April 2016

Montana Department of Transporation

# Rockfall Hazard Process Assessment
## State of Montana, Project No. 15-3059V

# Task 2 Report
## Review of Mitigated Sites

LANDSLIDE TECHNOLOGY
A DIVISION OF CORNFORTH CONSULTANTS

Prepared for:

Montana Department of Transportation
Helena, Montana

# ROCKFALL HAZARD PROCESS ASSESSMENT

## TASK 2 REPORT
## REVIEW OF MITIGATED SITES

April 18, 2016

Prepared by:

Landslide Technology
10250 SW Greenburg Road, Suite 111
Portland, OR  97223

## Contents



## List of Figures

## List of Tables

## Executive Summary

This document is the deliverable for Task 2 of the Montana Department of Transportation (MDT) research project "Rockfall Hazard Rating Process Assessment" (Project No. 15-3059V). The purpose of this task is to visit and assess sites that were new, have been mitigated, or significantly changed since the original RHRS ratings were completed in 2004. MDT provided a list of sites that Landslide Technology then visited in November 2015 (Figure 1). Application of the standard RHRS rating procedure at these sites reflected site updates and improvements and provided the basis for evaluating various rating/scoring methods described herein.

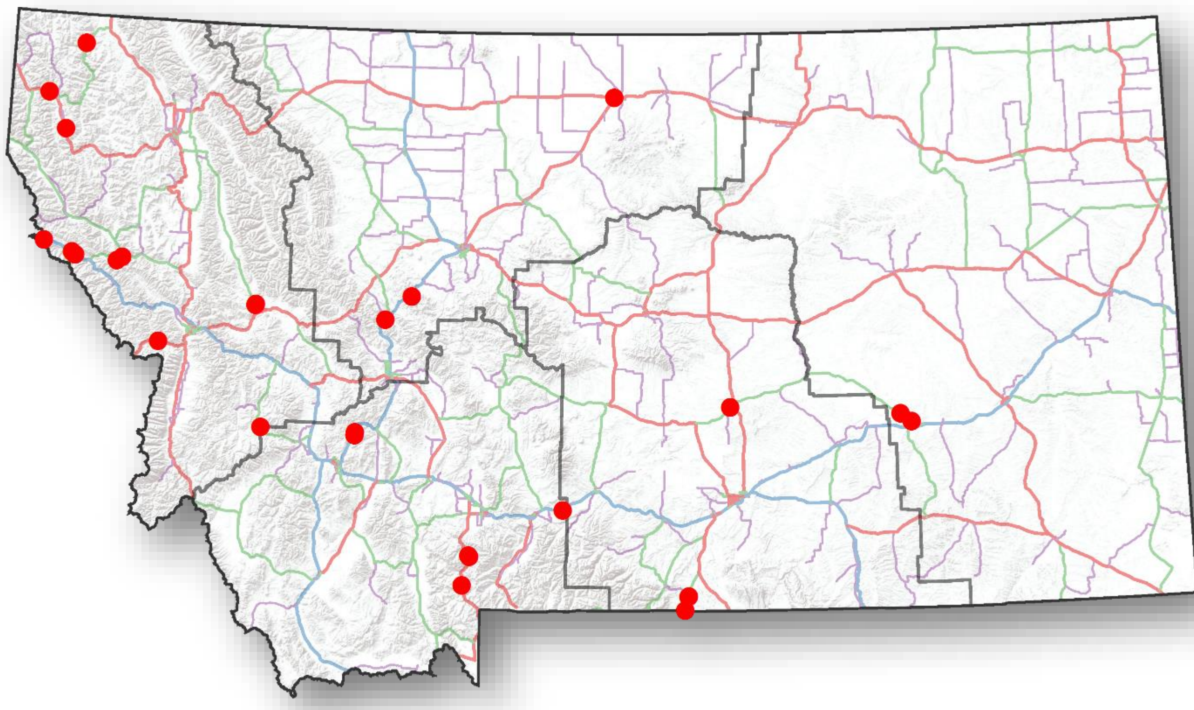

Figure 1: Sites visited as part of Task 2 indicated by red markers.

MDT provided three new combinations of certain RHRS criteria for evaluation. Task 2 sites had these methods applied to them and were then evaluated for magnitude of change in scores following mitigation activities. For purposes of this task, these quantitative measurement methods that judge slope characteristics are compared to one another by assessing percentage change in each method between the 2004 and 2015 ratings. MDT method 3 exhibited the greatest degree of change while still using the exponential-style scoring approach found in the RHRS while method 1 and 2 exhibited a decreasing change magnitude, respectively. We recommend that Task 3 evaluate these approaches further through application to the 2004 RHRS data for testing as a decision support tool.

