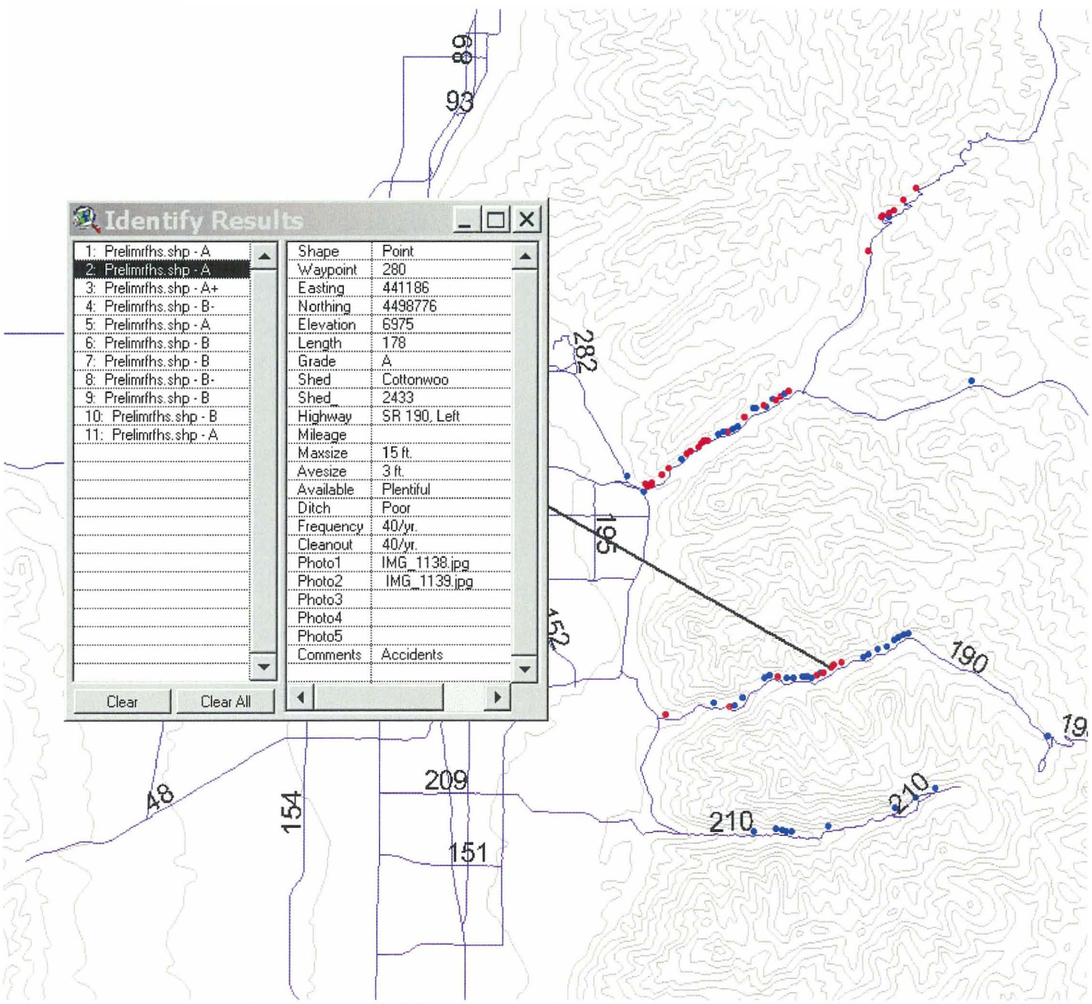


Figure 7. Example of how a rockfall point can be queried when the GIS display has been zoomed into a local area.

Figure 8. Photo IMG_1138 corresponding with the data point shown in Figure 7 can be retrieved from the database (see Part II, Section 2.4.6).

3.5 Implementation

The Phase I database was initially used for identifying rockfall sections within the Statewide Transportation Improvement Program or STIP (UDOT, 2003), a five-year program of highway and transit programs. The STIP is the official work plan for the development of highway projects through conceptual development, environmental studies, right of way acquisition, and plan development through advertisement of a construction project. A simple GIS query identified which rockfall sections lie within road sections that have been identified in the STIP as future projects. Figure 9 shows the sections of road identified in the STIP as well as the rockfall sections that fell within those sections. This provided an early means of lowering the hazard at rockfall sites by utilizing the current statewide project prioritization system.

The preliminary hazard ratings were a critical step in the development of a complete rockfall hazard rating system. It should be recognized that the A-B-C ratings were VERY preliminary and require an analysis that is more detailed than the 2 to 3 minutes spent on each site in order to be prioritized for remediation.

The Phase I inventory provided a first glimpse into the magnitude of the rockfall problem across the state. Upon its completion, maintenance personnel were able to better visualize where and how-often they are removing boulders and cleaning ditches, both within their own jurisdictions, and relative to other jurisdictions.

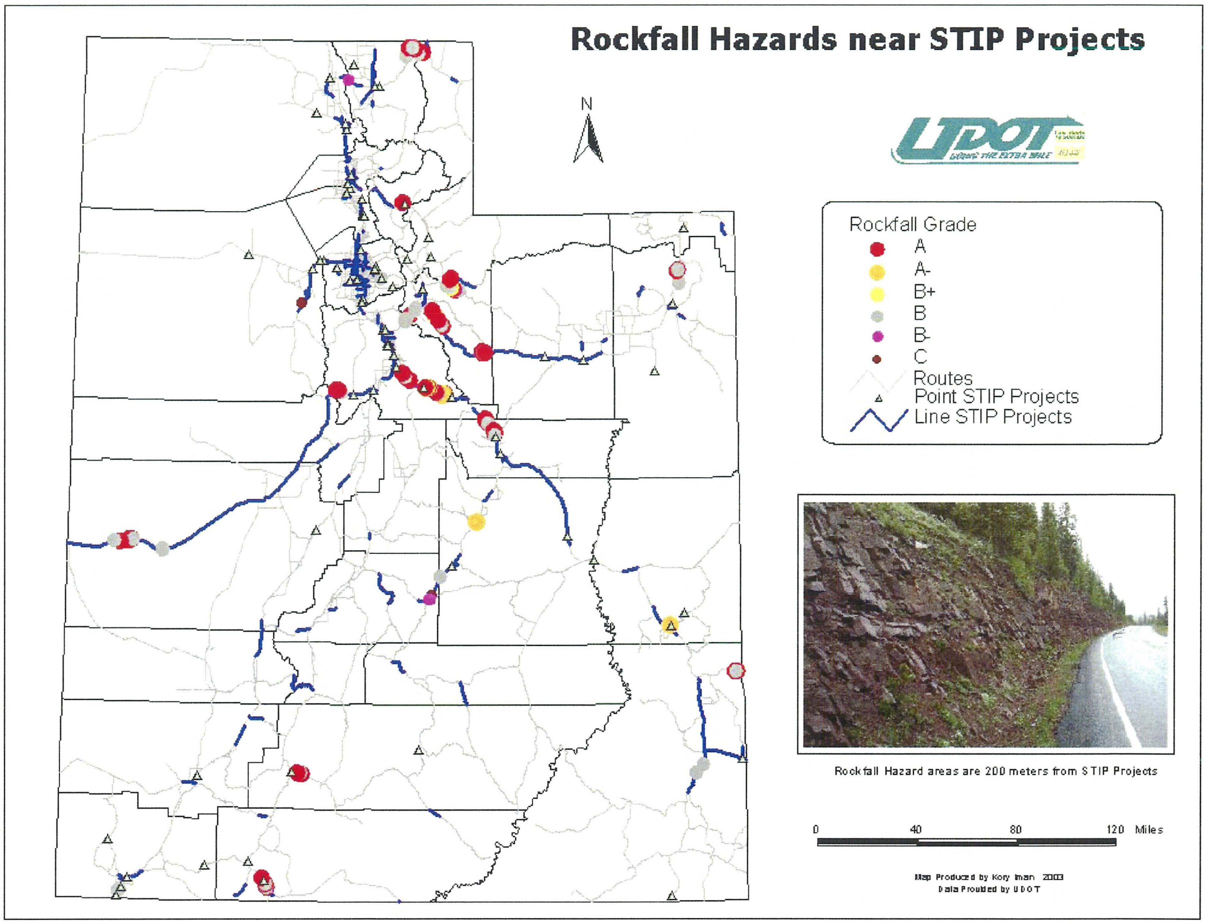


Figure 9. Rockfall hazards near STIP Projects.

4.0 DETAILED HAZARD STUDY (PHASE II)

4.1 Introduction

At the end of Phase I, it was initially recommended that a detailed rockfall hazard study be completed for 479 "A" sites that could require remediation. Those 569 sites given a "B" rating would then only be investigated as the budget permits in the future. However, to be more conservative and inclusive of the "borderline" sites, it was recommended that the "B+" sites be evaluated as well so that their true ranking relative to the A-ranked sites could be investigated. Therefore a total of 508 "A" and "B+" sites were slated to be revisited. Of the 508, three sites were not assessed because of being wrongly located or altered by construction. In addition, another two sites were discovered and added during the Phase II survey. The final survey tally is thus, 1099 sites for Phase I, 507 sites for Phase II, and 1101 sites for Phase I and/or Phase II. A total of 1101 sites are therefore found in the current database and includes both Phase I data and Phase II data.

While Phase I was being completed, a variety rockfall hazard rating systems in use in other states were evaluated. The intent of this effort was to select systems or features that would be applicable in a Utah rockfall rating system. Of these systems, three were chosen as candidates. Since the creation of the Oregon rockfall hazard rating system (RHRS) in the 1980s several states have adopted, and made modifications to, this original RHRS. This was chosen as the first candidate system. Other independently developed systems have also been implemented. After reviewing these alternatives, it was recommended that two additional systems be tested. The first was developed by the State of New York DOT during the 1990s as an improvement on a RHRS system that New York had adopted in the late 1980s. The New York system has some fundamental capabilities that have led to some increased utility in the State of New York. The second system was developed by the State of Oregon DOT as a attempted refinement of the original RHRS (ODOT, 2002). The new Oregon system has not been adopted state-wide but had been applied to at least one of their districts. Following is an introduction to the differences between these competing systems.

During Phase II, the "A" and "B+" sites were evaluated over a two-year period. Only the 318 sites evaluated during the first year were used to compare the three selected rockfall rating systems, as described in this chapter.

For the reader to gain an understanding of how the rating systems evaluate risk, a presentation of the variables included in each rating system and the associated scoring for each is presented in the following sections. It should be noted that each system includes cost considerations for prioritizing improvement projects. However, this report is focused on the scoring obtained solely on the basis of field variables. For a detailed study of each system including cost considerations, the reader is referred to Rock Fall Hazard Rating System: Participant's Manual by L.A. Pierson and R. Van Vickle (1993), ODOT Landslide and Rockfall Pilot Study (Final Report) by ODOT Geo-Hydro Section HQ Geo-Hydro Unit (2001), and New York State Department of Transportation Rock Slope Rating Procedure and Rockfall Assessment by Douglas J. Hadjin (2002). The references pertaining to each system contain the complete guides to the system variables, their measurement, use, contribution to scoring, and influence in hazard mitigation decisions. They also provide additional information as to how mitigation techniques and effectiveness may influence prioritization of safety projects.

4.2 ODOT I System

The existing ODOT rating system (ODOT I) computes detailed hazard ratings based on scoring road/traffic characteristics, geologic/hydrologic characteristics, and rockfall history. In addition, the system provides a method for estimating mitigation costs at a site. The total hazard score can be used alone for project identification and prioritization. Alternatively, the ODOT I method recommends that both cost and hazard score be used together to rank a site using the ratio of cost/score. With this ratio, high cost mitigations coupled with high scores can rank equivalent to low mitigation costs and low scores.

The system uses twelve parameters to evaluate hazards, ten of which contribute to the final hazard rating. Table 2 summarizes these parameters and presents a guide for compiling a hazard score from these parameters. The parameters include: slope height, ditch effectiveness, average vehicle risk, available decision sight distance, roadway width, geologic character (consisting of structural condition and rock friction or structural condition and difference in erosion rates of exposed strata), block size or volume of fall per event, climate and presence of water, and rockfall history. Five numerical categories (slope height, average vehicle risk, percent decision sight distance, roadway width, and block size or fall volume) are scored by generating an exponential value to which the number three is then raised. Each category score is restricted to a maximum value of 100. The remaining categories are limited to the distinct values shown in Table 2. After being scored, the final hazard rating is found by summing the scores for each of the ten contributing categories.

Table 2: ODOT I Category and Scoring Summary Table

Category			Rating Criteria and Score			
			3 Points	9 Points	27 Points	81 Points
*Slope Height			25 ft	50 ft	75 ft	100 ft
Ditch Effectiveness			Good Catchment	Moderate Catchment	Limited Catchment	No Catchment
*Average Vehicle Risk			25% of the Time	50% of the Time	75% of the Time	100% of the Time
*Percent of Decision Sight Distance			Adequate sight distance, 100% of low design value	Moderate sight distance, 80% of low design value	Limited sight distance, 60% of low design value	Very limited sight distance, 40% of low design value
*Roadway Width Including Paved Shoulders			44 ft	36 ft	28 ft	20 ft
Geologic Character	Crystalline	Structural Condition	Discontinuous joints, favorable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation
		Rock Friction	Rough, Irregular	Undulating	Planar	Clay infilling, or slickensided
	Sedimentary	Structural Condition	Few differential erosion features	Occasional differential erosion features	Many differential erosion features	Major differential erosion features
		Difference in Erosion Rates	Small difference	Moderate difference	Large difference	Extreme difference
*Block Size *Volume of Rockfall / Event			1 ft 3 cubic yards	2 ft 6 cubic yards	3 ft 9 cubic yards	4 ft 12 cubic yards
Climate and Presence of Water on Slope			Low to moderate precipitation; no freezing periods; no water on slope	Moderate precipitation or freezing periods or intermittent water on slope	High precipitation or long freezing periods or continual water on slope	High precipitation with long freezing periods or continual water on slope and long freezing periods
Rockfall History			Few Falls	Occasional Falls	Many Falls	Constant Falls

* Indicates scoring based on 3x where x is determined by conditions at site

A reduction from twelve to ten categories is based on the geologic character of the site. If the material is sedimentary (layered), the structural condition and difference in erosion rates are evaluated. If the rock is crystalline, the structural condition and the friction characteristics along fracture planes are considered. In cases where both types of rock contribute to the hazard at the site, each is scored separately and the material with the highest score when the two categories are summed is used in the calculation of the final hazard score.

The slope height is the vertical distance from the bottom of the slope to the highest point at which rockfall may be generated. The height includes any additional height on the natural slope behind the cut to the rockfall source. An exponent value is found by dividing the slope height by a benchmark value. Scoring is based on 3 raised to this calculated exponent.

Ditch effectiveness is a subjective score given by the rater based on ditch dimensions, anticipated volume per event, and slope characteristics that influence fall motion and energy. A small ditch may not be able to contain all of the material in a fall occurrence; however, even a large ditch may not be adequate if rocks bounce on slope ledges over the ditch and onto the roadway. The four categories and associated scores are shown in Table 2. For good catchment, almost all of the fall material is contained in the ditch; moderate catchment indicates that rocks occasionally reach the roadway; limited catchment is the condition where rocks frequently reach the roadway; no catchment allows all or nearly all rocks to fall onto the roadway.

Average vehicle risk considers the time that a vehicle is present in the rockfall section. The average vehicle risk (AVR) is found by multiplying the average daily traffic by the length of the rockfall section in miles and then by 100 to give a percentage. This is then divided by the posted speed limit and again by 24 hours per day. The category score is found by raising 3 to the exponent found by dividing the AVR percentage by 25.

Decision sight distance at the site is the distance that a six-inch object is visible to a driver along a roadway. The distance is divided by the AASHTO design amount for the posted speed limit, multiplied by 100 to give a percentage. The percentage is subtracted from 120 and then divided by 20 to produce the exponent to which 3 is raised, giving the score for the category. If the decision sight distance is greater than the AASHTO design criteria, then the final category score will be less than 3.

The roadway width is the smallest distance measured perpendicular to the slope face that includes the paved section of roadway. The ditch and unpaved shoulders are not included. The distance in feet is subtracted from 52 and then divided by 8, resulting in an exponent value to which 3 is raised for the calculation of the category score.

Geologic character presents scoring for two cases of rock: crystalline and sedimentary (layered). The crystalline rock is judged on its fracture patterns: discontinuous joints with no planes sloping adversely towards the roadway; discontinuous joints with no dominant planes sloping adversely towards the roadway; adverse joint conditions sloping towards the roadway, but not having continuous joint lengths (ten feet or more in length); and dominant joint patterns over ten feet in length that slope towards the roadway. The friction characteristics of the joints are also considered based on the interlocking capabilities if the joints are irregular, macro roughness of the joints if they are rough or undulating, friction of the rock surfaces on a micro level when the joints are planar, and the low friction materials that separate the rock surfaces when clay infilling or slickensided joints are present. The sedimentary (layered) rock is judged on the number of its erosion features: few features not distributed throughout the slope, minor features widely distributed, large and numerous features widely distributed, and severe cases with overhangs and considerably oversteepened soil and talus slopes. The difference in erosion rates also influences the likelihood of rockfall and is separated into four categories: erosion rates that create features that take many years to develop, rates that create features that take a few years to develop, rates that create features that may develop annually, and rates that create features that develop rapidly and continuously. If both sedimentary (layered) and crystalline rock types are present and creating a hazard, the category scores are found and summed for each and the greater score is used in the calculation of the final hazard rating.

Block size or volume per event is chosen based on the rater's observation of which is most likely to occur. If both situations are plausible, each may be scored and the most severe can be used in the final hazard scoring. For block size, the largest block that is likely to fall is measured on a side. The length in feet is used as the exponent to which 3 is raised, producing the category score. For volume events, the rater's estimate for fall volume (in cubic feet) is divided by three. The category score is found by raising 3 to this value. The greater of the category scores found for rockfall size or volume events is used in the final hazard score calculation.

Climate and water presence is categorized and scored in four increments: low precipitation and no freezing, moderate precipitation or short freezing or intermittent water on slope, high precipitation or long periods of freezing or continual water on slope, and high precipitation with long freezing periods or continual water on slope with long freezing periods. The benchmarks for high, moderate, and low precipitation values are given as 50 inches and 20 inches per year.

The final scoring category is the history of rockfall at the site. The number of historical falls is grouped thus: few falls or falls only during severe storm event, occasional falls during most storms, many falls occurring seasonally, and frequent falls occurring throughout the year or where severe events are common. The score for each category is displayed in Table 2. The category score is used in the final calculation of the hazard score.

To determine the final hazard score, the category scores are summed. The final score represents the apparent hazard associated with each site, and may be compared to scores for other sites in the survey to establish a relative comparison. The greater of any two scores has a higher perceived hazard. The ODOT I system further implements a cost-benefit analysis for remediation and prioritization of safety enhancement projects based on the cost of repairing the site and the method, by which the agency responsible for the sites in question chooses, to approach funding and hazard severity considerations. Cost consideration are not included in this study.

4.3 ODOT II System

The modified ODOT system (ODOT II) includes landslides as well as rockfall. It is an adaptation of the Washington State DOT's Unstable Slope Management System (USMS) and, like the original ODOT I system, uses an additive scoring system for rockfall, but with five sets of parameters instead of three. The five sets of parameters are (1) Failure Type/Hazard, (2) Roadway Impact, (3) Annual Maintenance Frequency, (4) Average Daily Traffic, and (5) Accident History. A score is calculated for each category, then added together to provide a total score. The system then multiplies the total score by two factors in order to provide a final ranking for the State Transportation Improvement Program (STIP). These factors are (1) the Maintenance Benefit Cost Factor (MBC) and the Highway Classification Factor (HCF). The first factor has to do with the 20-year maintenance cost and failure repair cost for the site. The second factor weights the final score depending on its district, regional, statewide, or interstate highway classification. Unlike the original ODOT I system where the cost is divided by the hazard score, this system multiplies the hazard score by a "cost factor" that varies between 0.5 and 1.5. Unlike the NYDOT system, this system is not risk-based and therefore cannot take into account the effects of partial risk reduction on priorities.

The system evaluates five sets of parameters with maximum scores of 100 then sums these to produce a hazard score, as summarized in Table 3, taken from the ODOT Landslide and Rockfall Pilot Study (ODOT, 2002). The sets of parameters are: Failure Type/Hazard, Roadway Impact, Annual Maintenance Frequency, Average Daily Traffic, and Accident History. The final score is achieved by multiplying the hazard score by two factors: a highway importance factor, and a maintenance benefit-cost factor. The benefit-cost factor is not used in the scoring presented in this paper. The inclusion of the cost-benefit factor may greatly influence the hazard score (reducing it by up to half, or increasing it by up to 50%), due to the importance of costs in determining the plausibility of remediation efforts. However, this is not included in this report because the project costs do not influence the hazard or the risk observed at any site.

The failure or hazard type, based on the speed of the slope movement, is somewhat inconsequential to the hazard evaluations included in this report. Because the initial survey of sites was based on the ODOT I system to determine which sites will be included in this detailed survey, most sites fall into the "High Hazard" category as related to the "Failure Type / Hazard". Some occurrences where lower categorizations were assigned during the detailed survey do exist. However, since the conditions of the site warrant the lower Hazard category rating, the Roadway Impact, which is also linked to these conditions, is likely to score lower on the rating scale, reducing the impact the limiting values associated with the Hazard category score have on the Roadway Impact category. High hazards include sites where falls have occurred in the past; medium hazards have not moved in the past, but have potential to move in the future; low hazards are slower slides that have little potential for causing a road hazard; and very small hazards are not scored because they will not likely affect the roadway. The high hazard sites are scored between 81 and 100 points based on the percentage of the AASHTO sight distance available to drivers reaching the hazard site. The score is found by multiplying the percent sight distance by 0.247 and then subtracting the result from 108.91 with limits to the score of 81 for the minimum and 100 for the maximum. Most of the distribution in this category scoring is due to this separation using sight distance.

Table 3: Summary Sheet for the ODOT II Rockfall Hazard Rating System

1	Failure Type / Hazard	Very small or insignificant failures that do not affect the roadway. (not scored)	Low Hazard; Slower slides with low potential for causing a road hazard. (9 points)	Medium Hazard; Slides that have not moved suddenly in the past, but have the potential to cause a road hazard. (27 points)				High Hazard; Rapid slides that have created a road hazard in the past. Includes debris flows and rockfall. (81-100 points based on sight distance)		
			Low Hazards receive 0 points	Medium hazards receive maximum of 54 points				High hazards can receive full point range		
2	Roadway Impact (pick one)	Landslides:	All Low Hazard slides above (0 points)	Would only affect shoulder during major failure (3 points)	Two-way traffic would remain after major failure (9 points)	One-way traffic would remain after major failure (27 points)	Total Closure in the event of major failure; 0-3 Mile Detour (54 points)	Total Closure in the event of major failure; 3-10 Mile Detour (70 points)	Total Closure in the event of major failure; 10-60 Mile Detour (88 points)	Total Closure in the event of major failure; >60 Mile Detour (100 points)
		OR								
		Rockfall:	Rocks are completely contained in ditch (3 points)	Rocks fall into shoulder only (9 points)	Rocks enter roadway (27 points)	No ditch, all falling rocks enter roadway (81 points)		Rocks occasionally fill part or all of a lane (100 points)		
3	Annual Maintenance Frequency	0 - 5 Failures Per Year: Sliding scale from 0 - 100 Points								
4	Average Daily traffic	0 - 40,000 Cars Per Day: Sliding scale 1 - 100 Points								
5	Accident History	No Accidents (3 points)		Vehicle or Property Damage (9 points)		Injury (27 points)		Fatality (100 points)		

500 total possible points

The roadway impact category is divided into two sections: landslides and rockfall. Landslide impacts are not evaluated in this study. Rockfall is scored on ditch effectiveness (as summarized in Table 3) because it does not affect a consistent width of the roadway.

The annual maintenance frequency score is developed using two formulas. If maintenance occurs at the site less than once per year, the score is 50 times the annual frequency. When maintenance occurs more than once each year, the frequency is multiplied by 12.5 and then added to 37.5, but may not exceed a maximum score of 100.

The average daily traffic is based on a sliding scale from zero to 100 points as traffic increases from zero to 40,000 cars per day on the roadway. The use of 40,000 as a benchmark is arbitrary and may be modified based on score separation and ADT values when the survey is completed.

Accident history is the final category in the ODOT II system. The historical data for accidents caused by slides and falls is generally unavailable in Utah, except for some which gain media exposure due to highway closure or death. A fatality receives a score of 100 due to the liability associated with an accident resulting in such severe consequences. Due to the lack of data for category scoring, all sites are assigned a value associated with data showing no historical accidents until such accident data is located. This scoring blanket narrows the scoring separation by effectively eliminating the category from the rating system.

The final hazard score may be found once each category score is calculated. Adding the five category scores and then multiplying by the highway importance factor establishes the hazard score. The highway factor is modified from the ODOT II classifications to fit the Utah Department of Transportation's roadway classification system. The four original categories (District, Regional, Statewide, and Interstate Highways) are reduced to three: Rural State (two-lane roadways), State (four-lane roadways), and Interstate Highways with factors of 1.0, 1.1, and 1.2 respectfully. The highway importance factor has little influence on the results of data gathered for this report because of the majority of surveyed sites being located in rural areas, requiring a highway factor of 1.0.

4.4 NYDOT System

In the system developed by the New York Department of Transportation (NYDOT) (Hadjin, 2002), a "Total Relative Risk" (TRR) is computed based on Geologic Factor (GF), road Section Factor (SF), and Human Exposure Factor (HEF). The factors used are similar to the ODOT system except they are formulated so as to be more directly related to the "probabilities" associated with consequences and hence risk. The GF represents the relative likelihood that the slope will produce rockfall. Given the rockfall does occur, the SF represents the likelihood the rock will not be stopped by the ditch and will therefore hit the road. Given the rock does hit the road, the HEF represents the likelihood rockfall will hit a car or be hit by a car. The GF, SF and HEF values are multiplied together, like a probabilistic risk assessment, to determine TRR. This risk approach is quite different from the "addition" of scores in the ODOT method and therefore possibly lends itself particularly well to the concept of "risk reduction". Risk reduction is defined as the benefit provided by one of several possible treatments applicable to a given rock slope. If the TRR after remediation is called the residual risk (RR), then Risk Reduction = TRR-RR. The NYDOT can assign different remediation efforts a RR value that can then be subtracted from TRR to determine Risk Reduction. This allows DOT officials to evaluate cost-benefits for given sites. Questions like, "How many dollars can be assigned to a site and at what benefit?" might be more readily answered with this approach. It was therefore recommended that NYDOT's Risk Reduction score system also be tested in Utah during Phase II.

The Geologic Factor (GF) uses six parameters that contribute to the slope physical condition at a site. Five of the variables used in the Geologic Factor coincide with those used in the ODOT systems:

Geology, Block Size, Rock Friction, Climate, and Historical events. The sixth parameter of the GF is a measure of the hazard contribution from the back slope above the roadway cut. The presence of boulders on the back slope influences the score when the back slope is greater than 25 degrees from horizontal. Each classification within the Geologic Factor is scored using five steps of either 1, 3, 9, 27, or 81 points ranging from best case (1 pt) to worst case (81 pts). The calculation of the Geologic Factor is based on the sum total of the 6 separate categories shown in Table 4.

Table 4. Scoring categories for Geologic Factor (GF)

SCORE			1 point	3 points	9 points	27 points	81 points
or	1a	Geology (crystalline)	Massive, no fractures dipping out of slope	Discontinuous factures, random orientations	Fractures forming wedges	Discontinuous fractures dipping out of slope	Continuous fractures dipping out of slope.
	1b	Geology (sedimentary)	Horizontal to slightly dipping	Raveling, occasional small blocks	Small overhangs or columns, numerous small blocks	Overhangs, some large unstable blocks, high columns	Bedding or joints dipping out of slope.
and	2	Block Size	< = 0.15 m	0.15 – 0.3 m	0.3 – 0.6 m	0.6 – 1.5 m	1.5 m +
	3	Rock Friction	Rough, irregular	Undulating	Planar	Smooth, slickensided	Clay, gouge - faulted
	4	Water / climate	Dry	Some seepage	Moderate seepage	High seepage / brush vegetation	High seepage with long backslope and high vegetation
	5	Rock fall history	No falls (0 – 4/ yr)	Occasional minor falls (5 – 14 / yr)	Occasional falls (15 – 24 / yr)	Regular falls (25 – 34 /yr)	Major falls / slides (35 + falls/ yr)
	6	Backslope Conditions	Flat / gentle 0 – 15 deg.	Moderate 15 – 25 deg.	Steep 25 – 35 deg.	Very Steep >35 deg. Or (25 –35 deg. With boulders)	Very steep slope > 35 deg. with backslope boulders

The Section Factor (SF) evaluates the adequacy of the actual ditch dimensions to contain a rockfall event through a comparison to required dimensions taken from Golder Associates (1988). The Section Factor calculation is linked to an empirical chart called the Ritchie Ditch Criteria, which is shown in Figure 10. (Ritchie, 1963). The evaluation of the Section Factor involves the physical measurement of slope angle (degrees), slope height (meters), actual ditch depth below pavement level (meters) (DD), and the actual ditch width (meters) from the pavement edge to the beginning of the cut face (DW). The slope angle and height values are taken to the Ritchie Ditch Chart and ideal ditch dimensions for width (RW) and depth (RD) are chosen based on the given curves. Values located between given curves are scaled. The Section Factor is based on a comparison of the actual conditions (DD) and (DW) to the ideal values taken from the Ritchie chart (RW) and (RD),

Section Factor (SF) = (RW + RD) / (DD + DW).

Values for this calculation range from a best-case value of 1 to a worst-case value of about 11. When the sum of the existing ditch values (DD + DW) is greater than or equal to the sum of the Ritchie values (RW + RD) then the Section Factor is given a value of 1 and the entire score for the site (TRR) is forced to a score of 1. The logic behind this is that, should a fall occur, the ditch conditions are such that the fall will be trapped in the ditch and will not hit the road.

The HEF represents the statistical probability that a moving rock will either impact a passing vehicle or that a passing vehicle will not be able to stop in time to avoid collision with any debris that has landed on the roadway from a rockfall event occurring previously. The HEF is broken into two parts referred to as the Passive Factor (Fp) and the Active Factor (Fa). The Passive Factor value (Fp) tends to dominate the HEF value, and characterizes the relative risk of a vehicle striking a rock that has previously fallen into the roadway. The Passive Factor calculation is based on four quantities:

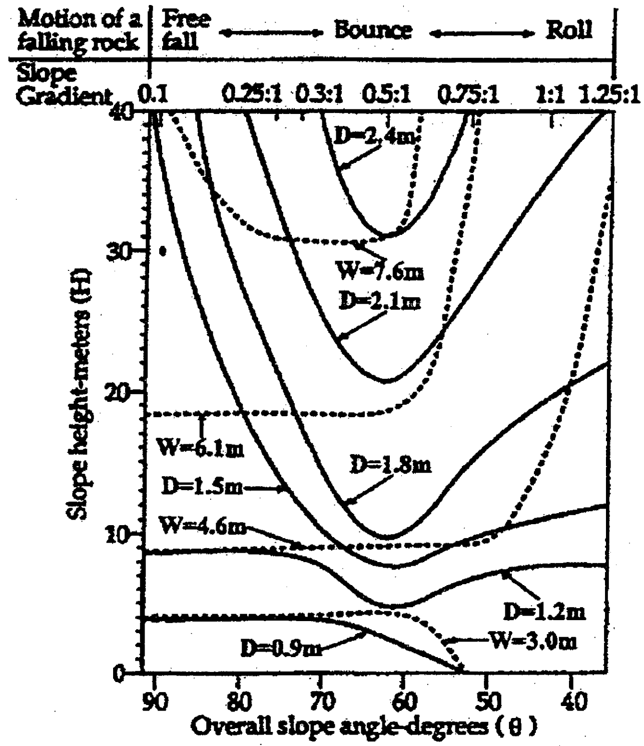


Figure 10. Ritchie Ditch empirical graph for determination of ideal ditch conditions (Ritchie, 1963).

(1) The Decision Sight Distance (DSD measured in meters) which is the measured distance at a site where a motorist can see debris in the roadway;

(2) The Site Length (L in meters) which is the measured outcrop or site length horizontally along the roadway. It should be noted that the site length is calculated as the difference between the beginning and end mileage (unlike Phase I where the distance was calculated as the difference between the beginning and end GPS coordinate);

(3) The Average Daily Traffic (ADT) which is the traffic count by roadway based on Utah Department of Transportation surveys. These values are updated by UDOT yearly.

(4) The Stopping Sight Distance (SSD measured in meters) which is the AASHTO recommended stopping distance for a roadway based on the posted speed.

The passive factor is then calculated by:

$$Fp = \log10\,(ADT) \times \log10\,(L)(\,a\,/\,(SSD - a))$$

where

$$a = (\,SSD - DSD) \text{ or } 0 \text{ if } DSD > SSD.$$

The factor "a" describes the relationship between the SSD and DSD measured during the roadside survey. When the field-measured DSD is greater than or equal to SSD, the "a" value by design defaults to a value of 0. The net effect when DSD > SSD is to eliminate the effect of the passive condition factor (Fp) which becomes a value of 0. The logic follows that when the actual sight distance is sufficient for a motorist to see debris in the roadway, the motorist will avoid the debris or stop before they reach it (NYDOT, 1996).

A second term of the HEF, the Active Factor (Fa), describes a situation where a driver is struck by a falling rock. The equation describing the active conditions is given by

$$Fa = ADT \times ((L \times SSD) / (V \times 24{,}000)).$$

All variables are the same as for the passive condition described previously, save for the value V. The V value is the vehicle velocity, which is taken from the posted speed limit at the site and then converted into kilometers per hour.

The HEF is then calculated by

$$HEF = (Fa^*Fp)/3.$$

Notably, the formulas for the HEF and the GF have divisors to reduce their respective numerical values. The GF without reduction would have a disproportionate influence on the risk score. The HEF, however, is much less than one when ADT values are small, as in rural areas (the majority of the 318 sites in this survey). In instances where the sum of Fa and Fp is already less than one, the divisor used in the HEF serves to increase the factor's influence on the total relative risk score.

4.5 Field Methods

Two types of data were collected during Phase II: quantitative data collected using measuring devices and qualitative data estimated using judgment and experience to fit site characteristics to category descriptions. The development of consistent results, when using a system that implements both forms of data to compare hazard severity between sites, requires consistency in measuring and judging data.

The collection of measurements and other quantitative field data was done using a laser distance finder. The distance finder internally calculates inclination angles, horizontal, vertical, and slope distances making data collection efficient and consistent. Sight distances, roadway widths and slope dimensions were easily found using the distance meter. In metric mode, the resolution for horizontal distances is one meter, which is not sufficient for estimating catchment widths. Where necessary, a measuring tape was used for greater precision.

Geologic and site parameters present difficulty in consistently rating the weathering, potential hazards and the extent of their possible severity, effectiveness of catchment, and the contribution of climate to overall hazard severity at a rockfall location. Awareness of local drought or flood conditions during site evaluation helped prevent improper categorization of the overall climate conditions that typically affect the rate of erosion of the slope. Monolithic structures that look to be teetering on the brink of a fall may last ten thousand years and present an unrealistic contribution to hazard severity. Volume or block size involved in a fall event, the fall's distribution along the slope face, and the degree of containment provided by a ditch or barrier all must be considered in order to rate the future extent of the hazard created by a fall occurrence. Soil slopes laden with boulders do not fit comfortably into categories describing joint friction characteristics, so the category describing "clay-filled" is used, based on the poor frictional resistance loose soil provides in preventing fall occurrences. Rainfall frequency, magnitude, and influence are judged by topography, elevation, latitude, and aspect. The qualitative decision process requires understanding of the variable interactions and consistency in judgment because of the comparative nature of the rating systems.

Site length in a western state such as Utah can be a difficult quantity to measure for field raters when faced with extensive roadside cliff bands that may extend to kilometers in length. Because of this, the establishment of set site limits are subjective and based on the experience of the raters.

The fall occurrence scale as shown in Figure 11 was used to evaluate historical fall data by grouping the data into categories used in the ODOT I and NYDOT systems. The scale is based on the number of falls per year in the historical data gathered in the initial survey of sites and designed to provide a separation of the scores implementing this data.

To gather all necessary data and describe the variables included in the hazard analysis systems, several specialized pieces of equipment were useful and allowed greater efficiency in the data gathering process. These included a Garmin GPSmap 76 GPS unit and a UniversalMAP Utah roadmap, an Impulse XL laser distance finder from Laser Technology Inc., a Breithaupt Kassel stratum compass, and a rock hammer. These were utilized for site location, data gathering, and geologic characterization of the slope and provided ease of measurement as well as consistency in the data gathering process.

Falls	ODOT I	NYDOT
<5	Few	None
<10	Few	Occasional Minor
<15	Occasional	Occasional Minor
<20	Occasional	Occasional
<25	Many	Occasional
<30	Many	Regular
<35	Many	Regular
>35	Year-Round	Major

Figure 11: Rating Scale for Fall Occurrences

4.6 Data Entry and Analysis

After collection, the data was entered into an electronic database for storage, score calculation and comparison. Microsoft Access was used because of the ease of creating a data entry interface. The field sheet interface replicated the field sheet used in data collection. These two items were simultaneously developed as patterns in data collection and data entry revealed organizational inefficiencies in the data field sheet and data entry form.

Once the data was entered into the database, it was first analyzed using MS Excel programmed with custom macros that evaluated the relative risk according to each of the three systems: ODOT I, ODOT II, and NYDOT. The spreadsheet was linked to the database into which the field data had been entered. The scoring distributions, the rank assigned to sites by each system, and the macroscopic differences in each system were examined within Excel.

The spreadsheet programming required all data fields in a site record to be filled before a score could be calculated for the site. Each hazard rating system was modularized in code to decrease confusion and complications associated with debugging and to facilitate modifications that may be implemented in the future.

4.7 Scoring Results

Each site score, as a percentage of the highest score, was calculated for each system so that a distribution of scores could be expressed relative to a maximum value. The distribution of ODOT I scores associated with the 318 sites surveyed during the first year of Phase II shows a majority of the scores falling into a centralized range, as shown in Figure 12. Several factors may have contributed to the shape of this distribution. It was initially speculated that the subjectivity of certain variables and their inexact fit to categories in the survey may have led to the assignment of a mid-range value by the rater in too many cases. On the other hand, the sites may have characteristics that naturally fall into the mid-range of scores. Interestingly, the distribution is approximately "normal" or Gaussian. This is the expected distribution when a large number of random variables (of any distribution) are added together.

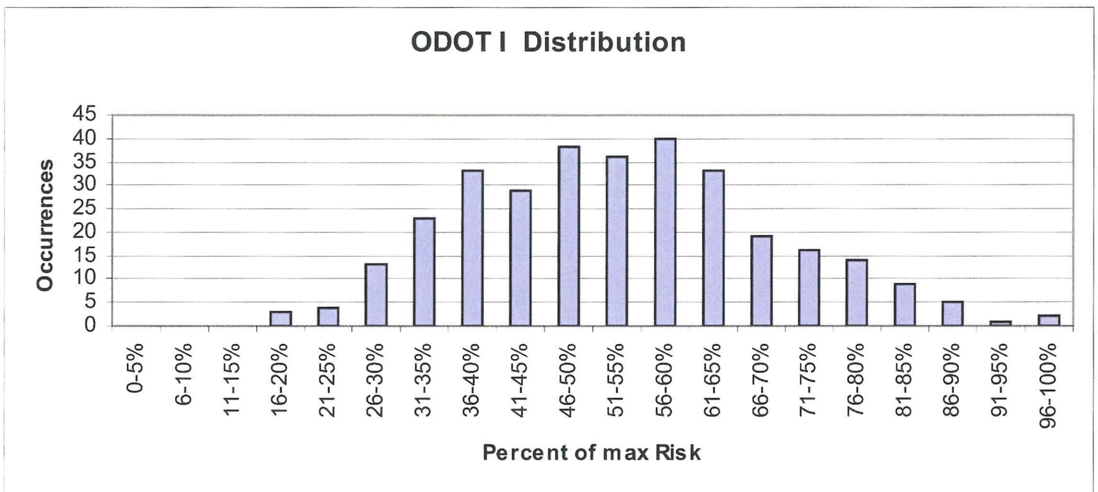


Figure 12. Relative Scoring Distribution Using ODOT I.

The ODOT II system groups sites in the Utah hazard survey into a bimodal distribution as shown in Figure 13. The ratings fall into ranges between 30-40%, and 55-70% of the maximum score in the survey. The maximum score for the 318 surveyed sites is 289.4. The lack of historical data regarding accidents and maintenance frequency as well as the subjectivity in evaluating the severity of a hazard and its impact on the roadway lead to a score that may not accurately prioritize rockfall hazards. Maintenance and historical data (fall and accident histories for ODOT I and NYDOT, and annualized maintenance rates and accident history for ODOT II) used in the survey are incomplete, requiring assumptions to estimate values to be used in the calculations. The maintenance cost/benefit ratio factor applied to hazard ratings in the ODOT II system is not used in this scoring of the sites because it does not influence relative risk. The low numbers of categories that contribute to hazard scoring in the ODOT II system does not allow adequate score separation as indicated by the groupings between 30 - 40% and 55 - 70% of the maximum.

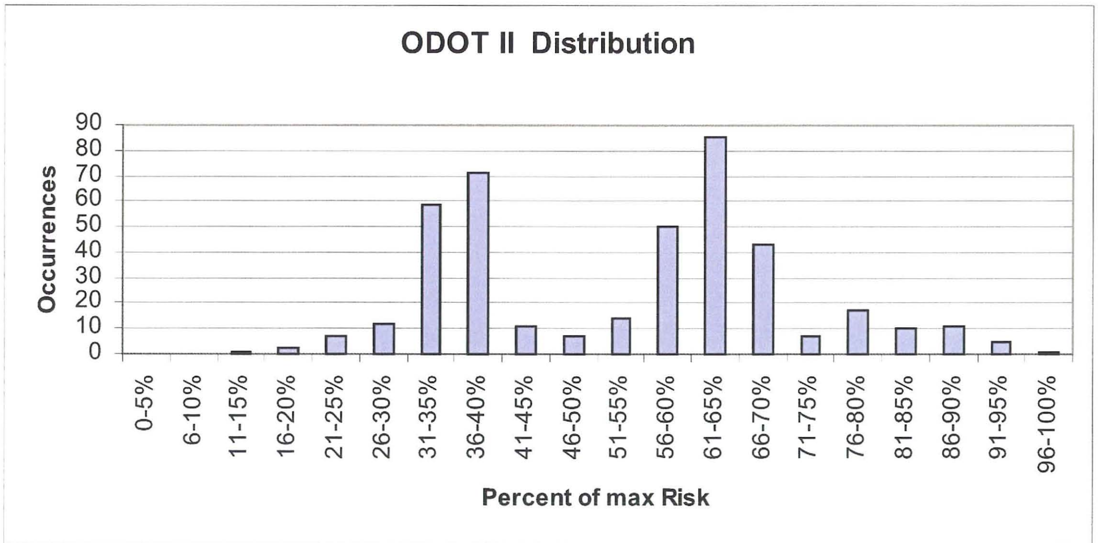


Figure 13. Relative Scoring Distribution using ODOT II.

The distribution of scores based on the NYDOT system is shown in Figures 14 and 15 for 100% of the sites and the lowest 20% of sites respectively. With this system, the number of occurrences decreases rapidly as Total Relative Risk (TRR) scores increase. The range of scores varies from 1682 at the top to less than 1 at the lowest. An examination of Figures 14 and 15 shows that most of the scores fall within the lowest 1-5% range. This is possibly due to the extremely low probability that damage will occur from a fall at a site with a low Human Exposure Factor (HEF). Although conditions specific to the Section Factor (SF) require the TRR in some cases to have a value of one, no such limit exists for conditions regarding the HEF. As a result TRR values may sink below one in such cases where the SF is greater than one, while the HEF is smaller than one.

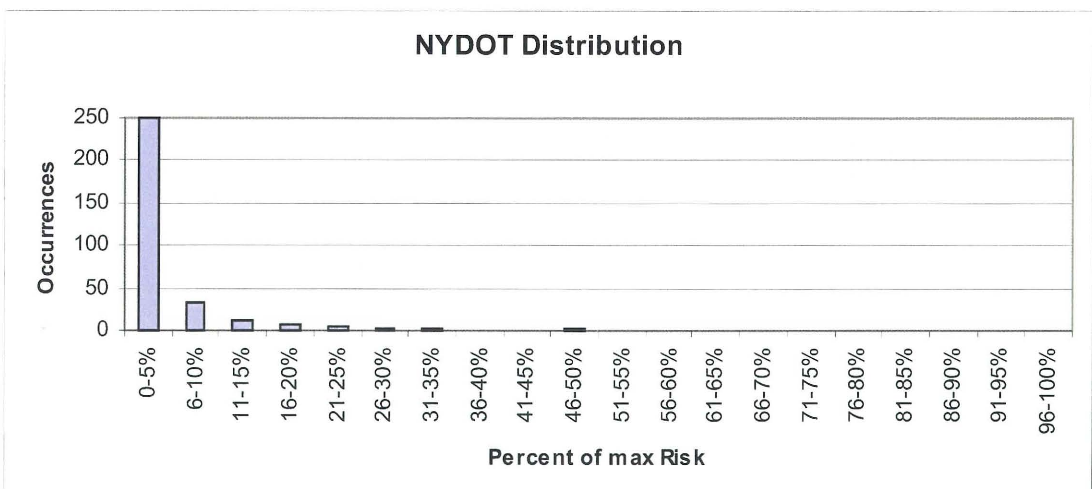


Figure 14: Relative Scoring Distribution of the 318 Year 1 sites using NYDOT system

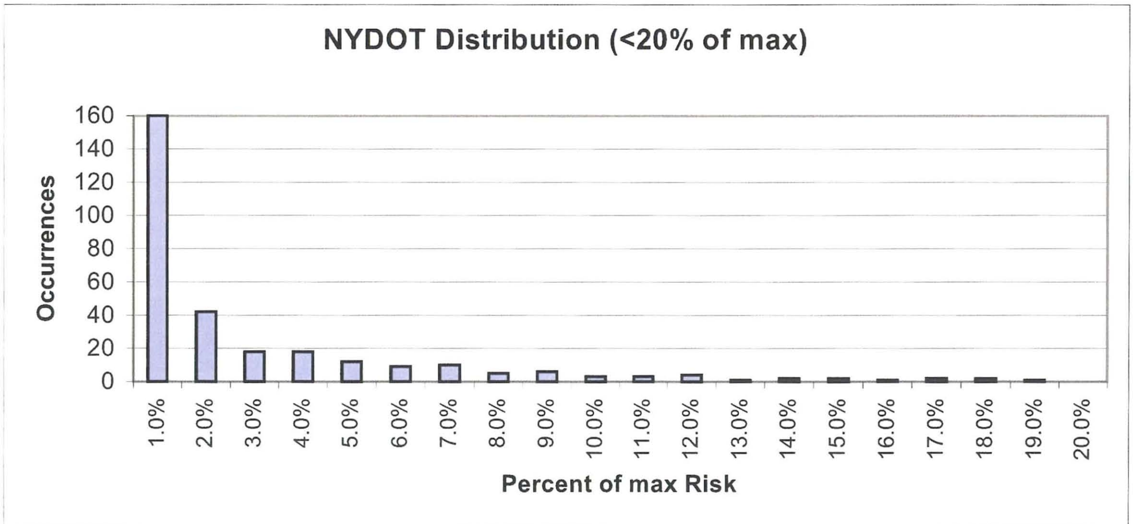


Figure 15: NYDOT Distribution for scores less than 20% of maximum relative risk

4.8 System Comparisons

Although the scoring systems use similar data to evaluate relative risk, the systems vary greatly in some instances as to what constitutes a hazardous site. Figure 16 displays the trend in the difference in rankings comparing all three systems. For example, if a site was ranked as the 45th worst site by the NYDOT system and was ranked 100th by the ODOT I system, then the difference in rank is 55. This would count as one occurrence in the blue bar in the 50-99 category. Figure 16 shows that many of the sites are similar in ranking. However, some are ranked considerably different in each system. Three of these sites, Morgan rf-1426-02 for NYDOT and ODOT I, Morgan rf-1426-04 for NYDOT and ODOT II, and Heber rf-3431-07 for ODOT I and ODOT II, show the largest difference in rankings between the system pairs. Hand calculations of the hazard scoring for each of these three sites are included in the Appendix B and a summary is provided below in Table 5.

It is important to remember that the NYDOT system contains many sites that receive a score set to 1.0 due to a Section Factor less than one. Therefore, the final hazard score cannot determine the rank for such a site. For this survey, rank is determined alphabetically by shed name and then numerically by site identification number for these sites.