We also utilized the approaches that built upon two years of research for the Alaska Geotechnical Asset Management Program for calculation of transportation asset management (TAM) compatible Condition Indexes and States from RHRS data. This approach produces results similar to bridge and pavement asset management systems. These approaches yielded greater percentage improvements for the same mitigation measures which simplify the ability demonstrate improvements to the rock slope through mitigation installation. These measures also feed into other deterioration and cost models using the

Condition approaches. We recommend incorporation of these metrics into the future Rockfall Hazard Process.

Economic analyses focusing on mobility and safety impacts to the travelling public were applied to the rerated sites. Calculation of the economic risk to the public through additional travel times was based on detour lengths, traffic volumes, standard AASHTO valuation approaches, and initial assumptions on annual likelihood models. These factors are standard calculations used in TAM models to assist in project selection, prioritization, and economic benefit analysis for mitigation measures.

# 1 Task 2 Introduction

The objective of this task is to determine actual mitigation and maintenance costs, successes, and lessons learned from previous MDT efforts. In September 2005, Montana Department of Transportation (MDT) released its Rockfall Hazard Classification and Mitigation System report. The report contained ratings of 869 sites throughout the state, completed in the summer of 2004. Eventually, slopes that received detailed rating scores above a cutoff value of 350 were determined to be "A" slopes, or the highest rating category (i.e. the most hazardous).

MDT is currently working to revise its existing RHRS system. A critical component of this work is using existing data to evaluate various methods to revise the current rating process, so the site location and rating information collected in 2004 was extracted to an Excel spreadsheet for use in testing. The various suggested methods would all move beyond the "total score" method currently applied to one that weighs and/or groups certain category scores over others so that the degree of impact each rock slope has on transportation safety and economic costs may be better incorporated.

This second of eight tasks for the current research project focused on rerating 29 sites throughout the state using the RHRS criteria in the 2005 report. These selected sites had received mitigation attention in the intervening decade and were therefore due for a rerating. This mitigation work ranged from site-specific rockfall hazard reduction projects to large-scale road realignment work that addressed multiple sites at once.

Two teams consisting of geologists and geotechnical engineers familiar with rock slope evaluation and MDT's unique rock slopes and low traffic volumes visited these sites in November 2015 (Figure 1). MDT geotechnical and/or maintenance personnel either visited the sites with LT staff or provided the information critical to the sites. The 2004 MDT RHRS rating procedure was performed at each site, with rating information entered into a spreadsheet for each site.

After the field efforts, MDT provided three methods of recombination of various RHRS criteria to assist in project prioritization and selection. Additional methods of ranking and scoring the rock slope that are consistent with other Transportation Asset Management (TAM) systems developed as part of separate statewide research project for the Alaska Department of Transportation and Public Faculties were tested with the rerated sites. Section 2 describes these methods while section 3 describes the rating results at each site.

# 2 Tested Scoring Methods

MDT internally developed three modified rating methods and requested that Landslide Technology (LT) test them using the existing 2004 data. All three methods seek to give more weight to factors that may be under-valued in the current rating system, but they would not alter or replace the rating categories currently used in the MDT RHRS program. The revised method may be used to generate a new minimum cutoff score for use in developing a final list of "A" slopes, which would receive more attention from the department than the remaining "B" slopes.

## 2.1 Total RHRS Score

Scores from both the 2004 and 2015 rating reconnaissance without alteration of the RHRS system were compiled and compared. Rating information pulled from Landslide Technology's original project files and entered into an Excel sheet served as the basis for this and all the other rating calculations evaluated.

## 2.2 MDT Rating Method 1

Rating Method 1 assessed a rock slope site's ditch catchment effectiveness, potential traffic impacts, failure potential, and rockfall history, as shown in Equation 1. Each category has a maximum possible score of 100 points, and the total possible score for a site under Method 1 is 400 points.

Equation 1: Rating Method #1

$$Method\ 1 = Ditch\ Effectivness + Traffic\ Impacts + Failure\ Potential + Rockfall\ History$$

The ditch effectiveness and rockfall history scores are obtained directly from the RHRS rating categories. Potential Traffic Impacts are calculated using Equation 2 and the Failure Potential is derived by averaging multiple RHRS category scores as shown in Equation 3.