The NYDOT system scores the Morgan rf-1426-04 site much lower then both of the ODOT systems. The site is on an interstate highway (I-84) that climbs through a canyon in northern Utah. The NYDOT system recognizes the geologic hazards and likelihood of fall occurrences shown by a large Geologic Factor of 13.0 and the more-than-adequate catchment is seen through a Section Factor of 0.59. The likelihood of a fall disrupting traffic flow, injuring persons in a passing vehicle, or causing property damage is consequently very low. Because of the large catchment area the Section Factor for the NYDOT system is below one, which results in a fixed hazard score of 1.0 and consequently a very low priority ranking. The ODOT I system recognizes the extreme height, massive volume of potential fall material, and location near a bend in the highway that reduces stopping sight distance. It does not however, put much weight on the presence of the large ditch. The ODOT II rating system assigns the maximum points to the hazard type for this location and 50 points for the amount of cleanup reported for the area. Though regular cleanup is required, apparently the ditch is handling it. The other categories score low in the system, but because the site is located on a major highway, the highway importance factor increases the total score for the site by 20%. This increase places the site in the top 40 for the ODOT II system.

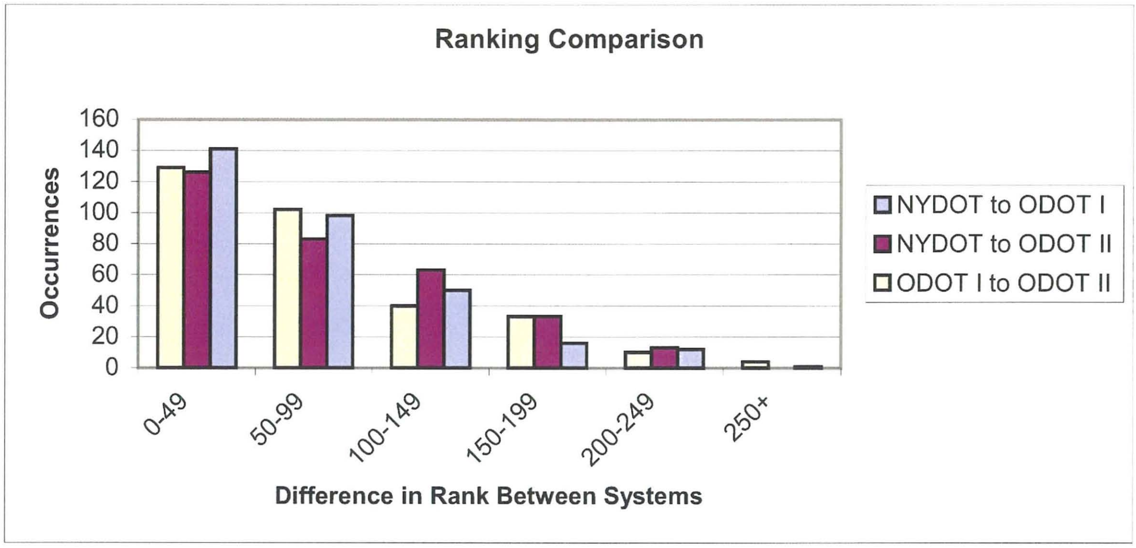


Figure 16. Difference in rankings between systems.

Table 5: Selected Site Comparison Table

		System					
Site		ODOT I		ODOT II		NYDOT	
Shed	Number	Score	Rank	Score	rank	Score	Rank
Morgan	rf-1426-02	450.5	25	198.5	44	1	286
Heber	rf-3431-07	129	314	210.1	37	11.3	279
Morgan	rf-1426-04	402.2	50	210	38	1	287

Both NYDOT and ODOT I assign a priority to Heber rf-3431-07 as being among the lowest 15 % of sites, while ODOT II assigns a priority in the top 15% of all sites. The site scores highly in the ODOT II system due to the maintenance information given for the site. Cleanup at the site occurs 5 times each year, which is the maximum used in the ODOT II system, resulting in a category score of 100. These points cause the site to jump to a leading position on the priority list for ODOT II. The other systems are influenced by the high number of falls occurring at the site, but the lack of hazards (roadway impact, no accidents in the history, and moderate weathering conditions at the site) and the apparent effectiveness of the catchment at the site reduce the overall priority ranking well below the majority of sites with prominent hazard features.

The Morgan rf-1426-02 site is located on Interstate-84 eastbound. The site contains many red conglomerate boulders, some the size of small cars. Both ODOT I and ODOT II prioritize the Morgan site high on the list – 25th for ODOT I and 44th for ODOT II. However, because of the 17-meter wide ditch that runs alongside the road at the site location, the NYDOT system shows adequate protection from falls resulting in a hazard score reduced to a value of 1 (resulting from a Section Factor indicating complete catchment in the event of a fall occurrence). If the limit to the final score, enforced because of the low Section Factor, were removed, the site would still only score 18.8 in the NYDOT system keeping the site low on the priority list.

The systems studied herein used ratings based on subjective benchmarks (in ODOT I and ODOT II) and reduction factors (in NYDOT). The systems were not modified except where necessary to make use of classifications and data already available to the state DOT and researchers. These modifications included a reduction in the number of roadway classifications for the ODOT II system, and the use of a scale created to relate historical data of fall occurrences to the severity classifications associated with the ODOT I and NYDOT systems, as explained previously.

5. Development of the UDOT Rockfall Hazard Rating System

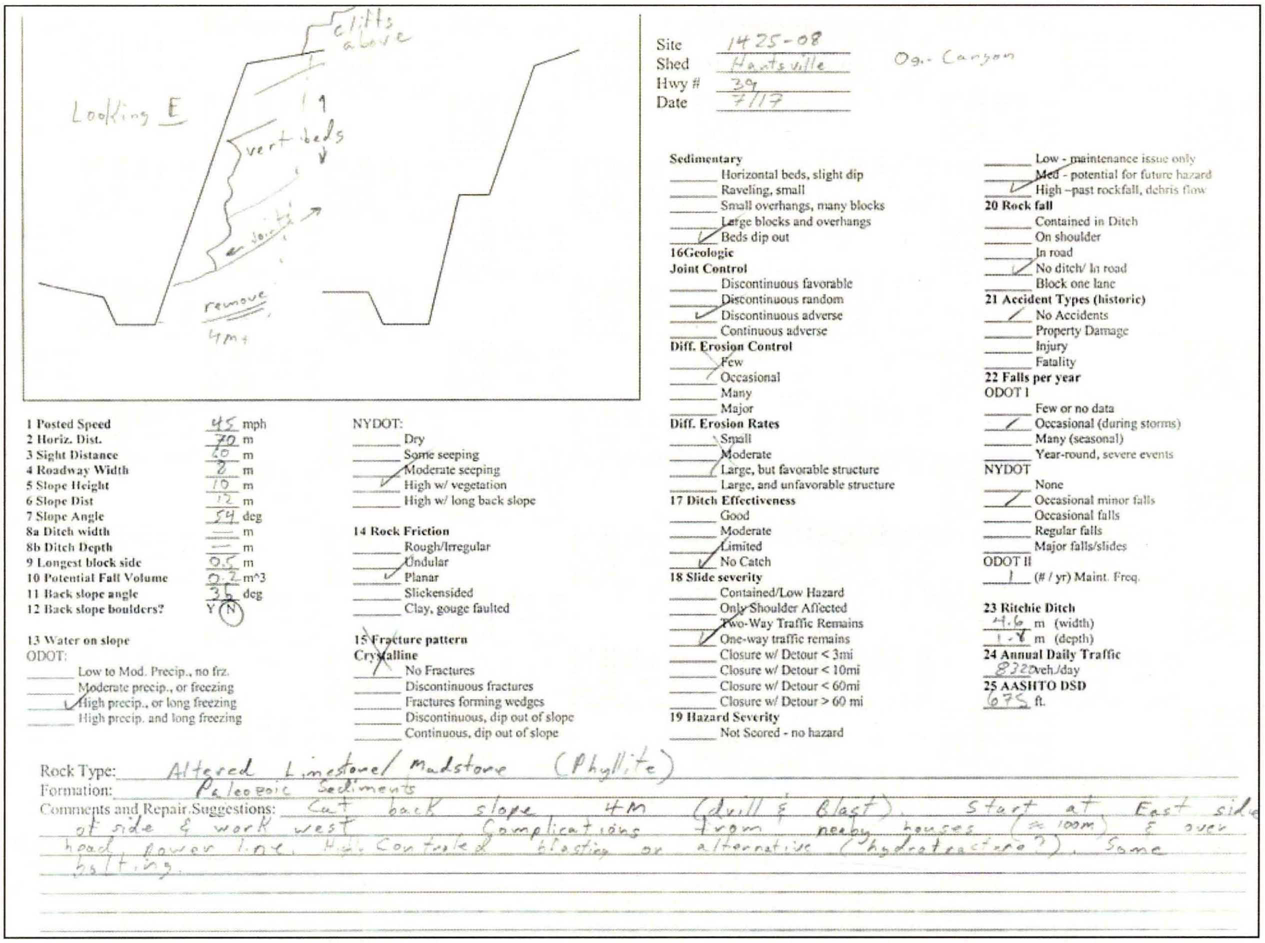
5.1 Introduction

Of the systems studied in the previous section, the UDOT Technical Advisory Committee and the author's agreed that the NYDOT system more realistically analyzes the "risk" associated with rockfall sites in Utah. It does so in the way that it more objectively handles consideration of ditch effectiveness and the exposure of traffic. Given this initial result, a study was then completed to identify more specifically the strengths and weaknesses of the NYDOT system within the state of Utah and determine what changes might better tailor it to Utah. This study also examined how different repair schemes might affect the factors that determine the post-remediation hazard score.

Five sites surveyed during the 2002 field season were chosen for detailed examination along with three additional sites surveyed during 2003. These sites are considered representative of the geologic and geographic variety across the state. They are located within the maintenance station areas of Huntsville, Morgan, Hurricane, Escalante, Cottonwood, Beaver and Bluff. Geologic host rocks for these sites include, quartzite, limestone, sandstone and volcanics. Each site is described in detail in Section 5.4.

This section breaks down the elements of each site's score by the GF, SF and HEF factors, then points out methods of remediation applicable to the given sites. Also explored is how the remediation method(s) affect each factor. Specific remediation examples include slope recut, ditch excavation, rock bolting, roadside barriers, smooth wall blasting, and mechanical scaling. Other potential methods include fencing, netting and draping of faces with mesh. The chosen remediation methods are applied site-specifically. However they would be considered prime candidates for many other sites across the state based on the observations of the 507 sites surveyed in 2002 - 2003. Because of budgetary limitations on this study, the application of a given remediation method by itself or in combination with other methods proposed in the study, may not be the optimum choice for a site or for any sites. However, the discussions in this section provide useful examples of how the overall rating system can be applied in Utah to prioritize the repair of problem sites within a highway region, and to illustrate the sensitivity of the parameters in the New York rockfall system.

Data input to the system was collected on field sheets, an example of which is shown as Figure 17. As per the other sites, this data was then entered into a Microsoft Access database where scores for the site were automatically generated by the computer according to the NYDOT scoring format, described below.



Site 1425-08
Shed Hantsville
Hwy # 39
Date 7/17
Og.- Canyon

1 Posted Speed 45 mph
2 Horiz. Dist. 70 m
3 Sight Distance 60 m
4 Roadway Width 8 m
5 Slope Height 10 m
6 Slope Dist 12 m
7 Slope Angle 54 deg
8a Ditch width — m
8b Ditch Depth — m
9 Longest block side 0.5 m
10 Potential Fall Volume 0.2 m^3
11 Back slope angle 35 deg
12 Back slope boulders? Y N

13 Water on slope
ODOT:
Low to Mod. Precip., no frz.
Moderate precip., or freezing
✓ High precip., or long freezing
High precip. and long freezing

NYDOT:
Dry
Some seeping
✓ Moderate seeping
High w/ vegetation
High w/ long back slope

14 Rock Friction
Rough/Irregular
Undular
✓ Planar
Slickensided
Clay, gouge faulted

15 Fracture pattern
Crystalline
No Fractures
Discontinuous fractures
Fractures forming wedges
Discontinuous, dip out of slope
Continuous, dip out of slope

Sedimentary
Horizontal beds, slight dip
Raveling, small
Small overhangs, many blocks
Large blocks and overhangs
✓ Beds dip out
16Geologic
Joint Control
Discontinuous favorable
Discontinuous random
✓ Discontinuous adverse
Continuous adverse
Diff. Erosion Control
Few
✓ Occasional
Many
Major
Diff. Erosion Rates
Small
Moderate
✓ Large, but favorable structure
Large, and unfavorable structure
17 Ditch Effectiveness
Good
Moderate
Limited
✓ No Catch
18 Slide severity
Contained/Low Hazard
Only Shoulder Affected
Two-Way Traffic Remains
✓ One-way traffic remains
Closure w/ Detour < 3mi
Closure w/ Detour < 10mi
Closure w/ Detour < 60mi
Closure w/ Detour > 60 mi
19 Hazard Severity
Not Scored - no hazard
Low - maintenance issue only
Med - potential for future hazard
✓ High –past rockfall, debris flow
20 Rock fall
Contained in Ditch
On shoulder
In road
✓ No ditch/ In road
Block one lane
21 Accident Types (historic)
✓ No Accidents
Property Damage
Injury
Fatality
22 Falls per year
ODOT I
Few or no data
✓ Occasional (during storms)
Many (seasonal)
Year-round, severe events
NYDOT
None
✓ Occasional minor falls
Occasional falls
Regular falls
Major falls/slides
ODOT II
1 (# / yr) Maint. Freq.
23 Ritchie Ditch
4.6 m (width)
1.8 m (depth)
24 Annual Daily Traffic
8320 veh./day
25 AASHTO DSD
675 ft.

Rock Type: Altered Limestone/ Mudstone (Phyllite)
Formation: Paleozoic Sediments
Comments and Repair Suggestions: Cut back slope 4M (drill & blast). Start at East side of side & work west. Complications from nearby houses (≈ 100m) & over head power line. High Controled blasting or alternative (hydrofracture?). Some bolting.

Figure 17. NYDOT rockfall hazard rating field data collection sheet that also includes parameters for two other hazard rating systems. This is Field Sheet 1425-08.

5.2 NYDOT System Results

The final outputs using the NYDOT system based on the detailed surveys of all 507 rockfall hazard sites across the state of Utah are shown in Figures 18-20. It should be noted that these results were based on data, including the AADT and the site length, which has since been altered slightly. So if the reader were to use the current database, they would see different information than shows up in these examples.

Figure 18 shows site counts on the vertical axis plotted against % of maximum score. The maximum score in Utah using the NYDOT system is Site 2433-27 located in the Cottonwood maintenance district with a score of 1682.6, which will be discussed in detail in a following section. The lowest ranked sites score below 1 pt. Close inspection of Figure 18 shows a nearly logarithmic distribution with the vast majority of sites falling in the lowest 20 % of scores when compared with the state maximum. Only seven sites fall above 50 % of the state maximum value. Interestingly, the most hazardous sites are widely separated in score from the majority of sites surveyed.

Figures 19 and 20 also show a nearly logarithmic NYDOT distribution of sites. Figure 19 shows the lowest 20 % of sites compared to the state maximum score. Figure 20 compares this population to the lowest 2% of sites. This consistently logarithmic distribution is likely due to the multiplicative nature of the system. This is a common distribution for relative risk scores in a risk analysis. This distribution permits planners to easily pick repair sites based on relative hazard score as a function of the state maximum score down to any desired level of hazard - depending on available funding.

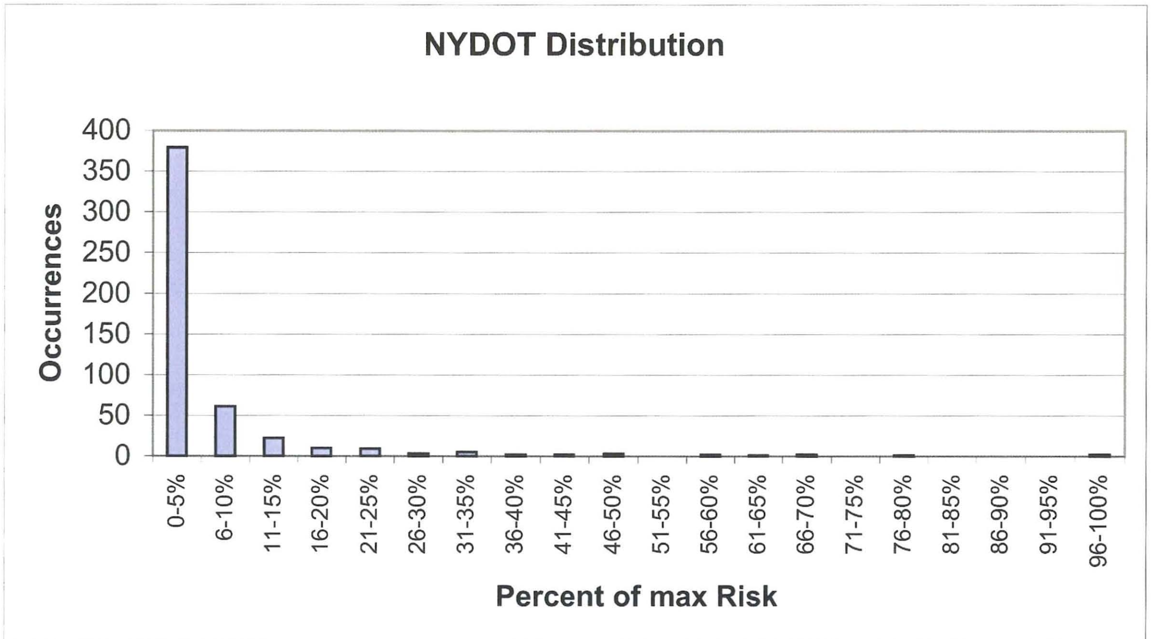


Figure 18. Results of detailed surveys of 507 rockfall sites in Utah plotted as a percentage of the maximum score of 1682.6.

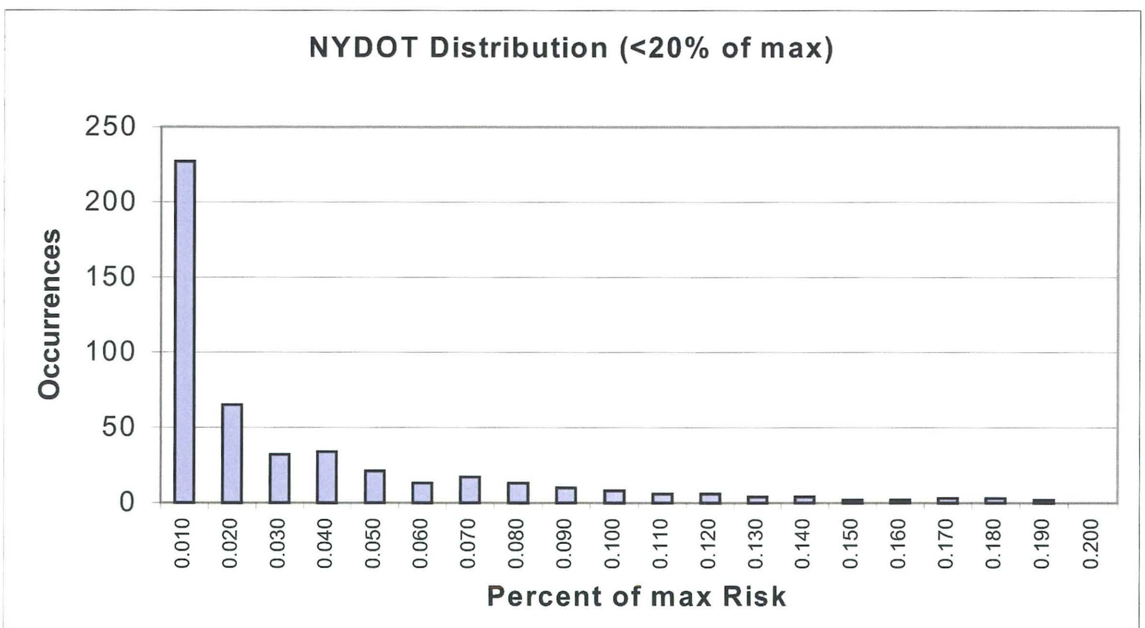


Figure 19. Enhanced view of the lowest 20% of sites surveyed in Utah as a percentage of the maximum state score of 1682.6.

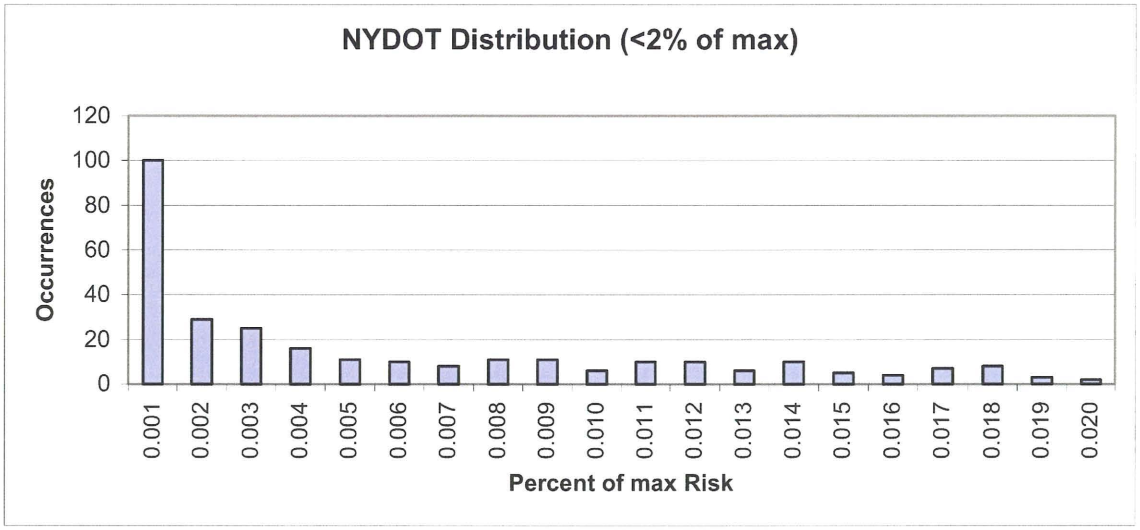


Figure 20. Enhanced view of lowest 2% of scores in Utah as a percentage of the state maximum score of 1682.6.

5.3 Score Reduction through Rehabilitation

Throughout the summer field seasons of 2002 and 2003, several repair methods were identified as being applicable to a wide variety of rockfall sites in the state of Utah. The repair methods most frequently proposed include ditch excavation, roadside barriers, mechanical scaling, slope recuts, slope bolting, smooth wall blasting, fencing, netting and draping with mesh. Each of these repair schemes affect one or more of the three factors that compose the overall site rating in the NYDOT system. Ditch cutting improvements, roadside barriers and some slope recuts improve the Section Factor. A slope recut changes the site geometry affecting all three factors, Human Exposure Factor, Geologic Factor and Section Factor. Other repair treatment methods such as smooth wall blasting, rock bolting, draping mesh and scaling target the Geologic Factor by reducing scores in one or more of it's six categories - for example removing backslope boulders.

The Section Factor is concerned with the geometry of the roadside region from the edge of the pavement to the beginning of the slope most often referred to as the ditch area or catchment. The catchment geometry is linked to the slope height using the Ritchie ditch graph shown in Figure 10 (Ritche, 1963). The roadside region between the slope and the pavement represents the most likely debris landing area and the effectiveness of the catchment is critical to the overall site hazard score. Section Factor reduction is accomplished primarily through roadside work effecting the depth and area of the catchment as slope height is not easily modified. Many sites have an existing catchment which is inadequate according to the Ritchie criteria. But with some enlargement, the overall score for the site can be greatly reduced even though the Ritchie dimensions have not been reached. The Ritchie criteria can therefore sometimes be used as a guideline rather than a rule.

It should be noted that the Colorado Rockfall Simulation Program (CRSP) has been used for many years to assess the path and ultimate landing zone of falling rocks (Pfeiffer and Higgins, 1990). The CRSP can be used to assess the effectiveness of modifications to roadside improvements, or to help determine the relevance of the SF score.

Geologic Factor improvement is gained through a variety of means, the most common being scaling loose areas of a face and the removing of perched boulders. Most scaling can be accomplished mechanically with a track-mounted excavator using either a bucket attachment or a hardened point with a vibrator. Of all available equipment, the tracked excavator is the one most useful over the widest variety of sites. It must be noted that mechanical scaling has a time limit to its effectiveness. Scaling essentially "turns back the clock" on mechanical weathering of a face. Depending on rock type, similar hazards will redevelop following scaling within a time frame determined by the rock type and climate.

An effective means of treating Geologic Factor conditions on hard and or massive rock outcrops is through the use of smooth wall blasting. This can eliminate the weathered portions of a face including overhangs in a much more enduring manner than with scaling. It is also more practical on large and/or high cuts. The treatment of a face with rock bolts can be both time-consuming and expensive but is appropriate in situations where access to heavy equipment is limited and blasting is not practical due to road closure constraints and/or the proximity to infrastructure. Bolting will improve site geology and rock friction by anchoring slippage planes and potential reduction of block size through the scaling process that is inherent to bolting activities.

The Human Exposure Factor characterizes the likelihood of vehicles being hit by debris actively falling from a slope or by hitting debris that is already in the roadway. Overall, this category measures the "risk" associated with material actually impacting a vehicle given it reaches the roadway surface (Kliche 1999). In order to reduce this exposure, site geometry can be altered to increase site distance which is most often accomplished by recutting the site and removing physical obstructions. Reducing the linear length of the rockfall problem can also reduce the Human Exposure Factor but this is not a practical approach in most situations. Recuts typically target the other factors (Geologic Factor or Section Factor) but can have beneficial effects on human exposure as described. Other factors that contribute to the exposure of rockfall to humans such as daily traffic volume, AASHTO stopping site distance (Pierson, Davis and Van Vickle, 1990) and speed postings are not readily altered.

5.4 Evaluations of the NYDOT Rockfall Rating System by Site

Following are the results of evaluations of remediation opportunities for eight sites in Utah. These serve as specific examples of some of the previous general discussion. Sites were chosen for detailed evaluation here, both as examples of system function and to illustrate some of the strengths and weaknesses of the NYDOT rockfall rating system and how it might be adapted to become the UDOT system. Additionally, geographic and geologic variation was sought in these examples. The road network in Utah exhibits a wide geographic and geologic variation and this analysis seeks to highlight this variation.

5.4.1 Huntsville Site Number 1425-08

The first site to be examined is in the Huntsville maintenance station jurisdiction and is located in Ogden Canyon. The site is east of the city of Ogden Utah along the south side of State Highway 39 and west of the Pineview Reservoir. Figure 21 shows that the site consists of a series of resistant ledges of altered carbonate and phyllite rock adjacent to a roadway with an average daily traffic volume of 8320 vehicles. The roadway is eight meters wide, and has two lanes, with a drop-off to a stream on the north side bordering the westbound lane. Because of the height of the cliffs (10 meters) south of the road, rockfall hazard exists in both lanes. General site dimensions and characteristics are listed in Figure 17, which is a copy of the field sheet generated during the summer 2002 survey.

Figure 21. Photograph of Huntsville Site Number 1425-08.

In order to understand the sensitivity of the site to different repair methods, a spreadsheet containing the hazard calculations was created for easy reference. Figure 22 is the score calculation sheet for the form given earlier as Figure 17. The total score for this site untreated is 618 and ranks 15th in the state at 37% of the maximum score. For this site, the most obvious problems exist with the Geologic Factor and Section Factor. The photograph bears this out, as there is an obvious series of outcrops immediately adjacent to the road with little or no catchment. The Human Exposure Factor is largely driven by the high traffic volume and minimal measured stopping site distance (Figure 17). While the stopping sight distance can be increased with the removal of vegetation and a recut of the slope, traffic volume cannot be altered.

The most obvious course of action for this site is to pursue remediation that reduces the Section Factor and the Geologic Factor. Looking at the photograph in Figure 21, it is very apparent that the ditch is narrow and will not accommodate a jersey barrier in its present condition. The field survey suggests that some type of recut might be in order to both improve the catchment area thus reducing the Section Factor and possibly improve the Human Exposure Factor through a sight distance increase. Pursuing a limited recut in order to accommodate a catchment is often an iterative process based on cost considerations and construction time restraints such as time for road closure. Since the ditch at this site is nearly absent, a solution might be a minimal 1.2 meter recut with the establishment of a 20 cm deep ditch against the new face. Using geometry collected during the site visit, a volume of 1 cubic meters / meter of site length was estimated. This results in a total volume of approximately 70 cubic meters removed for a 70-meter long site. Since any cutting on this site involves solid rock, volumes removed must be blasted and this should be figured into the removal cost along with the locations of potentially impacted utilities. It is important to remember that for the NYDOT system to recognize Section Factor improvement; additive ditch dimensions (width + depth) must be greater than 1 meter. The new "recut" ditch dimensions are added and then divided by the Ritchie dimension to create a Section Factor. The system uses a default minimum actual ditch rating of 1 (actual depth plus actual width). In cases such as this site where there is little or no ditch, improvements in the Section Factor can only be made by removing material creating final dimensions in excess of 1 meter of combined ditch depth and width into the slope. Application of the post repair slope geometry to the NYDOT system score yields a reduction of the Section Factor from 6.3 to 4.5. Since the total site score is a product function of all three factors, the overall reduction from this action is 176 points to 442 or 28.5% of the original rating.

Rock Altered Limestone and Phyllite (cambrian ?)

1, 3, 9, 27, 81

GF		Score
Bedding Condition	beds dip out	81
Block Size	0.5 M	9
Rock Friction	planar	9
Water	High w seeps	27
History	occasional minor	3
Backslope angle (boulders?)	36 deg	27
	Total	156

GF = **15.6** Total/10

SF

Ditch width (M)	0.5
Ditch depth (M)	0.5
Ritche Width (M)	4.5
Ritchie Depth (M)	1.8

SF = (RW + RD)/ (DD + DW) = 6.30

HEF

ADT	8320	
L (Site length) M	70	
Velocity (MPH)	45	72.42 km/hr
SSD (AASHTO)'	675	205.74 M
DSD (M)	60	

Fa = (ADT) x ((L + SSD) / (V x 24,000))

Fa = 1.3

A = (SSD - DSD)

A = 145.7

Fp = log10 (ADT) x log 10 (L) x (A/ (SSD - A))

3.9201 4.482 1.8451

Fp = 17.6

HEF = (Fa + Fp)/3 = **6.30**

Score = (GF) x (SF) x (HEF) **618.80**

Figure 22. NYDOT rockfall hazard rating worksheet for the Huntsville site number 1425-08.

Additional improvements to the Geologic Factor are also possible. The rock face is composed of phyllite and altered carbonate, both relatively resistant rocks in this area. Some scaling of loose material is possible with a large excavator. Another geologic treatment would be to use rock bolts on the face following scaling activities. Both repair schemes, bolting and scaling, treat three categories of the Geologic Factor, "bedding condition", "block size", and "rock friction". The actual expected numeric improvement of a site in these three categories is very subjective at this stage of analysis. Unless this type of repair is going after a specific geologic feature or features on a site such as an individual overhang, group of boulders etc., a conservative approach is recommended. Using both bolting and scaling, reductions of one step in each category are estimated. The overall result of these geologic treatments is a Geologic Factor reduction from a 15.6 to a 9, (sedimentary condition category from 81 to 27, block size from 9 to 3, and rock friction from 9 to 3). The effect of these activities, not considering Section Factor improvements mentioned previously, is a total score reduction of 261 points or 42%. If only scaling were to be considered, two categories might be improved by one step instead of three and appropriate reductions applied. It must be mentioned that time consuming roadside work on this site will have a considerable impact on traffic flow due to limited available space and lack of detour options.

The last factor to be examined is the Human Exposure Factor. In this situation, reduction of the exposure can best be accomplished by improving the stopping sight distance for approaching motorists. Sight distance improvement can be accomplished by either cutting back obscuring vegetation and or cutting back the slope itself, if practical. The degree of improvement available via these solutions can best be approximated by a site survey. For the purpose of this study, a modest improvement of 30 meters increased sight distance will be applied. A 30-meter sight distance increase results in a measured sight distance improvement from 60 to 90 meters, which in turn reduces the Human Exposure Factor from 6.3 to 3.5. This reduces the overall score by 270 points or 44 %.

Improvements of this site can take a variety of approaches. The purpose of this example was to illustrate how a wide variety of repair options affect the NYDOT score. A second reason for this example was to show repair options can interact and reduce multiple factors at the same time as in this case where Section Factor improvements might also improve sight distance and therefore Human Exposure Factor.

5.4.2 Cedar City Site Number 4524-25

This site is located on State Highway 143 northwest of the Brian Head ski area and southeast of the town of Parowan (Figure 23). The geology consists of slightly dipping sandstone with backslope boulders generated by an outcrop of conglomerate upslope. Vegetation is relatively abundant and consists primarily of evergreen trees and scattered aspen. The roadway is separated from the sandstone cliffs by a modest ditch on the north side and drops off to a small stream to the south. The steep angle of the backslope (35°), the abundance of conglomerate material on the slope and a known history of rockfall indicates that rockfall is a danger to both lanes of the roadway. Rockfall hazard from the immediate sandstone cliff is not the primary threat in large part due to the angularity of the cliff material (see Figure 23) where the conglomerate above contains abundant rounded material of various sizes.

Examination of the site characteristics using the NYDOT system indicates that the initial (before remediation) score is driven largely by the Geologic and Human Exposure Factors (Figure 24). By focusing on the Human Exposure Factor, some improvement in the sight distance could be gained by a relocation of the roadway 3 meters to the south. This conservatively increases the sight distance by 10 meters, lowers the Human Exposure Factor from 6.8 to 5.2 and gains a 126-point or 26% reduction in overall score. In addition, the treatment would generate an increased ditch width of 3 meters that reduces the Section Factor from a value of 5.2 to 1.3. The overall effect of this road improvement, including the combined effects on the Section Factor and Human Exposure Factor results in a reduction of 413 points or 77%.

Figure 23. Site Number 4524-25 located on State Highway 143 northwest of the Brian Head ski area and southeast of the town of Parowan.

The most imposing feature at this site is the long backslope with the presence of rounded boulders on the cliffs above. The most obvious treatments are those that would reduce or contain backslope falls that use the immediate roadside cliffs as a launch ramp. Treatment of the upslope source area is not feasible due to the steepness of the backslope and the wooded terrain. Damaging the tree cover immediately above the roadway to access the upper slope would increase the danger as the trees act as a natural catch fence for the material rolling down slope. The construction of a catch fence near the top of the lower cliff, though labor intensive, would provide a means of stopping the vast majority of fall material from reaching the roadway. A catch fence can conservatively be modeled by a reduction in the backslope condition from 81 points to 27 points, a one step reduction. The overall effect is a drop of 192 points or 36%. The maintenance of 100 meters of catch fence from year to year would likely be difficult and as previously mentioned, initial installation costs would be high.

Additional Section Factor improvement beyond roadway relocation would require a recut of the cliff face to create more catchment space, if practical. Because of the poor backslope access problems, getting heavy equipment on top of the site is not recommended. All recut activities would be attempted from the cliff base resulting in road closure and extensive excavation time considering a site length in excess of 90 meters. Different final face geometries can be fed back into the spreadsheet model and the score changes noted. Little improvement in the Geologic Factor would be expected because of the fall source location. However, improvement in the sight distance and an increase in the Section Factor parameters can be achieved. Performance of a recut is generally the most complete means of altering the overall site score by improving all three factors and is almost always expensive.

Rock **Dakota SS Jurasic**

1, 3, 9, 27, 81

GF

		Score
Bedding Condition	large blocks and o-hangs.	27
Block Size	0.3 M	3
Rock Friction	undular	3
Water	Moderate some seeps	9
History		27
Backslope angle (boulders?)	yes	81
	Total	150

GF = **15** Total/10

SF

Ditch width (M)	1
Ditch depth (M)	0.25
Ritche Width (M)	4.7
Ritchie Depth (M)	1.8

SF = (RW + RD)/ (DD + DW) = 5.20

HEF

ADT	2245	
L (Site length) M	91	
Velocity (MPH)	40	64.38
SSD (AASHTO)'	600	182.88
DSD (M)	45	

Fa = (ADT) x ((L + SSD) / (V x 24,000))

Fa = **0.40**

A = (SSD - DSD)

A = **137.88**

Fp = log10 (ADT) x log 10 (L) x (A/ (SSD - A))

3.3512 6.003 1.9590

Fp = **20.116**

HEF = (Fa + Fp)/3 = **6.84**

Score = (GF) x (SF) x (HEF) **533.35**

Figure 24. NYDOT rockfall hazard rating worksheet for the Cedar City site number 4524-25 before rehabilitation.

This site was a chosen example because it demonstrates the need to closely identify the fall source(s) prior to remediation recommendations. The presence of a cut face does not necessarily indicate a hazard. In this case the hazard lies on the backslope and not the cut face itself, as the ditch is capable of catching the angular low energy falls from the sandstone but not the high-energy conglomerates above. Backslope fall sources should be considered common when dealing with mountainous sites with high snowfall and freeze-thaw cycles.

5.4.3 Hurricane Site Number 4522-07

Located on State Highway 9 northeast of the city of Hurricane on the approach to Zion National Park, this site is composed of Paleozoic age limestone (Figure 25). The rock outcrop is northeast of the roadway and is composed of a tan, highly fractured limestone that dips in the direction of the road. The backslope area is covered with sparse grass and small clumps of sagebrush and contains abundant angular boulders. As the local climate is semi-arid, the vegetation does not grow to a size that would inhibit movement of material on the backslope. A small ditch is adjacent to the cut face. However, it shows evidence of becoming quickly filled in by small falls and is inadequate in its present state. The rockfall threat in this location is two-fold; backslope boulders and heavily fractured rock overhangs can fall and impact the entire road width.

The relatively high hazard score of 1053 is most influenced by the Geologic Factor (22), which contains two maximum values (81 pts.) in both the "fracture condition" and "backslope condition" categories and a high Human Exposure Factor (12.57), which is driven by a poor sight distance and large average daily traffic. Figure 25 shows an inclined roadway with a sharp curve in the middle of the site resulting in a poor sight distance. The Section Factor of 3.8 is relatively low when compared to other high-scoring sites. However, this ditch is subject to degradation as a result of fall material filling the ditch between cleanouts.

Figure 25. Rockfall site 4522-07 located on State Highway 9 northeast of the city of Hurricane on the approach to Zion National Park, looking west.

Since this site has a steep hillside to the west and a cliff to the east, road relocation is not practical without a large commitment of resources. As a result, all repair options would likely concentrate on the face itself. The bedding and backslope conditions are the greatest contributors to the high Geologic Factor score, so treatment of these categories could be pursued. Often, the best way to improve bedding conditions is to use rock bolts, mesh and shotcrete to increase the bond between beds. Due to the slope height of 18 meters and the lack of easy access to the backslope, rock bolting and mesh would be a time consuming procedure. Shotcrete following scaling is a viable repair alternative. However, taking into account the large area of the slope, this option would prove expensive. Since the rock appears heavily fractured, the scaling option would have a time-dependant benefit and the condition would deteriorate as new fractures opened up once exposed. Repair of the backslope would require significant excavation to allow equipment access followed by reseeding of the slope following boulder removal. Any one of these treatments should provide one step (81 pts – 27 pts) of improvement in "fracture condition" or "backslope condition" categories. A treatment of the face (bolting, scaling, shotcrete, or draping mesh) combined with backslope boulder removal would generate a minimum of a one-step reduction in both categories. In terms of scores, a one step reduction, (81 pts to 27 pts) in one category improves the Geologic Factor from 22 to 16.6 and the overall score from 1053 to 795, a 24% reduction. A two-step reduction, reducing both bedding and backslope conditions, results in a Geologic Factor improvement from 22 to 11.2 and an overall score reduction from 1053 to 536, or 49%. It must be emphasized that direct treatments of a face with a large height and site length combined with adverse rock and access conditions is both expensive and time consuming.

In light of the overall poor geologic condition of this site, a modest recut could be considered, if practical. Using smooth blasting techniques, rock bolting and, most of the adverse overhangs can be eliminated. A face recut will also provide more room for a larger ditch and increase the sight distance available. Pursuing a modest recut plan consisting of the removal of a 2.6 meter thickness of face material for the entire length of the site is an option as shown in the Figure 26 drawing. This would require the drilling and blasting of approximately 3230 cubic meters of rock. The projected improvement of site score is as follows:

- Geologic Factor of 22 improves to 16.6 (one step decrease in fracture pattern)
- Section Factor of 3.81 improves to 1.43 (widen ditch by 3 meters and deepen by 0.9 meters)
- Human Exposure Factor of 12.6 improves to 9.67 (increase sight distance by 10 meters)

The above changes result in an overall score improvement from 1053 to 229.5 or 78%

These values are conservative and in the case of recutting a slope face, a variety of geometry improvements are possible. This is particularly true when combined with other repair methods. However, in light of the expense anticipated for cliff face treatments that would be required to reduce the Geologic Factor alone, a full recut could be considered.

This example was chosen for several reasons. The most obvious is that it has the 6th highest hazard score in the state and as it is located on the approach to Zion National Park, a location with high visibility. It also readily displays how the different factors within the system interact to create a total score and by performing a comprehensive repair, all three factors can be improved.

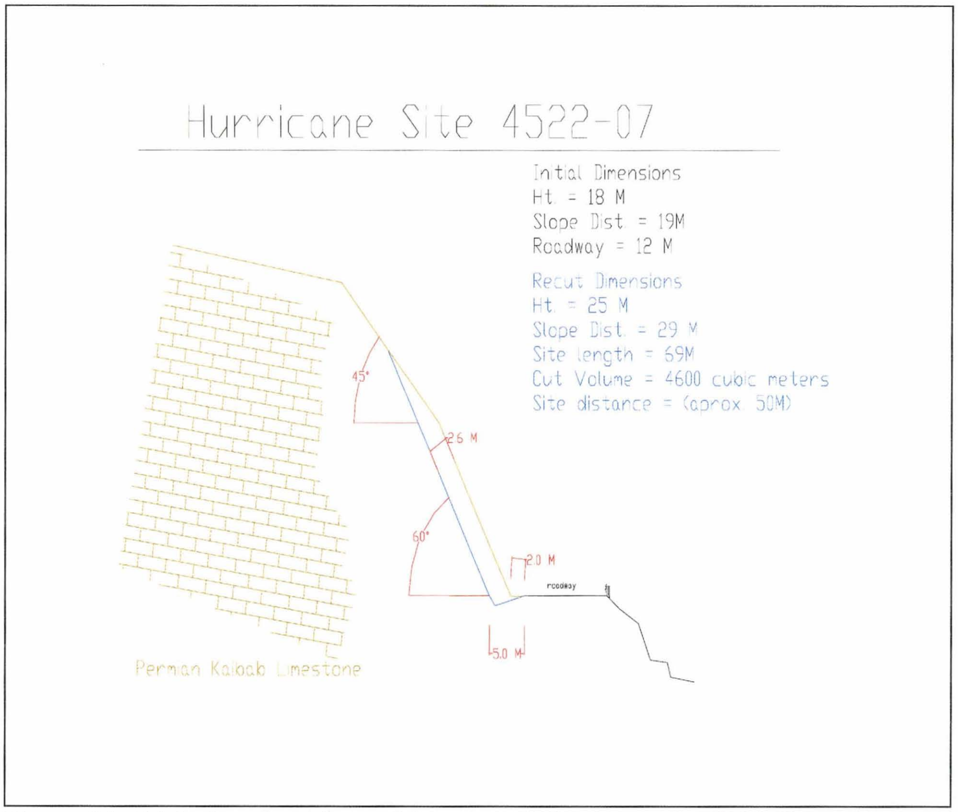


Figure 26. CAD drawing of possible recut at Hurricane Site 4522-07.

5.4.4 Bluff Site Number 4421-08

Site Number 4421-08 is located in southeast Utah west of the town of Bluff and north of the town of Mexican Hat, Arizona on State Highway 261 north bound (see Figure 27). This site is one of a number of problem sites located on a steep series of switchbacks as the roadway rises from the surrounding red desert terrain to the top of a large ridge. Site geometry is unique in this area for several reasons, foremost being that the roadway itself is primarily single lane and unpaved. The area geology consists of a series of resistant sandstone layers forming successive cliff bands, which form the ridge itself. The sandstones are interbedded with softer mudstones and jointed to various degrees. Rockfall hazard is principally the result of wind and water erosion of the rock, particularly as a result of flash flood events during the summer months. The local vegetation is best characterized as sparse desert cover with occasional juniper and pinion pine.

Examination of the site score by category shows that the overall score is driven by the Geologic Factor of 20.8 and by the Section Factor of 5.8. The Human Exposure Factor of 5.37 is not extreme but due to the restrictive site geometry with cliffs located on either side of the roadway, cannot be easily altered. The high Geologic Factor is the result of two maximum category values in both the block size and sedimentary (layered) fracture pattern scores. Additional contribution comes in the history category where "regular" falls are recorded annually by highway maintenance crews, which contributes 27 points to the GF calculation. The Section Factor contribution stems from the fact that there is little to no ditch area to catch falls before they impact the roadway. Essentially all falls will end up in the road and since the road is only 5 meters wide, they will likely block it.

Figure 27. Photograph of Site Number 4421-08 located in southeast Utah west of the town of Bluff and north of the town of Mexican Hat Arizona on State Highway 261 north bound.

Repair methods for this area are limited by a lack of access from both the roadway and to the slopes above and below the roadway. Repair methods must be accomplished from the roadway area only, resulting in road closure during the process. The slope height of 9 meters lends itself to treatment with a large excavator. Therefore, full face scaling is a viable option over the length of the entire face. The effect of full face scaling will be at least a full step improvement in the block size category and possibly in the sedimentary bedding condition category. It must be remembered, however, that the use of scaling will only improve the site for a finite period of time before weathering reproduces the hazard. In this semi-arid setting, the benefits of a complete scaling program could be relatively long-lived. Post scaling treatments such as rock bolting and meshing would tend to extend the life of the improvements created by scaling. However, these treatments would add significant expense to the project. At a minimum, a scaling project would reduce the block size category by one step from 81 to 27 points resulting in a Geologic Factor decrease from 20.8 to 15.4 creating an overall score improvement of 26%. If the bedding condition category is reduced by one step, particularly if the scaling operation is followed with rock bolts, the Geologic Factor is reduced from 20.8 to 10 resulting in an overall score reduction of 52%.

In light of the poor Section Factor and geologic condition of the site, a slope recut would normally be considered. However, the average daily traffic value for this roadway is only 160 vehicles. Since this site is one of several problem areas that exist along this isolated single lane section of road, any recut activities could be combined to repair multiple sites along several miles of roadway. Because of the obvious size and manpower requirement for a recut operation on this stretch of road it is questionable whether single site recuts in this area would be cost effective.

This example shows a site that is driven mainly by geometry in the form of Section Factor and Geologic Factor rather than the sight distance and traffic volume issues that heavily influence several other examples in this report. In terms of geography, the sites along State Highway 261 should be considered representative of many hazardous road cuts in the southeast and eastern portions of Utah. These desert sites are subject to minimal annual precipitation and often present the outward appearance of stability when viewed by raters. This can be deceiving. It must be remembered that rainfall drives many of the hazards at these sites just as it does sites in wetter climates. When rain falls in these desert settings it is often in the form of high volume events in very short periods of time producing intense runoff. This should be kept in mind when scoring the climate / water condition as part of the Geologic Factor.

5.4.5 Morgan Site Number 1426-17

Located 13 miles south of the city of Morgan, Utah adjacent to State Route 66, this site is composed of Tertiary age cemented conglomerates (Figure 28). The conglomerate forms resistant red stained ridges and cliffs in northern Utah and is similar to the conglomerates mentioned in Cedar City. Weathered debris at this site is primarily gravel and small cobbles. However, this site has significant potential for the generation of large backslope boulders. Because of the long site length (250 meters) this site contains a variety of features. It begins in the north as a relatively low cliff band as seen in Figure 28 but at its southern portion it becomes a single large cliff with perched boulders on ledges above the roadway. The southern boundary of the site contains a sharp corner on the shore of a lake and results in a poor stopping sight distance.

The northern portions of the cut require ditch improvement in the form of cleanup and deepening. The ditch has a width that varies from zero to 3 meters. At least one third to one half of the site could be drilled and blasted to widen and remove hard toe conditions in the roadside ditch. A width of 3 meters could be sought along with a depth target of 0.5 meters when cleaned out. The ditch improvement described would return an improvement in Section Factor from 6.9 to 1.97 and an overall score improvement of 71%.

This site was chosen in part because it allows for the illustration of several different combinations of repair activities. Due to the overall site length of 250 meters and at least 100 meters of ditch that could be cut, other repairs might be considered along with ditch improvement. Though not covered by the NYDOT System description, ditch improvements should reflect the size of the boulders that the ditch needs to catch. In this case, 1 meter plus sized blocks could be expected. Thus a substantial ditch improvement is required to be effective. The measured sight distance for this section of road is only 25 meters, which is the result of a sharp corner on the southern margin due to an isolated 20 meter long section of massive conglomerate creating a pillar on the inside of the curve. Removal of the pillar, which is approximately 1200 cubic meters in volume, would conservatively double the measured sight distance on the curve from 25 to 50 meters. The net score improvement for the removal of this portion of the cliff reduces the HEF from 9 to 3.34 and the overall score by 327 or 63%. This site improvement could be achieved with several controlled blasts over a relatively short period of time.

Figure 28. Site 1425-15 located 13 miles south of the city of Morgan Utah adjacent to State Route 66.

The final repair action to be discussed is the application of scaling activities. The vegetation covering this site is primarily grass with scattered sage and presents easy access for a large excavator operating near the roadway level. Scaling activity from the roadway area could cover the majority of the cliff area but upper slopes could not be accessed and, in order to completely scale the entire site, access would have to be established from upslope. A scaling operation might be considered as a one-step reduction in the block size reducing the category value from 27 to 9 and the Geologic Factor from 9 to 6.6. The net effect of this repair is an overall reduction in the site score from 521 to 410 or 21%.