Equation 2: Impact to Traffic Score

$$Impact\ to\ Traffic = AADT * 0.0082;\ maximum\ score = 100$$

Equation 3: Potential for Failure Score. The larger of the two values is applied to the total rating method score.

$$Potential\ for\ Failure = \left(\frac{Structural\ Condition + Rock\ Friction + Block\ Size\ or\ Volume}{3}\right)\ or$$

$$\left(\frac{Differential\ Erosion\ Features + Differential\ Erosion\ Rates + Block\ Size\ or\ Volume}{3}\right)$$

## 2.3 MDT Rating Method 2

Rating Method 2 assessed a rock slope's ditch effectiveness, potential traffic impacts, immediate hazard, failure potential, scale of the potential threat, and rockfall history, as shown in Equation 4. Each category has a maximum possible score of 100 points, and the total possible score for a site under Method 2 is 600 points.

Equation 4: Rating Method 2

$$Method\ 2 = Ditch\ Effectivness + Traffic\ Impacts + Immediate\ Hazard + Failure\ Potential + Block\ Size\ or\ Volume + Rockfall\ History$$

The ditch effectiveness, block size/volume, and rockfall history scores are obtained directly from the RHRS rating categories. Potential Traffic Impacts is calculated as in Method #1, using Equation 2. The Immediate Hazard was determined by averaging the sight distance and roadway width scores, as shown in

Equation 5. Failure Potential was derived by averaging multiple RHRS category scores as shown in Equation 6.

Equation 5: Impact to Traffic Score

$$Immediate\ Hazard = \left(\frac{Decision\ Sight\ Distance + Roadway\ Width}{2}\right)$$

Equation 6: Potential for Failure Score. The larger of the two values is applied to the total rating method score.

$$Potential\ for\ Failure = \left(\frac{Structural\ Condition + Rock\ Friction}{2}\right) or$$

$$\left(\frac{Differential\ Erosion\ Features + Differential\ Erosion\ Rates}{2}\right)$$

## 2.4 MDT Rating Method 3

Unlike Rating Methods 1 and 2, Rating Method 3 generates three distinct sub scores – slope rating, vehicular risk, and impact to traffic. The slope rating score comprises ditch effectiveness, potential for failure, and rockfall history, as shown in Equation 7. The ditch effectiveness and rockfall history scores are obtained directly from the RHRS rating categories, while the potential for failure is derived using the same equation applied in Method #1, Equation 3. The maximum possible Slope Rating Score in Method #3 is 300 points.

Equation 7: Rating Method 3 – Slope Rating Score

$$Slope\ Rating = Ditch\ Effectivness + Failure\ Potential + Rockfall\ History$$

The Vehicular Risk Score is the sum of the Sight Distance and Roadway width category scores, both of which are obtained directly from the RHRS ratings. The maximum possible Vehicular Risk Score is 200 points. This category essentially judges a vehicles ability to avoid a fallen rock in the road, based on sight distance and the roadway width available to safely steer around the fallen rock.

Equation 8: Rating Method 3 – Vehicular Risk Score

$$Vehicular\ Risk = Sight\ Distance + Roadway\ Width$$

The final component of Method #3, the Impact Rating consists of the ADT-based score calculated using Equation 2 and has a maximum possible value of 100 points. In the future, detour length impacts may also be incorporated. The use of a linear scoring method in this approach will work well with the exponential scoring methods of the other RHRS-derived categories and does not have any inherent incompatibility when compared to other score combinations.

## 2.5 Application of TAM-compatible Condition States to Existing RHRS Data

LT is currently working with the Alaska Department of Transportation (AKDOT) to develop the nation's first Geotechnical Asset Management (GAM) program that will be fully TAM-compatible. Both AKDOT's GAM program and MDT's RHRS program use similar rockfall hazard rating categories and apply exponential scoring systems. For the AKDOT GAM project, the Condition State for a rock slope is defined as a combination of the likelihood that a rockfall event will occur at the site and the likelihood that this event will affect the roadway. These two components are captured by the "Ditch Effectiveness" and "Rockfall History" categories.

The site condition assessments used in the MDT test are the same as those currently applied in AKDOT's GAM program. The same methods used to assess rock slope condition within AKDOT's GAM program are applied to MDT's 2004 and 2015 RHRS ratings, which measure how effectively mitigation activities improve asset condition. The means and methods used to derive Condition State are summarized in Section 2.5.1.