This site shows that several repair treatments could be applied with varying degrees of cost and effectiveness for long and short-term stability. The ultimate choice would likely be driven by cost and available resources. The most long-term benefit could best be achieved by modification of the sight distance through rock removal on the curve, which produces the largest decrease in score vs. effort required.

5.4.6 Cottonwood Site Number 2433-27

Located in Big Cottonwood Canyon just east of Salt Lake Valley, Cottonwood site 27 was chosen because it is one of the "most hazardous" sites scored by the NYDOT system (see Figure 29). Tragically, a rockfall fatality occurred at this site on January 13, 2005 during the course of this study. The location is in a sub-alpine canyon with steep walls composed of early Paleozoic and Precambian sedimentary rocks consisting primarily of resistant massive quartzite. State highway 190 travels nearly due east through the canyon from the Salt Lake urban area to the alpine community of Brighton, a distance of approximately 12 miles. This site is just over 5 miles east of the canyon mouth. Figure 29 shows a view of the site from the east looking almost due west in the direction of the canyon mouth. The roadway is closely flanked by talus and cliffs on the north with a steep drop to a creek located just south of the roadway out of the photo to the left. The visible cliffs to the right of the photo continue up slope for some distance with large detached blocks evident in various positions along with talus fields and scattered vegetation. The roadway is subject to high seasonal traffic and is the only access in winter to two major ski areas and popular summer recreation sites. Annual daily traffic ranges from 4425 to just over 5000 vehicles per day with a posted speed of 35 mph. However, weather conditions can significantly alter speed and exposure time along the entire site length.

Figure 29. Located on the north side of highway 190 in Big Cottonwood Canyon, this site is subject to frequent falls in the form of quartzite boulders visible in the foreground.

Of the three factors driving the high score of this site, the most critical is the Human Exposure Factor (HEF). The HEF score of 12.6 is the largest encountered in this study and could arguably be higher as a result of longer exposure times produced by slower driving in adverse seasonal weather conditions. The poor HEF score results primarily from the poor sight distance (30 meters) encountered on a sharp curve located in the western third of the site. The curve is clearly visible in Figure 29. The AASHTO recommended stopping sight distance is 160 meters. The moderate site length of 190 meters and relatively high traffic volumes for a mountain road make additional contributions to the high HEF score.

The other two factors contributing to the final score, Geologic (GF) and Section (SF), while not the highest values in the state, still represent less than favorable conditions. The geologic score is driven by category maximum scores for climate and block size, and high scores for fracture condition, fracture orientation, maintenance, and backslope condition. The poor Section Factor is the result of there being little to no ditch adjacent to more than 50% of the site. Again this is well illustrated by Figure 29.

Even though unfavorable conditions exist at this site, the available remediation options are many. However, the existence of numerous backslope sources for large detached blocks makes total risk reduction difficult to impossible. In many cases, these backslope areas are on property not controlled by UDOT. The most obvious remediation plan is to improve the catchment along much of the north roadside. The limited catchment space does not stop or retard falls from reaching the road surface and precludes the use of concrete barriers. Catchment enlargement will involve a slope recut that includes both loose rock removal and drill-and-blast of in-place quartzite cliffs. One option is a 2-meter recut for a distance of approximately 90 meters, if practical. The proposed recut, based on a measured slope angle of 64 degrees, results in approximately 4 cubic meters of rock removed per meter of cut length. A total of 328 cubic meters would be removed to create a serviceable catchment. The application of a 2 meter ditch dimension with an estimated 20 cm depth to the NYDOT score results in a Section Factor improvement from 5.3 to 2.41, creating a net score improvement from 1682.6 to 764.8 (reduction of 54.5%). A 2-meter recut would represent a large effort on this site such that a more modest 1-meter recut might be considered. Substituting a 1-meter wide ditch dimension with a corresponding 20 cm depth yields a modest Section Factor improvement from 5.3 to 4.42 and a total score of 1402.14 (16.6% reduction).

Ditch improvements with an additive size (width + depth) less than 1 meter are not recognized by the system. While the safety of a site with no catchment is improved with the installation of only a modest ditch, this condition is either not recognized or has only modest effect on the total scores as demonstrated in the 1-meter push back example for this site. This aspect of the NYDOT system rewards ditch design that is closer to the Richie criteria rather than remediation with smaller ditches.

A second area of concern raised by this example is the abundance of large backslope blocks and what treatments, if any, are available to minimize the risks from these fall sources. Section Factor improvements as described here are the most logical choice for stopping backslope origin falls when the backslope area presents limited access problems for heavy equipment. The situation is compounded by the abundance of large blocks that result in high-energy falls that cannot be contained in a modest catchment of only 2 meters in width, as is the case here and in the previous Morgan example. Larger blocks can be removed and various scaling regimes implemented. However, there will always be backslope boulders on this site. Temporary reductions in boulder size can be applied to the Geologic Factor score but in an active climate for freeze thaw action such as this site, these effects will have a finite time limit.

The lessons learned from the highest hazard site studied involve limitations imposed by nature. Some geometric improvements made to a site Section Factor may have large influences on site score when greater than 1 meter in size. However, upslope hazards may never be eliminated and in cases such as this one, may represent the highest source of hazard as a result of the abundance of fall material and the size of that material creating high energy falls. Not all sites can be fully repaired and hazards can remain following remedial action unless cost prohibitive solutions such as debris sheds or large robust rockfall fences are considered.

5.4.7 Beaver Site Number 4527-14

Located on state Highway 153 east of Beaver Utah, this site is unique in that it scores high without the normally associated high traffic volumes present at many other top 20 sites. The setting is in subalpine coniferous forest adjacent to a small lake and associated dam (Figure 30). The roadway has been cut into the canyon wall on the north side and is immediately adjacent to the stream and lake to the south. The area is subject to large quantities of seasonal snow and extended periods of freeze thaw activity. Host rock on this site consists of basalt flows and welded tuff layers. The volcanics are resistant and form cliffs the full length of the site.

As was the case in the previous Cottonwood and Cedar City examples, this is a high moisture site on a mountain road with little to no ditch catchment. However, there is no backslope source for high-energy falls. Falls here initiate on the immediate cut faces and impact the roadway directly. The HEF value is influenced by a small sight distance of 25 meters resulting from a blind curve to the west of the dam as seen in Figure 30. A poor Section Factor of 6.9 is based on the fact that much of the site has no catchment and the cliffs butt up against the roadway. The Geologic Factor of 15.4 is moderate and results from large block size and high precipitation, however no maximum scores exist in geologic categories.

Because the fall source exists in cliff faces immediately adjacent to the roadway, and not on an inaccessible backslope, several treatment options exist. The site is in a relatively tight mountain canyon where space is limited such that drastic improvements in ditch catchment would require the removal of vast quantities of rock. While a Section Factor improvement would be the most effective solution, it would be cost-prohibitive on such a rural road. Cost effective improvements to this site are best made in treating the faces themselves to improve the Geologic Factor and or limited blasting to improve the sight distance. The ability to evaluate the GF and HEF separately from a remediation standpoint, illustrates an effective aspect of the NYDOT system. Improvements are available despite the lack of a catchment and these can be evaluated independently.

Geologic treatment of the cut face is possible from the roadway. Despite the fact that the backslope region is relatively flat, it is heavily wooded and inhibits equipment access. The most basic geologic treatment involves mechanical scaling which could be applied for nearly the entire site length (600+ meters). The conservative effect of this action would be a one-step drop in the block size reducing the GF from 15.4 to 13.6 and the total from 1263.4 to 1115.72 (11.7%). Scaling, as discussed in previous examples, has a finite time limit particularly in high moisture climates. Combined with a scaling program, some type of physical reinforcement could be applied. Physical reinforcement of the face can take a variety of forms including rock bolts, shotcrete, draped mesh, and combinations of all three. In this case spot bolting and liberal use of wire mesh will maintain the benefits of the scaling activities and provide a minimum of one step reduction in rock friction. The GF of 13.6 following scaling will further be reduced to 12.8 by a one step reduction in rock friction, reducing the total score again from 1115.72 to 1066 (4.4%). In this manner, considering only mechanical treatment(s) of the cliff face, the Geologic Factor can be used to drop the site score a minimum total of 197 points to 1115 or (15.6%). The one step score reductions applied in this analysis are conservative and greater score reductions are possible depending on site conditions.

Figure 30. Beaver site 4527-14 forms a long cliff line on the north side of highway 153 bordered on the south by a small dam. Minimal catchment conditions are visible.

The HEF is sensitive to reduced sight distance, which is exactly the case just north of the dam abutment visible in Figure 30. Improvement of the sight distance will require the removal of a substantial quantity of rock and result in temporary road closure. However, an improvement in sight distance from the existing 25 meters to 35 meters will result in a HEF score improvement from of 34.7%. The measured sight distance has a large influence on the HEF score. This is much larger than the improvement of two categories within the Geologic Factor (37.4% vs. 15.6%).

The Beaver site illustrates several characteristics of the NYDOT system. The system is more sensitive to changes in the sight distance affecting the HEF than to improvements in one or two categories within the GF. Mechanically speaking, the reason for this is that the HEF is a function of multiplied factors where the GF is a function of a sum. This raises a question as to a potential limitation of the system. Is the HEF more important, or is it weighted too heavily? To put this question into perspective, if the sight distance improvement suggested is put into effect with no treatment of the cliff faces and no improvement to the roadside catchment, is the site safety "improved" by 37%? The NYDOT system shows that by performing this improvement, there will still be falls in the road (poor GF and SF) but that a motorist will be more able to avoid them due to the improved sight distance. In perfect conditions, daylight and good visibility, the system is likely correct. However, the NYDOT system makes no allowances for poor visibility (weather) or night conditions when sight distances are already lowered and elimination of falls and or preventing them from reaching the roadway may be of greater significance.

5.4.8 Huntsville Site Number 1425-15

This site is included as an example to illustrate how the NYDOT system differentiates between perceived hazards and site score. Located in the Huntsville maintenance district east of the city of Ogden, this site forms an imposing wall along Highway 158 immediately north of the Pineview Reservoir dam (see Figure 31). The geologic host rock is Paleozoic quartzite with smaller quantities of black carbonate rock. Large detached boulders and overhangs are abundant along the entire site with joint/bedding orientations of 30+ degrees dipping into the roadway. Although the joint and bedding planes are relatively tight, under close inspection, it appears they are loosened by freeze thaw and water action during the winter months. The cut height of approximately 46 meters necessitates a wide ditch according to the Ritchie criteria.

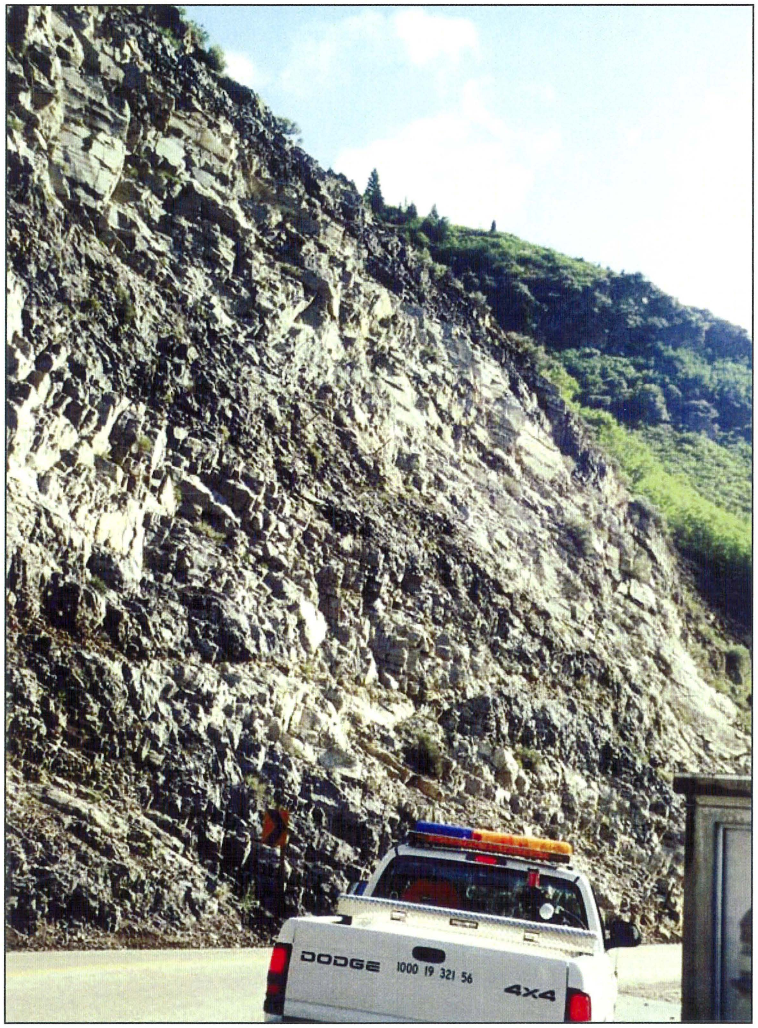


Figure 31. Rockfall hazard site 1425-15 that forms an imposing wall along Highway 158 immediately north of the Pineview Reservoir dam in the Huntsville maintenance area.

Examination of the relatively low overall hazard score of 35, given in Figure 32, might lead an observer to doubt the validity of the NYDOT system when faced with this visually imposing site. The Geologic Factor has one category maximum score (81 pts) for block sizes greater than 1.5 meters and four other categories with high intermediate scores of 27 points for bedding condition, water, history of regular falls and backslope angle. The Geologic Factor score of 19.8 points is in the high range observed state wide. The sheer size of the site (205 meters x 46 meters) makes repair that would significantly reduce the Geologic Factor a sizeable undertaking. The host rock is relatively competent and is amenable to scaling, bolting and drilling for possible blasting operations but upslope access is limited and the cliff height makes face access a problem. In addition, the proximity of critical dam facilities (spillways and power lines) makes a large-scale face repair complex.

This site immediately borders the existing dam and Pineview Reservoir to the south and the cliff face itself on the north. The existing ditch is approximately 3 meters wide but according to the Ritchie criteria, greatly inadequate for a catchment below a greater than 40 meter slope. The Ritchie criterion calls for a greater than 8 meter wide catchment. This is driven by the high energy of potential falls. Improving the Section Factor would require creation of space for a wider ditch, which in turn would require a site recut. A recut in this area would be a massive project. Some improvement in Section Factor could be attained by the installation of temporary concrete "jersey" barriers to increase the ditch depth along the roadway. However, this treatment creates the problem of space for cleanout of fall material behind the barrier with very limited space to begin with. Perhaps a better solution might be draping the slope with mesh.

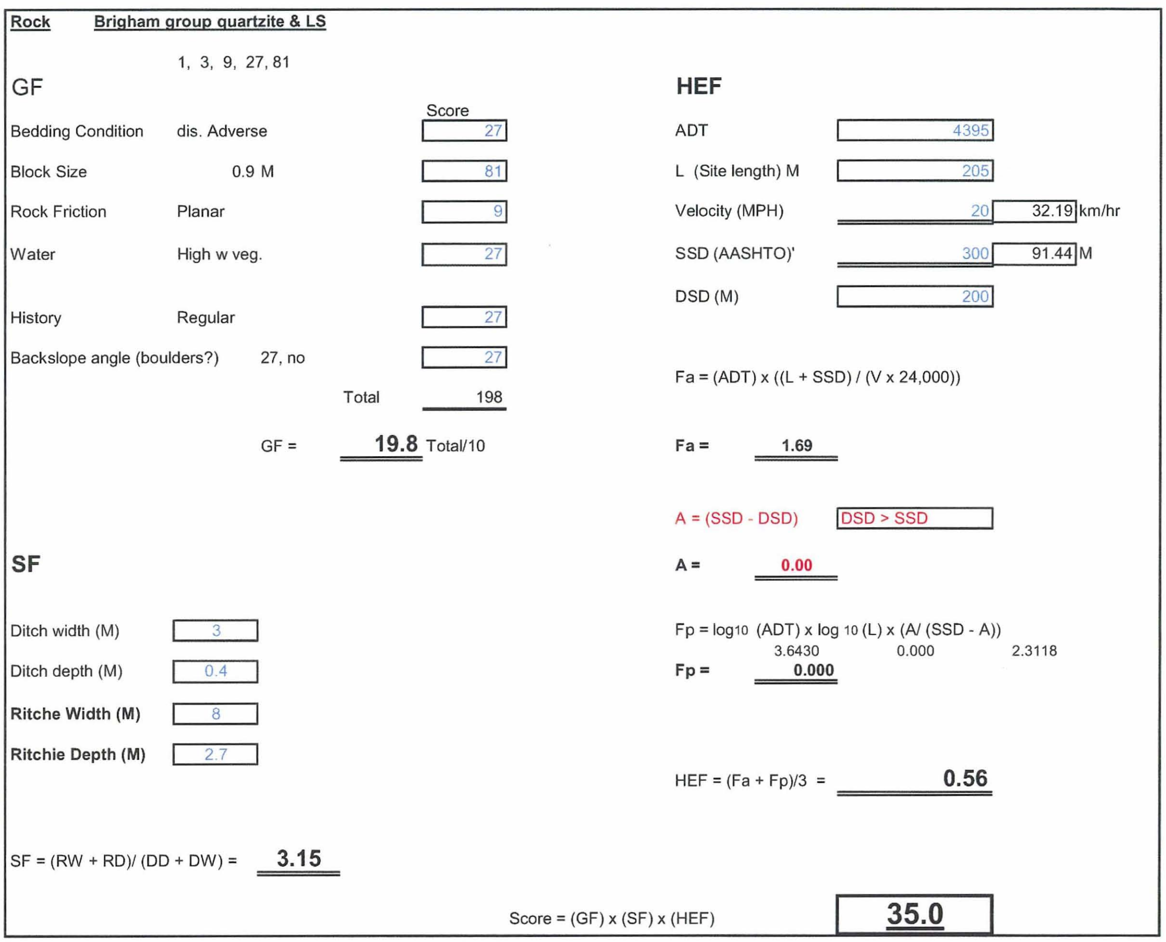

Rock Brigham group quartzite & LS
1, 3, 9, 27, 81
GF
Score
Bedding Condition dis. Adverse 27
Block Size 0.9 M 81
Rock Friction Planar 9
Water High w veg. 27
History Regular 27
Backslope angle (boulders?) 27, no 27
Total 198
GF = 19.8 Total/10
SF
Ditch width (M) 3
Ditch depth (M) 0.4
Ritche Width (M) 8
Ritchie Depth (M) 2.7
SF = (RW + RD)/ (DD + DW) = 3.15
HEF
ADT 4395
L (Site length) M 205
Velocity (MPH) 20 32.19 km/hr
SSD (AASHTO)' 300 91.44 M
DSD (M) 200
Fa = (ADT) x ((L + SSD) / (V x 24,000))
Fa = 1.69
A = (SSD - DSD) DSD > SSD
A = 0.00
Fp = log10 (ADT) x log 10 (L) x (A/ (SSD - A))
3.6430 0.000 2.3118
Fp = 0.000
HEF = (Fa + Fp)/3 = 0.56
Score = (GF) x (SF) x (HEF) 35.0

Figure 32. Spreadsheet rockfall hazards score for Huntsville site number 1425-15.

Examination of the Human Exposure factor is the key to understanding the score for this site. Unlike the previous example of Beaver-14, an exposure score of less than one is calculated for this site based on the relationship between the recommended AASHTO ideal stopping sight distance and the stopping site distance measured in the field. The system can drop the Human Exposure Factor to a value below one when the measured sight distance exceeds the AASHTO recommended sight distance as shown on Figure 32; the "a" value becomes 0 when DSD (measured) > SSD (AASHTO). The measured stopping sight distance for this roadway of 200 meters exceeds the AASHTO recommended stopping sight distance of 91 meters for the posted roadway speed of 20 miles per hour. The low Human Exposure Factor indicates that though rockfall is likely on the roadway, motorists should be able to stop and or avoid falls due to the low posted site speed and the large sight distance. Again, as was shown with Beaver 14, exception can be taken with these scoring criteria when one considers low visibility weather conditions. The NYDOT system does not address the risk of potential highway closure and its potential affect on several communities with primary access on this roadway.

How the NYDOT system handles the case of falling rocks hitting a moving vehicle on a site with a large sight distance was examined. This risk is covered by the (Fa), or active factor shown in Figure 32. Since the active factor describes a motorist being hit by a moving rock, this risk is independent of the ability of a driver to avoid or stop before a previously fallen rock. This site is likely a candidate for this type of risk considering the active slope history, and source area for falls.

This example demonstrates how a physically imposing site may not rate as highly overall when compared to less imposing sites. Not only does a site require material available to create a fall but also the fall must be able to reach the roadway such that a passing motorist cannot readily avoid it. The example also points out that the NYDOT scoring system does not take into account the critical nature of a roadway for access. If the blockage of a roadway such as State Route 139 causes undue hardship for residents and or blocks activities such as emergency vehicle access, then the site must be prioritized higher than that of the rockfall hazard score.

5.5 Discussion

The examples discussed here are only a small sample of the 507 sites covered in the state of Utah. This discussion is meant to stimulate thought in the application of field repairs based on the NYDOT system and some insight into what the scores mean beyond simply a number on a sheet of paper. Analysis of a site score based on the three factor values, (Geologic Factor, Section Factor and Human Exposure Factor), can give a planner, engineer or manager useful clues for repair and control measures before assets are sent to the field to conduct a detailed site survey. In this way, by analyzing the NYDOT scores before they leave the office, field employees and contractors can be more effective during detailed site surveys by knowing some of what they are up against before they reach a site. Similarly, technical and supervisory staff can be aware of potential equipment, budgetary, and human assets required for repair activities in their given region without having previously walked the sites in question. The NYDOT scoring system can provide a useful and interactive means for both rockfall site cataloging and the early stage planning and allocation of site repair / remediation efforts. However, the system does have some limitations and specific sensitivities as can be seen in the examples listed here and these must be kept in mind at all times.

The Section Factor is based on the conservative Ritchie Ditch criteria, which results in a level of comfort when designs are based on these criteria. However, these criteria can be thrown into question by the fact that ditch effectiveness is a function of both the elevation (energy level) that a fall originates from and also the fall volume and roundness of the fall boulders. The latter two characteristics are not considered when calculating the Section Factor because they are not considered by the Richie criteria. At present, it is unclear how to resolve this shortcoming in the NYDOT system and some further research is warranted.

In some cases, the NYDOT system heavily weights the Human Exposure Factor in comparison to the Geologic Factor. This results in low scores for highways in parts of Utah where average daily traffic volumes are low. This conclusion is consistent with the principles of risk analysis which dictate that even though the rockfall hazard may be high, a limited amount of traffic leads to a low risk of injury or death

The Cottonwood and Cedar examples demonstrate that despite significant improvements in site geometry, upslope hazards may be so significant that lowered site scores as a result of partial remediation may be unrealistic. The "global picture" of a site should be examined when evaluating the realism of the rockfall hazard evaluation.

5.6 Proposed UDOT System

The detailed rating of 507 rockfall hazard sites across the State of Utah coupled with the detailed analysis of 8 sites has verified that the NYDOT system is well suited for application in Utah. However, the weakest aspect of this system is the subjective nature of the Geologic Factor (GF) when compared with the more objectively determined Section Factor (SF) and Human Exposure Factor (HEF). Of particular importance when evaluating rockfall hazard is the known rockfall history of a site including the rockfall frequency and the observed block size. It is in-fact these two criteria that had a pivotal role in determining the A-B-C grade for the Phase I preliminary analysis. However, the NYDOT system weights these characteristics equal with the more subjectively determined parameters of fracture/bedding, rock friction, water/climate, and backslope conditions.

After a thorough review of the sites across the state and discussion of the characteristics of the NYDOT model, the UDOT Technical Advisory Committee and the principal author agreed that the rockfall frequency and block-size parameters should be doubled in weight over the other four factors. Hence the GF should be calculated by

$$GF = Geology + 2 * Block\_Size + Rock\_Friction + Water + 2 * History + Backslope$$

In the NYDOT system, GF differentiation between sedimentary rocks and crystalline rocks focuses more on physical characteristics of the rock than on lithology. However, the term "sedimentary" has a lithologic meaning and the term "crystalline" has an igneous or high grade metamorphic interpretation. Other lithologies could have these same physical characteristics. For example, layered igneous basalt flows (volcanic) often experience more sedimentary-like toppling failures whereas, massive sandstones are more crystalline in nature. The same could be said for metamorphic rocks that vary from slate (sedimentary-like) to gneiss (crystalline). It is proposed that, in order to avoid confusion, the term "sedimentary" be replaced by the term "layered" in the UDOT system to get rid of the lithologic meaning. The chosen category for a given rock type should therefore be judged by the likeness of mode of failure to that which occurs with more homogeneous crystalline-like rocks versus layered rocks.

With the suggested changes, the NYDOT system has been evolved into the new UDOT Rockfall Hazard Rating System. Other changes were considered but were not uniformly recommended by the group.

Appendix C provides the result of applying the UDOT System to the database. It lists 25 sites from each of the four Utah highway regions with the highest rockfall hazard ratings.

The eight sites discussed in Chapter 5 focused on an evaluation of the NYDOT system and its use in the evaluation of alternative remediation. The changes incorporated in UDOT system will have an impact on the original relative ranking of sites. Therefore the scores associated with these sites will have changed when rerun with the UDOT criteria. However, the logic behind the evaluation of GF, SF, and HEF scores in determining alternative remedial measures remains the same, whether the NYDOT or UDOT scores are used.

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Part II

PART II - TUTORIAL & USERS GUIDE

1.0 QUICK-START TUTORIAL

This section provides a quick introduction to the steps required to calculate a rockfall hazard rating using the UDOT RHRS Software. A more detailed description of each step is given in the next section.

1. On the software distribution DVD, find the RHRS subdirectory and using Windows Explorer, copy it into your desired working directory. This subdirectory will include over 1 GB of photos so ensure that you have ample workspace.

2. Start up Microsoft Access. Navigate to the directory where you placed the RHRS Software and the accompanying database of JPEG image files (photographs). Make this the current directory.

3. In Access, open the database called *RHRS.mdb*. This is the name of the database containing the tables, queries, forms and reports for the software.

4. In this main interface, click on the Forms icon to the left and then double click the form called *RHRS*. This brings up the data form showing the parameters for 1101 records. Note the preliminary *Hazard* score and detailed rockfall *Rating* shown in bold.

5. Click on the right arrow icon at the lower left of the form to increment through the rockfall records and photos in the database in order of Site Number given in the upper left hand corner. Note that only half the records have detailed hazard ratings (see Part I).

6. To sort through the records in descending order of rockfall hazard rating, click the *RHR* button within the *Sort By* group on the form. Again, click on the right arrow icon to increment through the records. Similarly, records can be sorted in descending order by SF, GF, or HEF by clicking the appropriate button in the *Sort By* group.

7. To only include records within a given UDOT Region, click the region number 1 through 4 buttons within the *Filter By Region* group on the form. To again view the records for the entire state, click on the *All* button.

8. To produce a printable report of all sites within state sorted by Site Number, click the *State by Site* button within the *Reports to Print* group.

9. The other three buttons within this group produce other reports that may be of interest.

10. When done reviewing the RHRS database and printing reports, close the form and exit MS Access.

2.0 USERS GUIDE

2.1 Installing the UDOT Rockfall Hazard Database

The distribution DVD for the Utah Rockfall Hazard Database contains the files shown in Table 6. This whole subdirectory should be copied from the DVD onto your workspace in your computer. It is approximately 1 GB in size.

The *Photos* subdirectory contains all the photographs used in the database. The files that have the names *Mileage-UTM83* and *AADT-UTM83* with various file extensions are ArcGIS "shape files" that are used to display the rockfall sites within a GIS system and update AADT values for new sites that may be added to the database in the future. These files are both in the NAD 83 UTM Zone 12N coordinate system. The *RHRS.mdb* is the MS Access database (ArcGIS geodatabase) that is the heart of the RHRS data and software. This manual is also in electronic form under the name *RHRS_Manual_v1.doc.*

Table 6. List of files that come in the RHRS folder of the distribution DVD.

Photos		File Folder	11/12/2005 9:40 PM
AADT-UTM83.dbf	332 KB	DBF File	10/11/2005 11:26 AM
AADT-UTM83.prj	1 KB	IDL project file	10/11/2005 11:26 AM
AADT-UTM83.sbn	34 KB	SBN File	10/11/2005 11:26 AM
AADT-UTM83.sbx	2 KB	SBX File	10/11/2005 11:26 AM
AADT-UTM83.shp	1,994 KB	AutoCAD Shape Source	10/11/2005 11:26 AM
AADT-UTM83.shp.xml	3 KB	XML Document	10/28/2005 8:33 AM
AADT-UTM83.shx	29 KB	AutoCAD Compiled Shape	10/11/2005 11:26 AM
Mileage-UTM83.dbf	158 KB	DBF File	10/11/2005 11:13 AM
Mileage-UTM83.prj	1 KB	IDL project file	10/11/2005 11:13 AM
Mileage-UTM83.sbn	15 KB	SBN File	10/11/2005 11:13 AM
Mileage-UTM83.sbx	1 KB	SBX File	10/11/2005 11:13 AM
Mileage-UTM83.shp	2,346 KB	AutoCAD Shape Source	10/11/2005 11:13 AM
Mileage-UTM83.shp.xml	13 KB	XML Document	10/27/2005 11:26 AM
Mileage-UTM83.shx	12 KB	AutoCAD Compiled Shape	10/11/2005 11:13 AM
RHRS.mdb	55,532 KB	Microsoft Office Access Application	11/13/2005 11:41 PM
RHRS_Manual_v1.doc	35,769 KB	Microsoft Word Document	11/14/2005 7:17 AM

2.2 Starting the Program

Start MS Access and under *Files* open the *RHRS.mdb* database file from your working subdirectory. Under the *Objects* sub-window click the *Tables* object. The screen shown as Figure 33 appears. It shows six database tables that form the heart of the system. Other tables associated with ArcGIS-generated geodatabase tables may or may not be present, depending on whether some GIS activities have taken place. Double click each of the table icons listed in Figure 33 to display the database and examine the data.

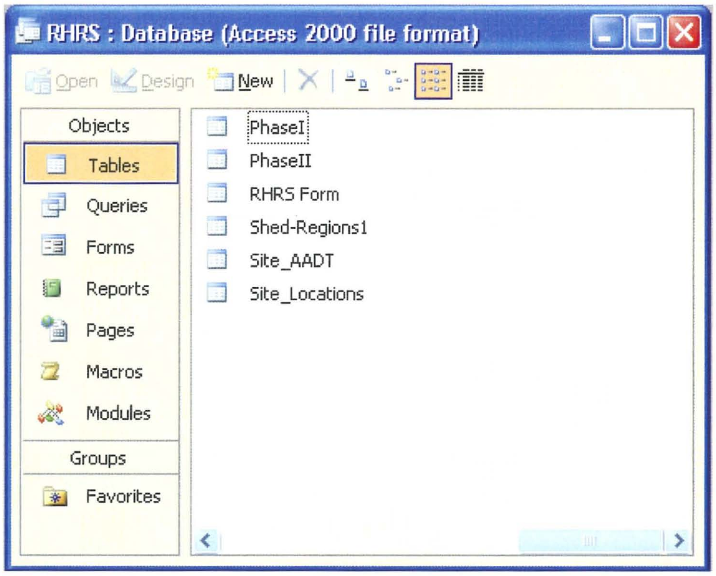

Figure 33. RHRS database tables.

Next, click the Queries object. This window (shown in Figure 34) includes the *Create RHRS Table* query that is used to assemble a custom table called *RHRS Form* from the other five tables in the database. This procedure is explained in Section 2.3.3.

Figure 34. RHRS Query called *Create RHRS Table* used to create the *RHRS Form* database table for use in analyses.

Next, click the *Forms* object. The *RHRS Form* (shown in Figure 35) is used to enter, sort, review and print rockfall hazard data. The form includes custom functions to recalculate new RHRS scores when site parameters are modified or updated.

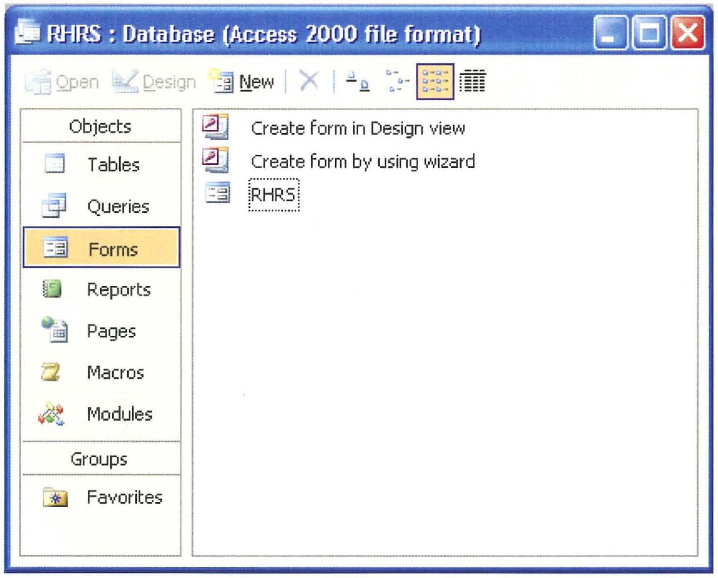

Figure 35. *RHRS Form* used to enter, sort, and review and print rockfall hazard data.

Finally, click on the *Reports* object. Four custom reports (shown in Figure 36) are found that are invoked from within the *RHRS form*. These reports are fully customizable by the RHRS user to meet format requirements.

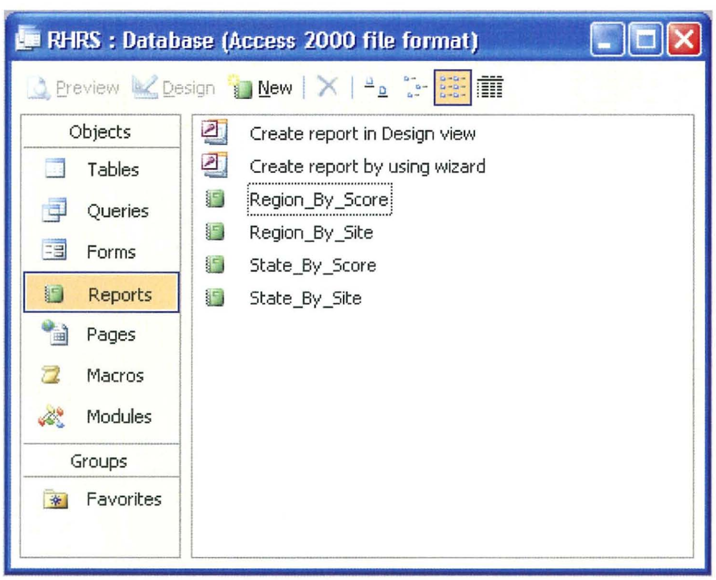

Figure 36. RHRS reports that are available. They are invoked from within the *RHRS Form.*

2.3 Understanding the RHRS Tables

2.3.1 Table Relationships

The RHRS consists of five tables as shown in Figure 37. These consist of:

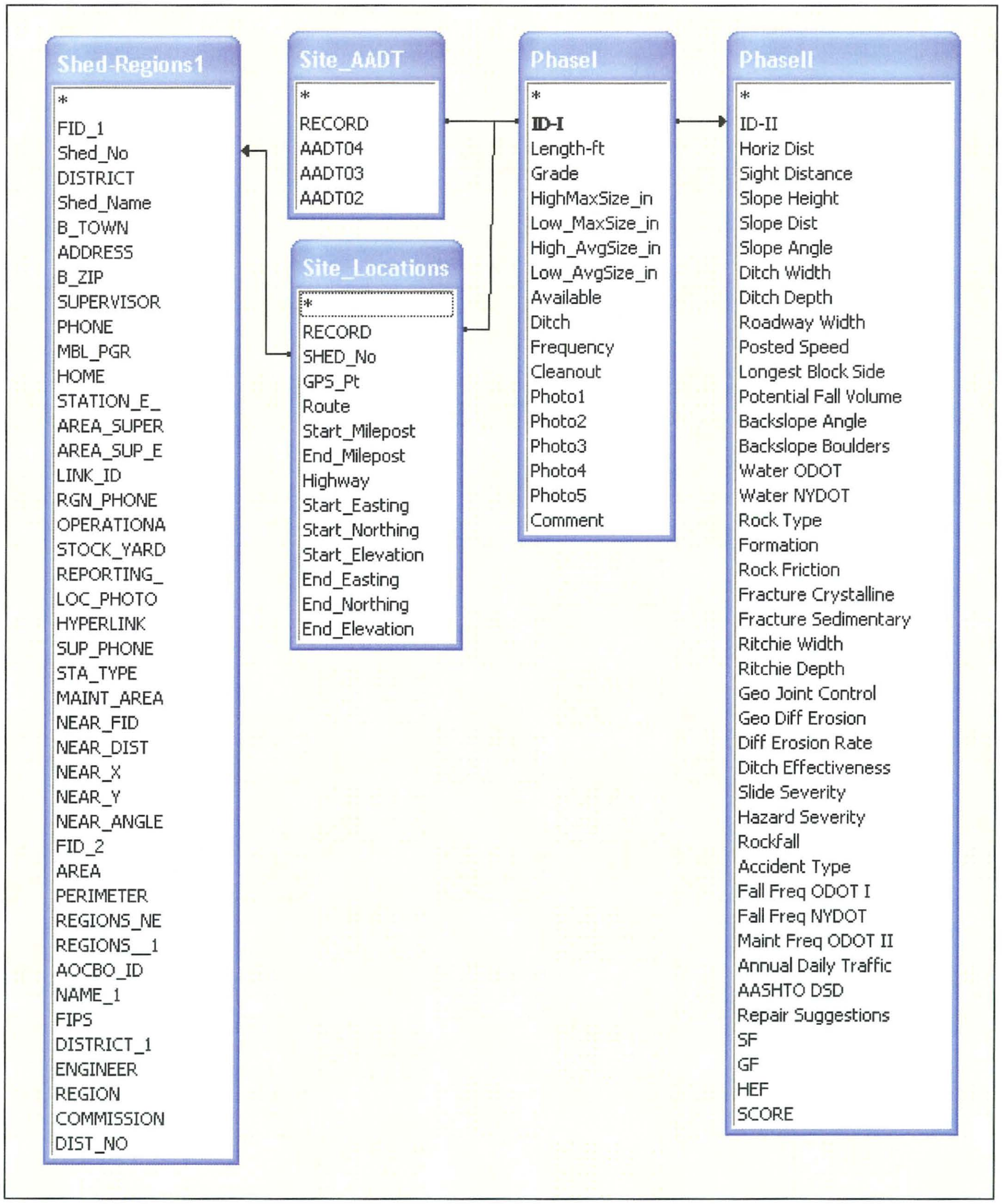

Figure 37. Database table relationships within the UDOT RHRS.

- Phase I – Data for 1101 sites, 1099 of which were visited during the first phase of the study. Two records are blank as they were only visited during Phase II. This table contains the preliminary rockfall hazard data. Each site is labeled by a unique identifier called ID-I. The ID consists of "rf" for rockfall followed by four digits representing the maintenance station number, then the unique site number.

- Phase II – Data for 504 sites visited during the second phase of the study. This table contains the detailed rockfall hazard data. Each site is labeled with the same unique identifier that was originally used in Phase I.

- Site Location – At each site, location information was collected in the field including GPS coordinates at the beginning and end of each site, shed number, as well as the Route Number. Mile posts were then calculated using the UDOT mileage GIS shape files.

- Site AADT – For each site, the average annual daily traffic (AADT) for each year between 2002 and 2004 was compiled using UDOT GIS shape files.

- Shed Regions1 – Indexed by Shed Number, this table provides shed (maintenance station) data including what district and region it is in. Though not specifically used in the RHRS, the table includes a variety of other shed-specific data that may be of use, although some of the data will likely change over time.

The lines that connect the tables in Figure 37 represent the formal "relationships" setup within the Access database that allow the data to be seamlessly associated together.

2.3.2 Creating the *RHRS Form* Table Using a Query

The five tables described above can be automatically joined by the RHR system to create a table customized for RHRS analysis. Figure 38 shows the workflow where the tables are combined automatically into a *RHRS Form* table. The *RHRS Form* table is considered a "temporary" table that is used for analysis. When it is created, it contains no RHRS scores. These must be calculated on-the-fly using the RHRS Form. The reason for this approach is to ensure that the underlying data in the system isn't inadvertently modified during an analysis and permanently saved. Permanent changes must be done within any one of the underlying five tables. This approach also has the advantage of easily incorporating changes to UDOT mileage conventions and updated AADT's each year.

The steps required to create the *RHRS Forms* table are as follows:

- Double click on the *Create RHRS Table* icon under the *Queries* Objects

- The system will then warn you that "You are about to run a make-table query that will modify data in your table". What this is warning you is that the RHRS Form table is about to be deleted and recreated. This action will erase the "temporary" edits you may have previously made to the *RHRS Form table* using the *RHRS Form.* If this is what you want to do, click the Yes button.

- A second window then comes up warning you that the table "RHRS Form" will be deleted. This gives you a second chance to not overwrite your temporary edits (if any). If you are still sure it is ok, click Yes.

- A final screen will come up that will indicate "You are about to paste 1101 row(s) into a new table". If RHRS records have been deleted or added to the Phase II table, this number or rows may be different than 1101. Click Yes.

The *RHRS Form* table is now recreated and ready to be viewed using the form.

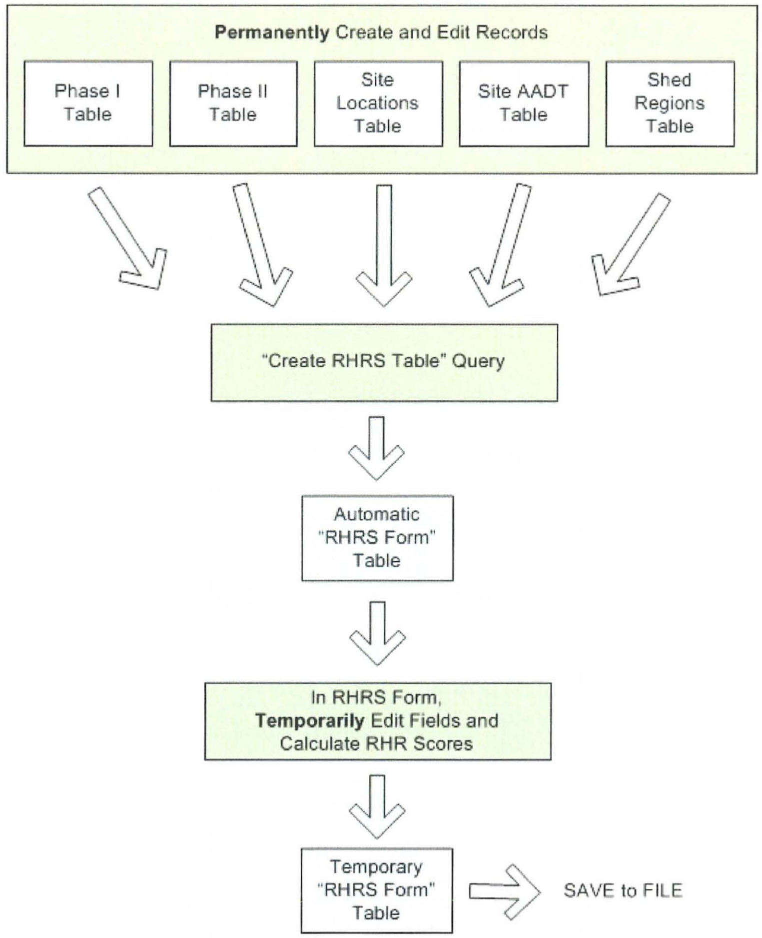

Figure 38. Temporary and permanent editing of RHRS data.

2.3.3 Updating Data

Whenever edits or updates to the RHRS database are made, they should be done within one of the five original tables as shown in Figure 38. As explained in the previous section, the *RHRS Form* table can be automatically generated from the five tables at any time. When a new rockfall site is added, a record must be added to each of the tables and the data entered. Prior to doing this, it is recommended that the existing database file *RHRS.mdb* be saved to another name and permanently archived.

Edits within the *RHRS Form* table should be considered temporary and for the purpose of exploring the effects of rehabilitation efforts on the RHRS factors and score. The reason for this is that any time the *RHRS Form* table is regenerated, the modified data is destroyed and regenerated with the updates completed in the original tables. This approach facilitates yearly AADT updates and other changes caused by construction and new rockfall assessments.

2.4 Using the RHRS Form for Analysis

2.4.1 Introduction

The *RHRS Form* is the main user interface for rockfall hazard rating system (RHRS) database. Figure 39 shows a sample screen shot of this form. The records in the database can be reviewed one-by-one by pressing the right and left triangles at the lower left corner of the form. As this is done, the photographs update along with the data values.

At the upper right corner of the form, the *UDOT Rockfall Hazard Ratings* can be found. The *Geologic Factor*, *Section Factor* and *Human Exposure Factor* are colored pink, yellow and green respectively. The colored field labels on the form correlate with the factor it influences. For example, the Ditch Width field is yellow indicating that it is used in calculating the *Section Factor*. The uncolored fields represent relevant data that are not used directly in the hazard rating calculation. If the *RHRS Form table* has been newly created, the hazard ratings will be blank. These need to be calculated as described in the next section.

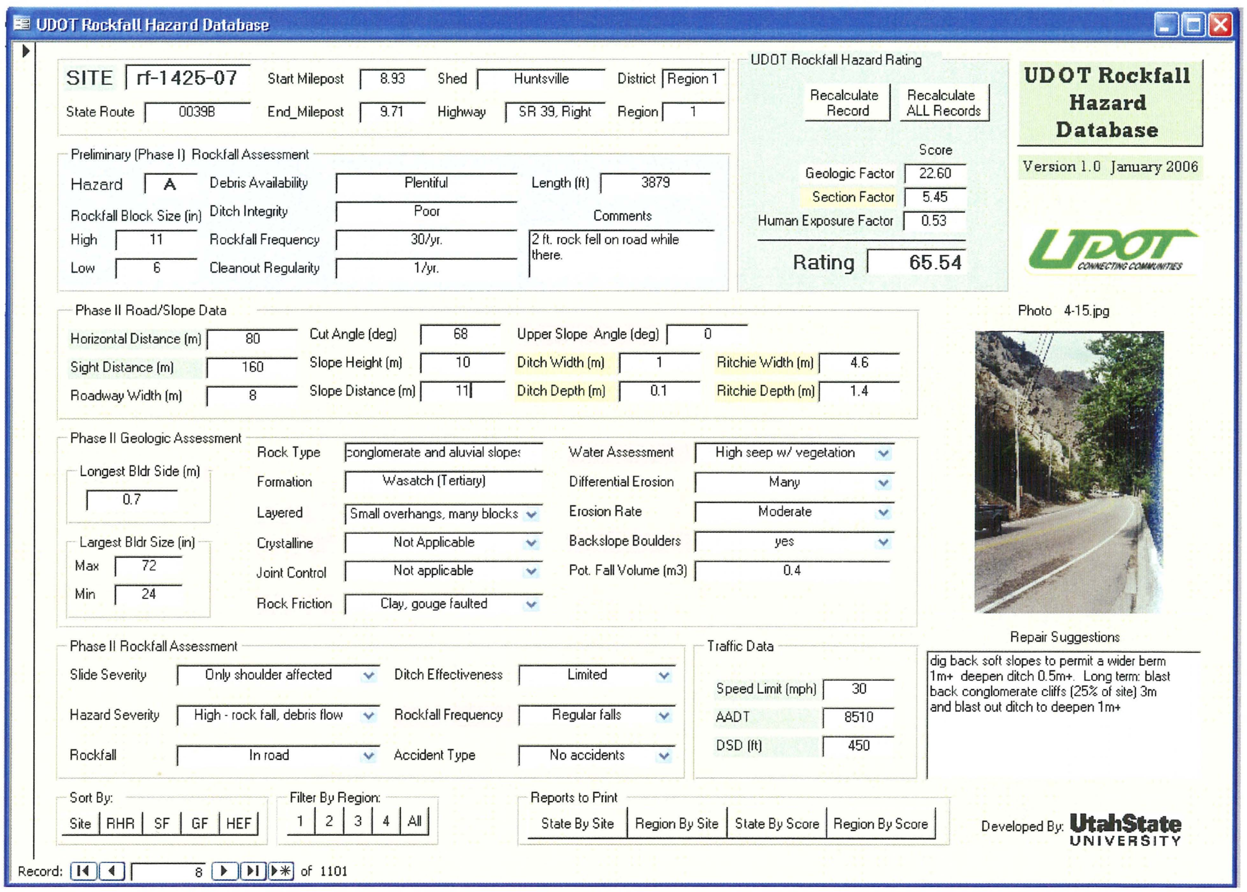

Figure 39. Example screen shot of a RHRS Form.

2.4.2 Calculating Hazard Ratings

To calculate or recalculate all hazard ratings at once, click the *"Recalculate ALL Records"* button in the UDOT Rockfall Hazard Rating box.