A critical aspect of TAM-compatible assessment systems is the ability to demonstrate the economic benefit of implementing mitigation measures that reduce the likelihood of mobility interruptions, vehicle accidents, and maintenance activity and their associated costs. For instance, consider the hypothetical situation that rockfall mitigation measures may reduce the likelihood of mobility interruptions and rockfall-related accidents on an I-90 slope over a 30-year period from one adverse event per 10 year period to once every 20 years. In this hypothetical situation, the total 30-year economic loss pre mitigation may be $19.6 million dollars; if mitigation measures had been implemented the loss would have be $9.3 million. Therefore, if mitigation measures that cost $2 million dollars reduce likelihood by 50%, the public realizes an approximately 515% [(19.6-9.3)/2] return on their mitigation dollar. This criterion was calculated using an approximation for likelihood based on 2004 and 2015 RHRS data. This parameter may be refined by compiling a history of past rockfall occurrences, currently underway by MDT geotechnical staff.

### 2.5.1 Derivation of Condition State & Condition Index from RHRS Category Scores

In developing measurements for asset condition, it is important to understand that the desired outcome of asset management programs is to maintain or achieve acceptable asset condition within defined transportation corridors. Future MDT TAM policy will eventually set acceptable condition by as part Performance Measures and Goals, but is typically set network-wide as a percent in a 'Good' condition (e.g. 85%) with a maximum acceptable percentage in a 'Poor' condition (e.g. 3%). To meet these future goals, preservation or reconstruction actions, analogous to chip seals for pavements or new paint on metallic bridge elements, are carried out to reverse, rehabilitate, or prevent asset deterioration.

In order to focus only on conditions that typically deteriorate, the Condition Index/Condition States focus only those characteristics that degrade in the absence of maintenance or mitigation. For rock slopes, these characteristics are rockfall activity and ditch effectiveness. Most mitigation measures also heavily focus on improving these two measures. Other typical RHRS measures, such as slope height, average vehicle risk, and sight distance do not typically degrade. Other aspects, such as the effects of geologic condition and block size/volume can be captured in the rockfall activity and ditch effectiveness categories. For instance, if a rock slope has adversely oriented planar joints but is not producing rockfall during its 30-year history and the ditch is wider than the slope is tall, the slope condition is Good. If the slope begins to produce rockfall due to the joints, the slope condition has deteriorated even though the geologic conditions have not changed. Other slope characteristics such as launch features and mitigation measures intended to improve these categories are within these two criteria.

The MAP-21 legislation, discussed in our Task 1 report, requires a three-category system to describe bridge or pavement assets as Good, Fair, or Poor. These relatively broad categories are used at the programmatic-planning level to help identify both those assets that are currently performing poorly and those that would benefit most from preservation actions to prevent deterioration from, for example, a Fair to a Poor Condition State. For the sake of consistent terminology, the Condition States developed for rock slopes are also Good, Fair, or Poor. However, during work on the AKDOT GAM program, five numerical Condition State categories better captured the range of maintenance and preservation demands, while remaining clearly identifiable in a routine visual inspection. These five divisions are presented in Table 1 and can be directly mapped to a Good/Fair/Poor Condition State as follows: 1 – Good, 2 or 3 – Fair, and 4 or 5, Poor. The Condition State is generally presented as a whole integer (1, 2, 3, etc.) or as a category (Good, Fair, or Poor). An asset's Condition State is calculated without consideration of the potential risk posed to the public in the event of failure.

Using these linear scores permit equal or semi-equal comparability with other TAM programs, such as bridges and pavements. These evaluation criteria are common in TAM programs and as MDT's program matures, the Rockfall Hazard Assessment with have a subset of numerical and Good/Fair/Poor indicators on a slope's condition. This permits the rock slope program to be already compliant with MDT's TAM program as it develops.

MDT's B-slopes that do not have a detailed rating would be classified as Condition State 1 – Good Slopes since they generally do not have a medium or high likelihood of producing rock onto the roadway. This would result in all 1,869 rock slopes evaluated in the previous ratings to have a place in the TAM-compatible rockfall assessment program, a distinct advantage of utilizing condition assessments.