The hazard rating can be calculated interactively if one wishes to play with the parameter values for a given construction or rehabilitation scenario. This is done by clicking the *"Recalculate Record"* button. The changes will be stored in the *RHRS Form table.* If these changes need to be saved, the table should be saved to a file with a different name using the *Save As* command under the *File* pop-down menu. This is necessary because when the RHRS database is next recreated from the underlying tables, these changes will be lost. Permanent changes need to be made in the underlying table (see Section 2.3.3).

2.4.3 Sorting by Scores

The database can be sorted to display the records in several different orders. This function is found in the *Sort By* box in the lower left hand corner of the RHRS form.

- To sort the records in increasing order of *Site Number*, click the *Sort By Site* button.
- To sort the records in descending order of *RHRS Rank*, click the *Sort By* RHR button.
- To sort the records in descending order of *Geologic Factor*, click the *Sort By GF* button.
- To sort the records in descending order of *Section Factor*, click the *Sort By SF* button.
- To sort the records in descending order of *Human Exposure Factor*, click the *Sort By HEF* button

When sorting by the rockfall hazard factor or rating, the record number turns represents the "rank" of the site from a regional perspective (when filtered by region) or from a state-wide perspective (when unfiltered).

2.4.4 Filtering by Region

The database can be filtered to include any of the four UDOT highway regions. This function is found in the *Filter By* box at the bottom of the RHRS form next to the *Sort* By box. For example, if a Region 1 filter is applied, only the 198 sites in UDOT Region 1 out of 1101 total state-wide sites will be displayed.

- To filter the records to only show UDOT Region 1 hazard sites, click the *Filter By Region 1* button.
- To filter the records to only show UDOT Region 2 hazard sites, click the *Filter By Region 2* button.
- To filter the records to only show UDOT Region 3 hazard sites, click the *Filter By Region 3* button.
- To filter the records to only show UDOT Region 4 hazard sites, click the *Filter By Region 4* button.
- The take the filter off to display all sites in the state, click the *Filter By Region All* button.

2.4.5 Printing Reports

Reports can be automatically generated by clicking buttons found in the lower right-hand corner of the form.

- To create a report giving the rockfall hazard ratings for sites across Utah sorted by *Site Number*, click the *State By Site* button in the *Reports to Print* button group. This produces a report with the headings as shown in Figure 40.

Region	Site	RATING	Shed	Route	Mileage		SF	GF	HEF
1	rf-1425-01	291	Huntsville	0039B	13.06	12.97	3.45	22.00	3.83
1	rf-1425-02	929	Huntsville	0039B	12.82	12.73	6.00	22.00	7.04
1	rf-1425-03	191	Huntsville	0039B	12.59	12.38	4.60	22.00	1.88
1	rf-1425-04	992	Huntsville	0039B	12.22	12.09	5.10	17.20	11.31

Figure 40. Report giving the rockfall hazard ratings for sites across Utah sorted by *Site Number*.

- To create a report giving the rockfall hazard ratings sorted by *UDOT Region* and *Site Number*, click the *Region By Site* button in the *Reports to Print* button group. This produces a report with the headings as shown in Figure 41.

REGION	Site	RATING	Shed	Route	Mileage		SF	GF	HEF
1									
	rf-1425-01	291	Huntsville	0039B	13.06	12.97	3.45	22.00	3.83
	rf-1425-02	929	Huntsville	0039B	12.82	12.73	6.00	22.00	7.04
	rf-1425-03	191	Huntsville	0039B	12.59	12.38	4.60	22.00	1.88

Figure 41. Report giving the rockfall hazard ratings sorted by *UDOT Region* and *Site Number*.

- To create a report giving the rockfall hazard ratings sites across Utah sorted by *Hazard Rating*, click the *State By Score* button in the *Reports to Print* button group. This produces a report with the headings as shown in Figure 42.

REGION	RATING	Site	Shed	Route	Mileage		SF	GF	HEF
4	2584	rf-4524-09	Cedar City	0014B	7.97	8.18	5.38	46.80	10.25
2	2384	rf-2433-27	Cottonwood	0190B	6.48	6.48	5.30	36.00	12.49
4	1499	rf-4325-26	Panguitch	0143B	37.94	37.66	6.18	22.20	10.92

Figure 42. Report giving the rockfall hazard ratings for sites across Utah sorted by *Hazard Rating*.

- To create a report giving the rockfall hazard ratings sorted by *UDOT Region* and *Hazard Rating*, click the *Region By Score* button in the *Reports to Print* button group. This produces a report with the headings as shown in Figure 43.

REGION	RATING	Site	Shed	Route	Mileage	SF	GF	HEF
1								
	1015	rf-1436-39	Logan	0089B	473.45 473.35	5.00	23.00	8.82
	992	rf-1425-04	Huntsville	0039B	12.22 12.09	5.10	17.20	11.31
	956	rf-1425-05	Huntsville	0039B	11.88 11.72	6.10	18.40	8.52

Figure 43. Report giving the rockfall hazard ratings sorted by *UDOT Region* and *Hazard Rating*.

The format of any of these reports can be modified using the *Report Editor* with Access. Figure 44 shows the window used to edit the *Region By Score* report. This is accessed by double clicking the *Region By Score* icon under the Report objects list. Any number of fields from the *RHRS Form table* can in added or deleted within this form.

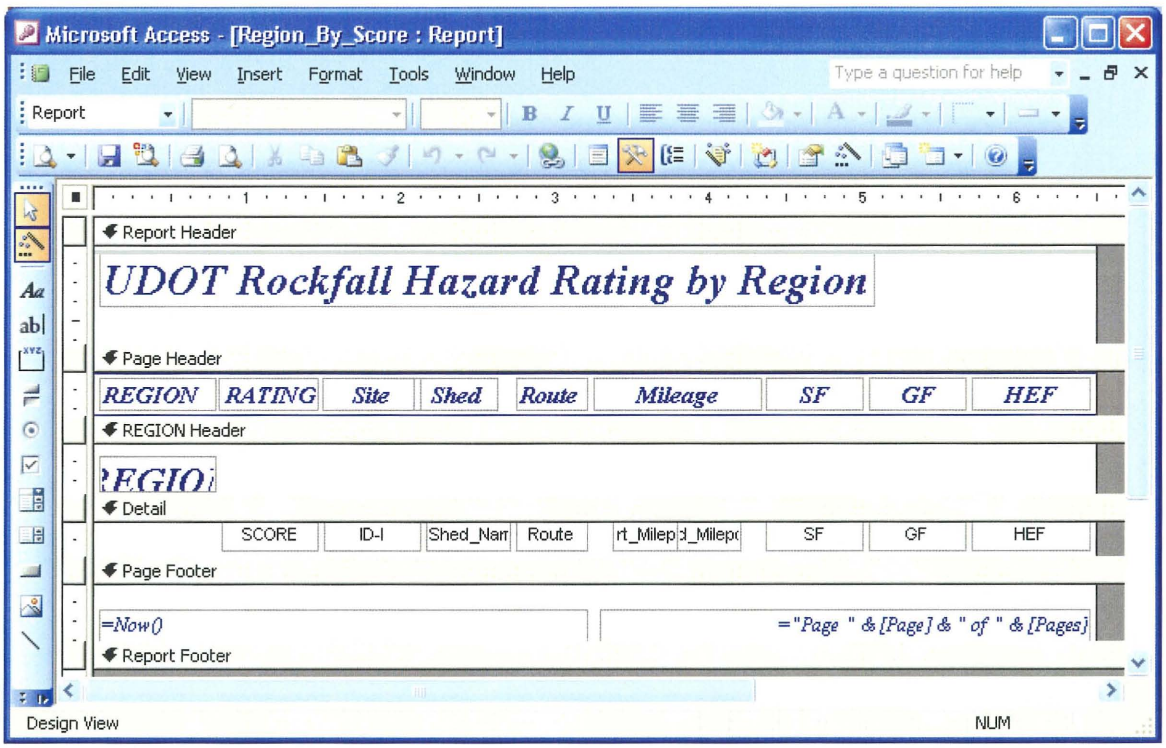

Figure 44. *Report Editor* used by MS Access to customize the *Region By Score* report.

2.4.6 Viewing All Photos for a Site

The form shows a representative photo of the site. However, the database can contain two or more photos for a given site and sometimes the user might want to look that the photos in more detail by zooming in or by doing photo enhancements. This can be done by accessing the PhaseI table in Access, manually finding the site record of interest using the ID-I field, then looking up the photos numbers under any of the five photo fields (there are a maximum of five photos for any given site). Once the photo number(s) are identified, the associated image files having those photo numbers can be found in the "Photos" subdirectory of the database.

2.4.7 Data Definitions

Parameter names found on the RHRS Form are defined in Tables 7 through 13. Each table represents a section on the form. For each field label, the table provides the associated field name found within the database tables.

Table 7. Site data definitions.

Form	Field	Table	Definition
Site	ID-I	PhaseI	A unique identification number was ascribed to each inventory site. It includes "rf" for rockfall, followed by four digits representing the maintenance station number to avoid number duplication in other maintenance stations. The final digits are the site number within that maintenance station.
State Route	Route	Site_Locations	Official UDOT route identifier
Start Milepost	Start_Milepost	Site_Locations	Milepost at which the rockfall section starts
End Milepost	End_Milepost	Site_Locations	Milepost at which the rockfall section ends
Shed	Shed_Name	Shed-Regions1	Maintenance station (shed) name
Highway	Highway	Site_Locations	Qualitative entry of the Highway name and sometimes the right or left offset
District	DISTRICT	Shed-Regions1	Highway District in which the rockfall site is located
Region	REGION	Shed-Regions1	Highway Region in which the rockfall site is located

Table 8. Preliminary Rockfall Assessment data definitions.

Form	Field	Table	Definition
Hazard	Grade	PhaseI	Rockfall hazard rating using the ODOT I system. See the section on Methodology for an explanation of the A-B-C rating.
Rockfall Block Size High	HighAveSize_in	PhaseI	This is the average maximum size of boulders noted by UDOT to have hit the highway in inches
Rockfall Block Size Low	LowAveSize_in	PhaseI	This is the average minimum size of boulders noted by UDOT to have hit the highway in inches
Debris Availability	Available	PhaseI	This is a subjective description where plentiful means that a plentiful supply of loose boulders can be seen on or above the slope adjacent to the roadway. Limited means that few loose blocks or boulders were noted.
Ditch Integrity	Ditch	PhaseI	Qualitative estimate of how well the ditch is performing in catching debris (good, fair, or poor)
Rockfall Frequency	Frequency	PhaseI	This is an estimate of how often UDOT maintenance personnel need to clean the roadway of rockfall each year.
Cleanout Regularity	Cleanout	PhaseI	This is an estimate of how often UDOT maintenance personnel need to clean the ditch of rockfall each year.
Length	Length-ft	PhaseI	Horizontal distance of slope exposure along roadway in feet as calculated by the straight-line distance between two GPS coordinates.
Comments	Comment	PhaseI	Any miscellaneous comments about the site are entered here.

Table 9. Photo data definitions.

Photo	Photo1	PhaseI	This is one of a total of five columns listing ID numbers of site photo(s). Each photograph is labeled with an ID number so as to relate it to the proper site.

Table 10. Phase II Road/Slope data definitions.

Form	Field	Table	Definition
Horizontal Distance	Horiz Dist	PhaseII	Total length of the rock cut section in meters measured as the distance between the beginning and ending mileposts.
Sight Distance	Sight Distance	PhaseII	Shortest sight distance along cut section in meters. Used to calculate the percent of decision sight distance for the ODOT I system.
Roadway Width	Roadway Width	PhaseII	Width of the traveled roadway including paved shoulders in meters (from ODOT I)
Cut Angle	Slope Angle	PhaseII	Angle of the rock cut in degrees measured from the horizontal. Used to determine the Richie criteria (from NYDOT)
Slope Height	Slope Height	PhaseII	Measure of the vertical distance in meters from the bottom of the slope to the highest point at which rockfall may be generated (from ODOT I)
Slope Distance	Slope Dist	PhaseII	Length of the slope in meters
Upper Slope Angle	Backslope Angle	PhaseII	Measure of the steepness of the slope above the rock cut in degrees. (from NYDOT)
Ditch Width	Ditch Width	PhaseII	Measured average ditch width along rockfall section in meters (from NYDOT)
Ditch Depth	Ditch Depth	PhaseII	Measured average ditch depth along rockfall section in meters (from NYDOT)
Richie Width	Richie Width	PhaseII	Required ditch width in meters given the Ritchie criteria (see Figure 17, from NYDOT).
Ritchie Depth	Ritchie Depth	PhaseII	Required ditch depth in meters given the Ritchie criteria (see Figure 17, from NYDOT).

Table 11. Phase II Geologic Assessment data definitions.

Form	Field	Table	Definition
Longest Bldr Side	Longest Block Side	PhaseII	Measure of the maximum longest block dimension on the slope measured in meters (from NYDOT)
Max Largest Bldr Size	HighMaxSize_in	PhaseII	Maximum largest boulder size in inches (from ODOT I)
Min Largest Bldr Size	Low_MaxSize_in	PhaseII	Minimum largest boulder size in inches (from ODOT I)
Rock Type	Rock Type	PhaseII	Rock lithology or type
Formation	Formation	PhaseII	Geologic formation of the rock cut
Layered	Fracture Layered	PhaseII	Measure of the dip of the bedding or layering, occurrence of raveling, overhangs, and occurrence of different sizes of blocks (from NYDOT)
Crystalline	Fracture Crystalline	PhaseII	Measure of facture orientation relative to the cut slope, fracture continuity, and the occurrence of wedges (from NYDOT)
Joint Control	Geo Joint Control	PhaseII	Crystalline structural condition relative to joint orientation and continuity (from ODOT I)
Rock Friction	Rock Friction	PhaseII	Measure of how rough, irregular, undulating, planar, or slickensided the factures are. Includes whether or not clay gouge or evidence of faulting is present (from NYDOT)
Water Assessment	Water NYDOT	PhaseII	Measure of the amount of seepage, presence of brush or high vegetation, and the presence of a long backslope (from NYDOT)
Differential Erosion	Geo Diff Erosion	PhaseII	Layered structural condition governed by the amount of differential erosion features (from ODOT I)

Erosion Rate	Dif Erosion Rate	PhaseII	If the rock is layered, how severe is the differential erosion? Varies from small to extreme (from ODOT I)
Backslope Boulders	Backslope Boulders	PhaseII	Specifies whether or not backslope boulders are present (from NYDOT)
Potential Fall Volume	Potential Fall Volume	PhaseII	Potential rockfall volume in cubic meters.

Table 12. Phase II Rockfall Assessment data definitions.

Form	Field	Table	Definition
Slide Severity	Slide Severity	PhaseII	Roadway impact by a landslide. Varies from only shoulder impact to a total closure with a 60 mile detour (from ODOT II)
Hazard Severity	Hazard Severity	PhaseII	Landslide failure type and hazard (from ODOT II)
Rockfall	Rockfall	PhaseII	Roadway impact by rockfall. Varies from rocks being contained in ditch to rocks filling part of all of a lane (from ODOT II)
Ditch Effectiveness	Ditch Effectiveness	PhaseII	How effective is the ditch in catching debris? Varies from good to none. (from ODOT I)
Rockfall Frequency	Fall Freq NYDOT	PhaseII	Measure of the number of falls that have been documented per year. Grouped into five groups. (from NYDOT)
Accident Type	Accident Type	PhaseII	Accident history for the site from no accidents to fatality (ODOT II)

Table 13. Traffic and repair data definitions.

Form	Field	Table	Definition
Speed Limit	Posted Speed	PhaseII	Posted speed limit at the rockfall section in miles per hour (from NYDOT)
AADT	AADT04	Site_AADT	Average annual daily traffic as measured or estimated by UDOT during 2004 (from NYDOT & ODOT II).
DSD	ASHTO DSD	PhaseII	Measure of the distance in feet at the site where a motorist can see debris on the roadway (from NYDOT)
Repair Suggestions	Repair Suggestions	PhaseII	Judgment on the part of the rater as to what some of the options are for rehabilitating the site. This opinion should be considered tentative and Utah State University offers no guarantee that they are accurate.

2.5 Using ArcGIS to Plot Rockfall Site Locations

The database is in ArcGIS geodatabase format (a variety of MS Access *.mdb format). This format enables maps of the rockfall site locations to be conveniently mapped using ESRI ArcGIS. Following are the recommended steps to do this:

- Open ArcMap and create a new empty map as prompted by ArcGIS.
- Click the *Add Data* button, and navigate to the subdirectory where the RHRS data is located. Add the *Mileage-UTM83* shape file and the *RHRS Form* table found within the *RHRS.mdb* geodatabase
- Click the *Tools* pop-down menu and click *Add Route Events*.

- In the *Add Route Events Window* (Figure 45), fill in the blanks as shown below. Click OK and this will create a *RHRS Form Event* layer with each rockfall section plotted for the entire state.

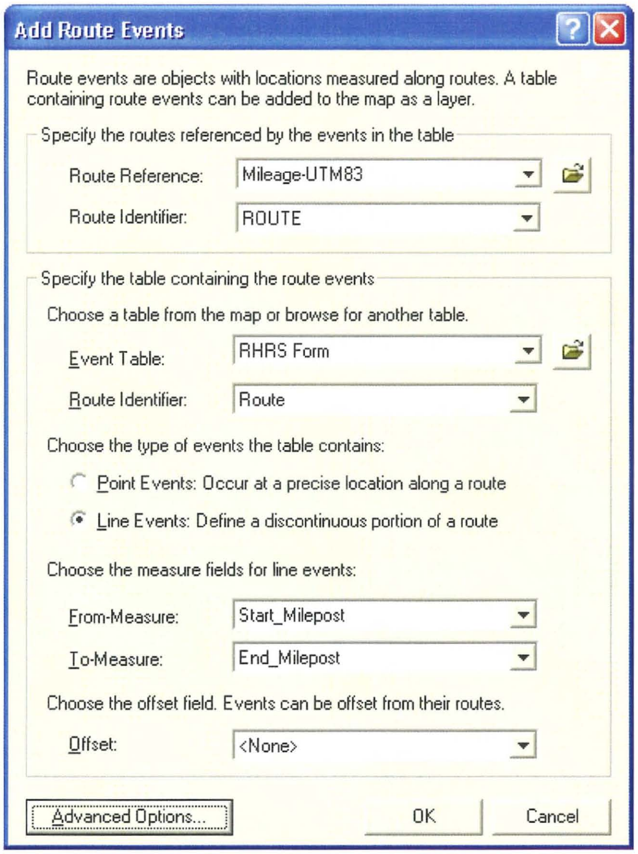

Figure 45. Add Route Events Window.

- Figure 46 shows the resulting plot of rockfall locations along a highway. In this case, the example is Parley's Canyon, near Salt Lake City, Utah. This data is in a UTM Zone 12N map projection with the North American Datum 1983 (NAD83).

- Using ArcGIS layer property manipulation, the rockfall sections can be colored and labeled. It is assumed that the user has some experience with ArcGIS and can customize the required map layout. Figure 47 is an example of such a custom map.

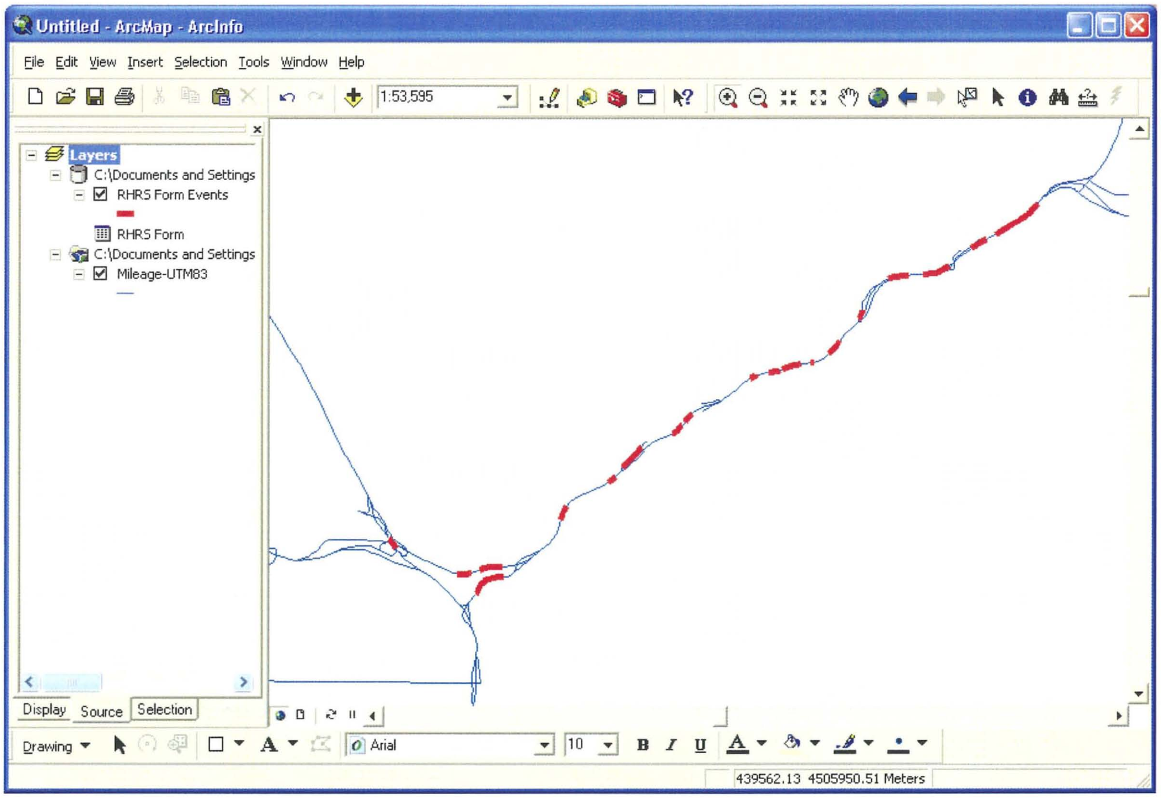

Figure 46. ArcMap plot of rockfall locations in Parley's Canyon, Utah.

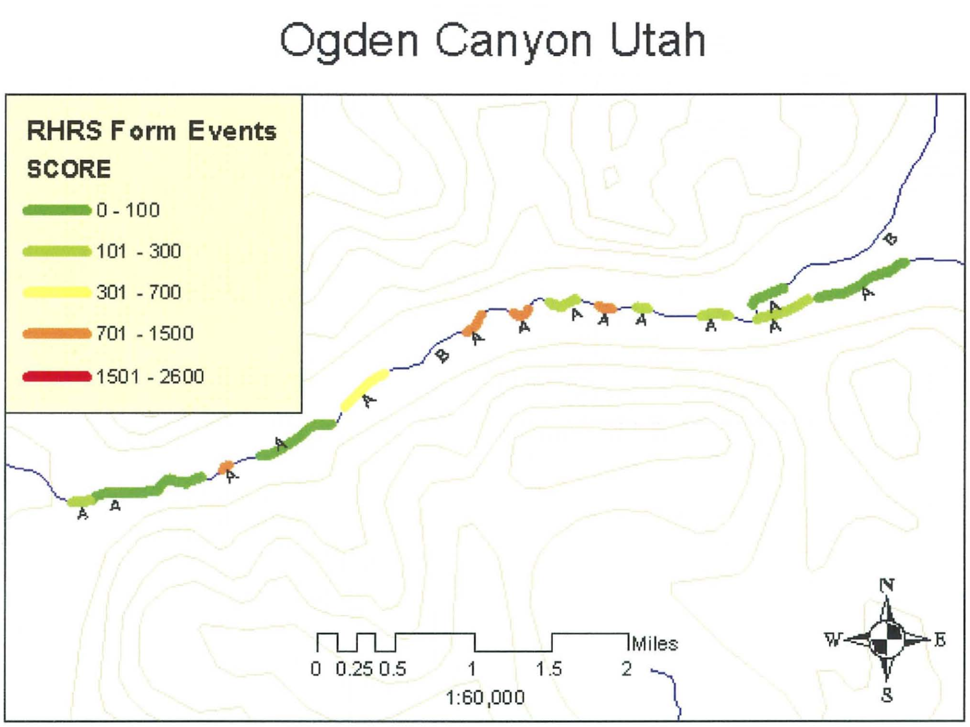

Figure 47. Sample map showing rockfall site data in Ogden Canyon, Utah

Appendix A

Phase I Rockfall Inventory Summary

Table A1. Number of rockfall sections by maintenance station.

	Total Number of Road Sections Per RHRS Rockfall Classification								
Maintenance station	**A+**	**A**	**A-**	**B+**	**B**	**B-**	**C+**	**C**	**Total**
Beryl		4			5				9
Beaver		14		1	11				26
Blanding		3			3				6
Bluff		11			11				22
Bothwell					1			2	3
Brigham					1				1
Cedar		24			2				26
Colton		13			13				26
Cottonwood	1	7			21	10			39
Cove Fort		4			6			1	11
Duchesne		10			5				15
Echo		2			4			1	7
Emery		2			3			1	6
Escalante		2		1	17	21			41
Eureka		6			4	1			11
Garrison		12			16	1		1	30
Green River		4			4			2	10
Hanksville	1	4	2	4	25	12			48
Heber		7			5				12
Huntington		24	1		3				28
Huntsville		20			6				26
Hurricane		7			3				10
Junction		8		2		1			11
Kamas		11		5	24	3			43
Kanab		6			4				10
Kimballs Jct		3		2	9				14
Laketown		13			10			1	24
Lehi		15		2	27	6	1		51
Loa		2	1		12	7			22
Logan		22	4		26	8		1	61
Long Valley		19			1				20
Manilla		13			6				19
Milford					2				2
Moab	1	16	2	4	20	10		1	54
Monticello		6	3	1	6				16
Morgan		13			10				23
Mt. Pleasant		10			2				12
Orem		2			15	4			21
Panguitch		19			12				31
Parley's		25		2	12	1			40
Richfield		3		1	7				11
Roosevelt					2	2			4
Salina		9			3	2			14
Scipio						1		2	3
Spanish Fk		10	5	3	3				21
St. George		1			6			2	9
Strawberry		11	1		6				18
Tabonia		8			6				14
Thompson		3			2				5
Tooele		2			15			6	23
Vernal		7			6				13
Wanship		9			7			2	18
Wellsville		11			21			27	59
Grand Total	**3**	**457**	**19**	**28**	**451**	**90**	**1**	**50**	**1099**

Table A.2. Estimated length rockfall sections by maintenance station given in meters.

	Total Meters Of Road Within Preliminary RHRS Classifications								
Maintenance station	**A+**	**A**	**A-**	**B+**	**B**	**B-**	**C+**	**C**	**Total**
B eryl		521			1058				1579
Beaver		6959		138	3325				10422
Blanding		2009			635				2644
Bluff		6826			1563				8389
Bothwell					372			194	566
Brigham					184				184
Cedar		9297			805				10102
Colton		2778			2170				4948
Cottonwood	557	578			4007	4144			9286
Cove Fort		990			1138			132	2259
Duchesne		3228			988				4216
Echo		1188			944			311	2443
Emery		803			1371			136	2310
Escalante		293		247	2488	3829			6857
Eureka		2023			390	57			2470
Garrison		1725			2369	84		80	4258
Green River		1215			1559			872	3646
Hanksville	182	906	571	585	5170	2806			10220
Heber		2433			1122				3556
Huntington		13952	183		772				14907
Huntsville		8577			1942				10519
Hurricane		1155			500				1655
Junction		1869		392		405			2665
Kamas		3621		20591	24109	4097			52419
Kanab		1642			304				1946
Kimballs Jct		323		159	597				1079
Laketown		1190			1369			151	2711
Lehi		1681		161	3481	471	0		5795
Loa		213	307		2116	1300			3936
Logan		2807	738		2552	712		123	6931
Long Valley		3811			135				3946
Manilla		4187			930				5117
Milford					304				304
Moab	330	4688	697	2219	8538	3240		45	19756
Monticello		548	874	147	1853				3422
Morgan		2966			1316				4282
Mt. Pleasant		4902			235				5137
Orem		532			3552	1862			5945
Panguitch		2141			1379				3519
Parley's		5090		291	1748	55			7184
Richfield		916		95	861				1872
Roosevelt					319	208			527
Salina		4410			636	132			5178
Scipio						303		255	559
Spanish Fk		2152	1286	320	644				4402
St. George		150			1113			246	1509
Strawberry		1374	64		901				2339
Tabonia		2262			422				2684
Thompson		1418			248				1666
Tooele		371			4844			605	5820
Vernal		1663			814				2477
Wanship		2607			2022			1117	5746
Wellsville		2058			4075			3253	9387
Grand Total	**1069**	**129047**	**4720**	**25345**	**106291**	**23705**	**0**	**7520**	**297696**

Appendix B

Selected Site Scoring Details

Morgan RF-1426-02

Number	Variable	Value	Units
1	Posted Speed	55	mph
2	Horiz. Dist	1000	m
3	Sight Dist	200	m
4	Road Width	13	m
5	Slope Ht	45	m
6	Slope Dist	46	m
7	Slope Angle	81	deg
8	Ditch Width	17	m
9	Ditch Depth	1.3	m
10	Longest Block Side	2.7	m
11	Potential Fall Vol.	5	m^3
12	Backslope Angle	32	deg
13	Backslope Boulders	no	
14	Water (ODOT)	High or Freezing (3)	
15	Water (NYDOT)	High w/ Veg. (4)	
16	Rock Friction	Undular (2)	
17	Fracture-Cryst.	NA (1)	
18	Fracture-Sed.	Large Blks and Ovrhngs (5)	
19	Geo-Joint	NA (1)	
20	Geo-Diff Erosion	Major (5)	
21	Geo-Diff Ero. Rates	Moderate (3)	
22	Ditch Eff.	Moderate (2)	
23	Slide Severity	2-way Traffic (3)	
24	Hazard Severity	High (4)	
25	Rockfall	Mod./On Shoulder	
26	Accidents	None (1)	
27	Fall Freq. ODOT	Occasional (2)	
28	Fall Freq. NYOT	Occasional (2)	
29	Maint. Freq.	1	#/year
30	HWY Factor	Interstate (1.2)	
31	Ritchie Width	8	m
32	Ritchie Depth	2.1	m
33	ADT	5212	cars/day
34	AASHTO DSD	875	ft

ODOT I				Score
#5	Slope Ht	3^(147.638/25)		**100**
#25	Ditch Effectiveness			**9**
#33, #2, #1	AVR	5212*0.6214*100/(24*55) 3^(245.5/25)		**100**
#3, #34	%DSD	200/875*3.28*100 3^((120-74.99)/20)		**11.85**
#4	Road Width	3^((52-42.65)/8)		**3.61**
#20, #21	Geologic	Erosion Features Erosion Rates	81 9	**90**
#10, #11	Blk Size Fall Vol	3^(8.858) 3^(176.5/3)	100 100	**100**
#14	Climate			**27**
#27	Fall History			**9**
			Total	**450.46**

ODOT II				Score
#24, #3, #34	Hazard	108.91-74.99*0.247		**90.39**
#25	Roadway Impact	Rockfall	9	**9**
#29	Maintenance	12.5*(1)+37.5		**50**
#33	Traffic	5212/400		**13.03**
#26	Accidents			**3**
			Subtotal	**165.42**
#30	HWY Factor			**1.2**
			Total	**198.50**

NYDOT				Score
GF #18, #10, #16, #15, #28, #12, #13	(27+81+3+27+3+9)/10			**15**
SF #31, #32, #8, #9	(8+2)/(17+1.3)			**0.55**
HEF #33, #2, #1, #34				
Fa	ADT[(L+SSD)/(Vx24000)]		3.1	
Fp	$(\log_{10}ADT)(\log_{10}L)[a/(SSD-a)]$		3.7	
			(3.1+3.7)/3	**2.27**
			Subtotal	**18.73**
		SF<1 Gives:	Total	**1.00**

Heber RF 4331-07

Number	Variable	Value	Units
1	Posted Speed	55	mph
2	Horiz. Dist	320	m
3	Sight Dist	180	m
4	Road Width	15	m
5	Slope Ht	10.5	m
6	Slope Dist	11	m
7	Slope Angle	71	deg
8	Ditch Width	4	m
9	Ditch Depth	0.4	m
10	Longest Block Side	0.5	m
11	Potential Fall Vol.	0.25	m^3
12	Backslope Angle	0	deg
13	Backslope Boulders	No	
14	Water (ODOT)	High or Freeze (3)	
15	Water (NYDOT)	Moderate (3)	
16	Rock Friction	Undular (2)	
17	Fracture-Cryst.	Discont. (3)	
18	Fracture-Sed.	NA (1)	
19	Geo-Joint	Discon. Random (3)	
20	Geo-Diff Erosion	NA (1)	
21	Geo-Diff Ero. Rates	NA (1)	
22	Ditch Eff.	Good (1)	
23	Slide Severity	Two-Way Traffic (3)	
24	Hazard Severity	High (4)	
25	Rockfall	On Shoulder (2)	
26	Accidents	None (1)	
27	Fall Freq. ODOT	Many Seasonal (3)	
28	Fall Freq. NYOT	Regular (4)	
29	Maint. Freq.	5	#/year
30	HWY Factor	Rural State (1.0)	
31	Ritchie Width	4.6	m
32	Ritchie Depth	1.5	m
33	ADT	2335	cars/day
34	AASHTO DSD	875	ft

ODOT I				Score
#5	Slope Ht	3^(34.45/25)		**4.54**
#25	Ditch Effectiveness			**3**
#33, #2, #1	AVR	2335*0.1989*100/(24*55)		
		3^(35.17/25)		**4.69**
#3, #34	%DSD	180/875*3.28*100		
		3^((120-67.47)/20)		**17.89**
#4	Road Width			
		3^((52-42.21)/8)		**1.47**
#20, #21	Geologic	Joints	9	
		Friction	9	**18**
#10, #11	Blk Size	3^(2.297)	6.06	
	Fall Vol	3^(17.657/3)	25.36	**25.36**
#14	Climate			**27**
#27	Fall History			**27**
			Total	**128.95**

ODOT II				Score
#24, #3, #34	Hazard	108.91-67.47*0.247		**92.24**
#25	Roadway Impact			
		Rockfall	9	**9**
#29	Maintenance			
		12.5*(5)+37.5		**100.0**
#33	Traffic	2335/400		**5.84**
#26	Accidents			**3**
			Subtotal	**210.08**
#30	HWY Factor			**1.0**
			Total	**210.08**

NYDOT			Score
GF			
#18, #10, #16, #15, #28, #12, #13			
	(9+27+9+1+81+27)/10		**15**
SF			
#31, #32, #8, #9			
	4.6+1.5)/(4+0.4)		**3.82**
HEF			
#33, #2, #1, #34			
Fa	ADT[(L+SSD)/(Vx24000)]	0.0466	
Fp	$(\log_{10}ADT)(\log_{10}L)[a/(SSD-a)]$	0.279	
		(0.0466+0.279)/3	**0.11**
		Subtotal	**6.39**
		Total	**6.39**

Morgan RF-1426-04

Number	Variable	Value	Units
1	Posted Speed	55	mph
2	Horiz. Dist	200	m
3	Sight Dist	80	m
4	Road Width	17	m
5	Slope Ht	62	m
6	Slope Dist	68	m
7	Slope Angle	65	deg
8	Ditch Width	16	m
9	Ditch Depth	3.1	m
10	Longest Block Side	1.5	m
11	Potential Fall Vol.	2.5	m^3
12	Backslope Angle	0	deg
13	Backslope Boulders	No	
14	Water (ODOT)	High, or Freeze (3)	
15	Water (NYDOT)	High seep w/ veg (4)	
16	Rock Friction	Planar (3)	
17	Fracture-Cryst.	NA (1)	
18	Fracture-Sed.	Small Ovrhng (4)	
19	Geo-Joint	Discont. Adverse (4)	
20	Geo-Diff Erosion	NA (1)	
21	Geo-Diff Ero. Rates	NA (1)	
22	Ditch Eff.	Good (1)	
23	Slide Severity	Two-Way traffic (3)	
24	Hazard Severity	High (4)	
25	Rockfall	On Shoulder (2)	
26	Accidents	No Accidents (1)	
27	Fall Freq. ODOT	Occasional-Storm (2)	
28	Fall Freq. NYOT	Occasional-minor (2)	
29	Maint. Freq.	1	#/year
30	HWY Factor	Interstate (1.2)	
31	Ritchie Width	8	m
32	Ritchie Depth	3.3	m
33	ADT	5212	cars/day
34	AASHTO DSD	875	ft

ODOT I				Score
#5	Slope Ht	3^(203.4/25)		**100**
#25	Ditch Effectiveness			**3**
#33, #2, #1	AVR	5212*0.1243*100/(24*55)		
		3^(49.07/25)		**8.64**
#3, #34	%DSD	80/875*3.28*100		
		3^((120-30)/20)		**100**
#4	Road Width			
		3^((52-55.77)/8)		**0.6**
#19, #20	Geologic	Geo-Joint	27	
		Fracture-Sed	27	**54**
#10, #11	Blk Size	3^(4.92)	100	
	Fall Vol	3^(88.29/3)	100	**100**
#14	Climate			**27**
#27	Fall History			**9**
			Total	**402.24**

ODOT II				Score
#24, #3, #34	Hazard	108.91-30.0*0.247		**100.00**
#25	Roadway Impact			
		Rockfall	9	**9**
#29	Maintenance			
		12.5*(1)+37.5		**50.0**
#33	Traffic	5212/400		**13.03**
#26	Accidents			**3**
			Subtotal	**175.03**
#30	HWY Factor			**1.2**
			Total	**210.04**

NYDOT			Score
GF			
#18, #10, #16, #15, #28, #12, #13			
	(9+81+9+3+3+1)/10		**13**
SF			
#31, #32, #8, #9			
	(8+3.3)/(16+3.1)		**0.59**
HEF			
#33, #2, #1, #34			
Fa	ADT[(L+SSD)/(Vx24000)]	1.145	
Fp	($\log_{10}$ADT)($\log_{10}$L)[a/(SSD-a)]	19.96	
		(1.145+19.96)/3	**7.04**
		Subtotal	**54.00**
		Total	**1.00**

Appendix C

Top Rockfall Hazard Ratings By UDOT Region

Region 1 Top Rockfall Hazard Ratings

Rank	SCORE	ID-I	Shed Name	Route	Start Milepost	End Milepost	SF	GF	HEF
1	1015.00	rf-1436-39	Logan	0089B	473.45	473.35	5.00	23.00	8.82
2	992.00	rf-1425-04	Huntsville	0039B	12.22	12.09	5.10	17.20	11.31
3	956.00	rf-1425-05	Huntsville	0039B	11.88	11.72	6.10	18.40	8.52
4	929.00	rf-1425-02	Huntsville	0039B	12.82	12.73	6.00	22.00	7.04
5	874.00	rf-1425-08	Huntsville	0039B	9.85	9.91	6.40	21.60	6.32
6	790.00	rf-1426-17	Morgan	0066B	2.77	2.89	6.90	15.00	7.63
7	497.00	rf-1436-13	Logan	0089B	475.03	475.39	2.95	31.20	5.40
8	489.00	rf-1436-03	Logan	0089B	462.09	462.18	2.23	28.20	7.77
9	481.00	rf-1435-12	Wellsville	0101B	19.27	19.23	5.25	13.40	6.84
10	407.00	rf-1435-50	Wellsville	0101B	9.12	8.89	3.27	17.20	7.23
11	381.00	rf-1435-33	Wellsville	0101B	13.52	13.38	4.60	12.00	6.90
12	352.00	rf-1426-23	Morgan	0066B	13.75	13.83	3.05	15.00	7.69
13	345.00	rf-1425-10	Huntsville	0039B	10.77	11.11	6.40	18.60	2.90
14	318.00	rf-1426-15	Morgan	0066B	1.95	2.01	6.40	16.80	2.96
15	298.00	rf-1435-14	Wellsville	0101B	18.63	18.57	4.67	16.20	3.94
16	291.00	rf-1425-01	Huntsville	0039B	13.06	12.97	3.45	22.00	3.83
17	266.00	rf-1436-06	Logan	0089B	471.77	471.77	1.66	19.00	8.43
18	266.00	rf-1436-27	Logan	0089B	488.29	488.18	2.64	17.80	5.67
19	239.00	rf-1435-29	Wellsville	0101B	14.24	14.04	1.70	23.40	6.02
20	196.00	rf-1425-23	Huntsville	0039B	31.57	31.37	2.35	15.00	5.57
21	191.00	rf-1425-03	Huntsville	0039B	12.59	12.38	4.60	22.00	1.88
22	175.00	rf-1425-12	Huntsville	0039B	13.39	13.58	3.68	12.60	3.77
23	172.00	rf-1435-56	Wellsville	0101B	8.15	8.04	1.94	19.80	4.47
24	167.00	rf-1426-20	Morgan	0066B	4.71	4.74	1.97	25.20	3.36
25	154.00	rf-1436-37	Logan	0089B	474.17	474.15	2.40	13.60	4.71

Region 2 Top Rockfall Hazard Ratings

Rank	SCORE	ID-I	Shed Name	Route	Start Milepost	End Milepost	SF	GF	HEF
1	2384.00	rf-2433-27	Cottonwood	0190B	6.48	6.48	5.30	36.00	12.49
2	911.00	rf-2434-26	Parley's Canyon	0084N	130.02	130.02	6.10	12.00	12.45
3	387.00	rf-2434-10	Parley's Canyon	0084N	130.10	130.10	3.25	34.20	3.48
4	195.00	rf-2437-23	Kamas	0150B	4.05	4.23	3.00	19.20	3.38
5	192.00	rf-2435-09	C. LaMar Richins Silver S	0224B	2.10	2.10	5.20	13.80	2.68
6	146.00	rf-2433-01	Cottonwood	0190B	2.06	2.15	2.16	21.60	3.14
7	133.00	rf-2435-05	C. LaMar Richins Silver S	0224B	0.73	0.84	4.30	12.60	2.46
8	126.00	rf-2434-02	Parley's Canyon	0080PC12910	0.09	0.19	2.47	15.40	3.33
9	118.00	rf-2436-14	Wanship	0084N	149.07	149.23	1.65	18.00	3.96
10	116.00	rf-2436-11	Wanship	0084N	150.23	150.23	1.52	17.40	4.38
11	112.00	rf-2434-03	Parley's Canyon	0080PC12910	0.19	0.19	1.49	14.20	5.32
12	109.00	rf-2437-31	Kamas	0150B	29.70	29.77	6.10	9.60	1.86
13	105.00	rf-2434-08	Parley's Canyon	0084N	129.78	129.87	1.05	20.00	5.00
14	100.00	rf-2434-40	Parley's Canyon	0065B	6.98	6.75	4.00	16.80	1.49
15	96.00	rf-2437-05	Kamas	0035B	5.97	6.46	1.58	27.00	2.25
16	90.00	rf-2436-16	Wanship	0084N	149.99	149.33	1.67	19.80	2.71
17	76.00	rf-2434-04	Parley's Canyon	0080PC12910	0.19	0.34	1.36	10.20	5.48
18	74.00	rf-2434-35	Parley's Canyon	0065B	6.66	6.74	1.94	19.80	1.94
19	73.00	rf-2437-24	Kamas	0150B	4.73	5.41	1.44	22.20	2.28
20	69.00	rf-2434-31	Parley's Canyon	0084N	127.96	127.85	1.57	19.60	2.25
21	60.00	rf-2437-42	Kamas	0150B	37.93	38.05	1.60	13.20	2.82
22	59.00	rf-2437-36	Kamas	0150B	33.77	33.85	2.52	12.40	1.88
23	56.00	rf-2437-04	Kamas	0032B	8.96	8.93	1.82	16.80	1.85
24	51.00	rf-2434-37	Parley's Canyon	0065B	7.93	8.00	2.03	16.20	1.55
25	41.00	rf-2434-23	Parley's Canyon	0080NR13204	0.06	0.13	1.33	5.20	5.96

Region 3 Top Rockfall Hazard Ratings

RANK	SCORE	ID-I	Shed Name	Route	Start Milepost	End Milepost	SF	GF	HEF
1	1197.00	rf-3425-15	Provo Canyon	0092B	26.05	26.05	7.30	25.80	6.36
2	804.00	rf-3423-29	Lehi	0144B	1.86	1.60	6.90	20.80	5.60
3	407.00	rf-3426-11	Spanish Fork	0.75	192.76	192.54	4.43	14.40	6.38
4	394.00	rf-3434-04	Duchesne	0191B	265.22	264.63	1.89	36.00	5.80
5	354.00	rf-3421-05	Eureka	0.75	143.72	143.79	3.00	22.60	5.23
6	290.00	rf-3425-04	Provo Canyon	0189B	18.25	18.38	7.45	34.20	1.14
7	195.00	rf-3434-05	Duchesne	0191B	264.54	264.17	1.27	28.80	5.33
8	194.00	rf-3423-18	Lehi	0092B	15.36	15.24	6.80	16.80	1.70
9	193.00	rf-3421-04	Eureka	0.75	143.42	143.62	2.03	16.60	5.72
10	185.00	rf-3436-16	Manila	0044B	18.24	17.49	1.78	28.80	3.62
11	179.00	rf-3421-10	Eureka	0.75	143.83	143.75	3.24	19.60	2.81
12	161.00	rf-3426-01	Spanish Fork	0089B	309.53	309.71	1.14	34.20	4.11
13	157.00	rf-3421-02	Eureka	0.75	142.33	142.65	1.50	18.00	5.81
14	148.00	rf-3436-11	Manila	0191B	397.29	397.49	2.76	26.20	2.04
15	145.00	rf-3423-22	Lehi	0092B	14.18	14.20	2.52	23.20	2.48
16	137.00	rf-3423-10	Lehi	0092B	9.62	9.73	6.50	19.20	1.10
17	134.00	rf-3423-06	Lehi	0092B	8.96	8.96	3.50	23.20	1.65
18	119.00	rf-3436-10	Manila	0191B	395.01	395.09	2.90	15.40	2.65
19	112.00	rf-3436-09	Manila	0191B	392.71	392.79	1.60	17.80	3.92
20	107.00	rf-3436-05	Manila	0044B	17.65	17.41	1.38	22.20	3.50
21	105.00	rf-3436-12	Manila	0191B	393.74	393.56	1.31	38.40	2.08
22	105.00	rf-3436-08	Manila	0044B	13.13	12.17	1.16	34.20	2.64
23	93.00	rf-3421-03	Eureka	0.75	142.69	143.36	1.13	13.80	5.96
24	81.00	rf-3423-21	Lehi	0092B	14.66	14.56	3.10	23.40	1.12
25	80.00	rf-3423-20	Lehi	0092B	14.01	14.67	3.24	11.40	2.18

Region 4 Top Rockfall Hazard Ratings

RANK	SCORE	ID-I	Shed Name	Route	Start Milepost	End Milepost	SF	GF	HEF
1	2584.00	rf-4524-09	Cedar City	0014B	7.97	8.18	5.38	46.80	10.25
2	1499.00	rf-4325-26	Panguitch	0143B	37.94	37.66	6.18	22.20	10.92
3	1333.00	rf-4522-07	Hurricane	0009B	13.23	13.17	3.81	27.40	12.77
4	1277.00	rf-4527-14	Beaver	0153B	14.41	13.85	6.90	26.20	7.06
5	988.00	rf-4433-27	Huntington	0029B	8.98	6.13	6.10	37.80	4.29
6	848.00	rf-4527-24	Beaver	0153B	7.68	7.42	8.10	35.20	2.98
7	839.00	rf-4524-02	Cedar City	0014B	1.22	1.40	8.33	24.60	4.09
8	810.00	rf-4522-09	Hurricane	0015N	37.04	37.04	2.70	30.80	9.74
9	698.00	rf-4524-10	Cedar City	0014B	8.18	8.81	7.45	28.00	3.34
10	691.00	rf-4527-01	Beaver	0153B	3.74	4.08	5.90	32.40	3.62
11	639.00	rf-4325-31	Panguitch	0143B	40.57	40.63	3.81	24.40	6.86
12	634.00	rf-4527-03	Beaver	0153B	7.80	8.36	6.20	32.40	3.16
13	633.00	rf-4421-08	Bluff	0261B	7.73	8.79	5.27	24.40	4.92
14	582.00	rf-4524-25	Cedar City	0143B	11.05	10.68	5.20	18.00	6.22
15	521.00	rf-4326-04	Junction	0062B	5.69	5.40	3.39	22.00	6.98
16	486.00	rf-4334-06	Mt. Pleasant	0031B	5.07	3.89	2.60	43.20	4.33
17	464.00	rf-4324-28	Escalante	0012B	54.65	54.76	5.91	15.40	5.09
18	445.00	rf-4421-07	Bluff	0261B	8.14	7.74	6.54	18.40	3.70
19	382.00	rf-4334-05	Mt. Pleasant	0031B	5.47	5.11	2.00	36.00	5.31
20	345.00	rf-4326-05	Junction	0062B	5.37	5.14	3.76	14.80	6.20
21	340.00	rf-4332-10	Hanksville	0095B	42.72	42.61	2.27	31.00	4.82
22	324.00	rf-4533-09	Garrison	0.75	26.16	26.21	1.88	23.40	7.38
23	324.00	rf-4527-17	Beaver	0153B	12.94	12.66	6.73	28.80	1.67
24	311.00	rf-4433-28	Huntington	0029B	6.09	3.86	2.25	48.60	2.85
25	296.00	rf-4524-26	Cedar City	0143B	9.79	9.71	7.45	13.60	2.92


DVD
UDOT Rockfall Hazard Rating System
Utah Department of Transportation
Research Division
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