Table 1: Condition States for Rock Slope Geotechnical Assets

| Numerical Condition State and Condition State Text | Description |
|---|---|
| **1 – Good** | Rock slope produces little to no rockfall and no history of rock reaching the road. Little to no maintenance needs to be performed due to rockfall activity. Rockfall mitigation measures, if present, are in new or like new condition. |
| **2 – Fair** | Rock slope produces occasional rockfall that may rarely reach the road. Some maintenance needs to be performed on a scheduled basis due to rockfall activity to address safety. Mitigation measures, if present, are in generally good condition, with only surficial rust or minor apparent damage. |
| **3 – Fair** | Rock slope produces many rockfalls with rock occasionally reaching the road. Maintenance is required bi-annually or annually to maintain safety. Mitigation measures, if present, appear to have more significant corrosion or damage to minor elements. Preventative maintenance or replacement of minor mitigation components is warranted. |
| **4 – Poor** | Rock slope produces constant rockfall with rocks frequently reaching the road. Maintenance is required annually or more often to maintain ditch performance. Much of the required maintenance response is unscheduled. Mitigation measures, if present, are generally ineffective due to significant damage to major components or apparent deep corrosion. |
| **5 – Poor** | Rock slope produces constant rockfall and nearly all rockfall reaches the road. Virtually no rockfall catchment exists or is effective. Maintenance must respond to rockfalls regularly, possibly daily during adverse weather. If present, nearly all mitigation measures are ineffectual either due to deferred maintenance, significant damage, or obvious deep corrosion. |

The rating categories used in MDT's RHRS program utilize an exponential scoring function, with "1" being an excellent score and "100" being a failed condition or worst-case scenario. This approach produces significantly greater score separation within a rating category, which is useful for identifying the most hazardous sites in a corridor. However, it differs from the traditional TAM scoring methodology, where a linear function is used. In TAM, a score of 100 represents an excellent or new condition and a score of zero (0) represents a failed condition. This linear scoring system is more useful for presenting information to the public, because it is similar to the grading practices the public is already accustomed to using in school settings. The algorithm presented as Equation 9 and Equation 10 is applied to convert from RHRS exponential to TAM linear scores.

Equation 9: Algorithm for RHRS category score to linear score conversion given that 0 < RHSR Category Score ≤ 81

$$Linear\ Score = 100 - \left(25 \times (RHRS\ exponent - 1)\right)\ where$$

$$RHRS\ exponent = \frac{\ln(RHRS\ Category\ Score)}{(\ln 3)}$$

Equation 10: Algorithm for RHRS category score to linear score conversion given that 81 < RHRS Category Score

$$Linear\ Score = (RHRS\ Score\ \times -1.3158) + 131.58$$

The linear scores are then averaged together to generate a linear Condition Index (Equation 11), which is in turn used to calculate rock slope Condition State (Equation 12).

Equation 11: Condition Index Equation for Rock Slopes

$$Condition\ Index = \frac{(Ditch\ Effectiveness\ Linear\ Score + Rockfall\ History\ Linear\ Score)}{2}$$

Equation 12: Condition State Equation for Rock Slope Geotechnical Assets

$$Condition\ State = Roundup\left(\frac{\left(100 - (Condition\ Index)\right)}{20}\right)$$

The relationships between RHRS category scores, TAM-compatible linear scores, Condition Index, and Condition State are summarized in Table 2.

Table 2: Summary of the relationships between RHRS category scores, linear category scores, Condition Index, and asset Condition State.

| RHRS Score | RHRS Exponent | Linear Score | Condition Index Component Range* | | Condition State |
|---|---|---|---|---|---|
| | | | High | Low | |
| **3** | 1 | 100 | 100 | 80 | 1, Good |
| **9** | 2 | 75 | 79.99 | 60 | 2, Fair |
| **27** | 3 | 50 | 59.99 | 40 | 3, Fair |
| **81** | 4 | 25 | 39.99 | 20 | 4, Poor |
| **100** | NA | 0 | 19.99 | 0 | 5, Poor |

* The site's condition index score is an average of the two translations from exponential scores to linear scores. For instance, an RHRS history score of 81 and RHRS ditch effectiveness score of 27 translates to 25 and 50, respectively. The site's Condition Index is then (25+50/2)=37.5, and a Condition State of 4, Poor.

### 2.5.2 Incorporation of Economic Costs via Risk Valuation

In addition to the three methods proposed by MDT and the Condition Index/Condition State approach, sample calculations that captured mobility and safety risk costs using a conventional TAM approach was applied to these test sites. For this test application, MDT's RHRS categories were subdivided into those used to describe event likelihood (site hazard components) from those used to describe the effects these events have on roadway function and traveler safety (site risk components). This test approach developed presents both annual economic loss and the projected total economic loss over the 30-year lifespan of typical improvement work (rockfall mitigation). The annual discount rate (e.g. monetary cost of borrowing or deferring projects) is currently set as a "typical value" but an MDT-specific annual discount rate can be incorporated as MDT develops their TAM plan. It is important to note that in these equations, mitigation work does not eliminate all potential service disruptions, rather it reduces their likelihood.

The cost constants used in these equations were obtained from the AASHTO Red Book[1]. The detour length was calculated using Google Maps. When assessing detour length, a judgement is made of the median additional travel length for the route at least half the affected vehicles would take. For example, in examining an event on I-90 between Taft and Lookout Pass most travelers are likely through-going from Coeur d'Alene, ID to St Regis, MT. Therefore, the detour length used in the economic cost calculations was the extra travel distance required between Coeur d'Alene and St Regis, instead of the greater extra travel distance required to go from Taft to Wallace.

Since relating an RHRS score to event likelihood or accident rates has not been done before, professional judgement was used in developing a hypothetical likelihood parameter which would result in one event per year and the safety consequence parameter which would result in one crash per rockfall event if all scores were maxed out to 100 points. In this hypothetical example, the maximum possible likelihood-related score for an RHRS site is 600. The maximum possible safety-related score for a site is 300. Using a likelihood parameter equal to the maximum possible score generated rockfall return intervals that were judged to be too high. If the likelihood parameter was set at six times the maximum possible score, or 3600, then the minimum possible return interval for a service disruption became 6 years. Applying this likelihood parameter to the 2004 rating sites that have since been mitigated, the highest calculated likelihood of service disruption was 13%, which equates to a recurrence interval of approximately 7.7 years. Only at one site where service disruptions were quite high (Flint Creek), did we use a higher recurrence interval. For most sites, the calculated recurrence interval for a road closing event was between 10 and 20 years. This appears to be a conservative but reasonable value for demonstration purposes

A current weakness of the risk calculation method is that all hazard category scores are summed together to generate the recurrence interval. For example, the risk parameter score contains geologic character information scores, such as joint orientation or differential erosion characteristics, which are altered by only a few mitigation measures (such as shotcrete), and will not be changed by most mitigation activities. Therefore, the calculated annual probability of service disruption following mitigation activities may be overestimated under the current risk valuation. These parameters can be adjusted as more information on road closing events are obtained from MDT where parameters based on actual road closing events, durations, and slope conditions.

[1] User and Non-User Benefit Analysis for Highways, AASHTO, 2010.

# 3 Inventoried Slopes

Landslide Technology and MDT personnel visited the slopes described in this section were visited in November 2015. Section 2 described the criteria applied to site RHRS ratings and summarized and tabulated in each District's section, starting with District 1 – Missoula, below.

## 3.1 D1 – Missoula

Thirteen mitigated rock slopes were visited within the Missoula District, as shown on the map in Figure 2. Table 3 contains the RHRS rerates, test-rating approaches, and sample user cost risk calculations for the evaluated sites within the Missoula District.

The slopes include four sites on Interstate 90 (MP 6.5, 22.5, 24.0, and 24.5) that have been mitigated in response to three road-closing events where significant quantities of rock debris entered the roadway. These four events have all occurred since 2012. These events forced MDT into an emergency response with consequences to public safety, mobility, and public perception. The response necessitated the closure of the westbound lanes and the diversion of all traffic onto eastbound lanes for a number of months. A similar reactionary response was needed when a rock block larger than 10 feet in size failed on a planar feature near Lolo Pass, west of Missoula (C000093E, MP 18.11). This event affected traffic for over one week and required a specialty contractor to break-up and remove the rock.

Three slopes at two locales (Libby Creek South, C000001E, MP 47.37 and Clearwater Junction North C000083N, MP 4.18 and 4.63) were reconstructed as part of highway improvement projects. Previously, these cuts either were small "B" rated slopes or were not constructed when the 2004 rating reconnaissance was performed. In all three cases, the new slopes were constructed to better condition (ditch effectiveness and activity) that had been present prior.

Two of the slopes had been mitigated primarily to reduce rockfall activity and prevent rock from entering the roadway, the Libby Wedge and Flint Creek (C000001E, MP 47.37 and C000019, MP 27.99, respectively). Mitigation measures included scaling, blast scaling, rock bolting and long dowels, shotcrete, barrier fences, and early generation attenuator fences. Maintenance personnel have reported significant decreases in rockfall activity at both sites, though some deterioration of mitigation measures has occurred and will eventually result in increased rockfall activity.

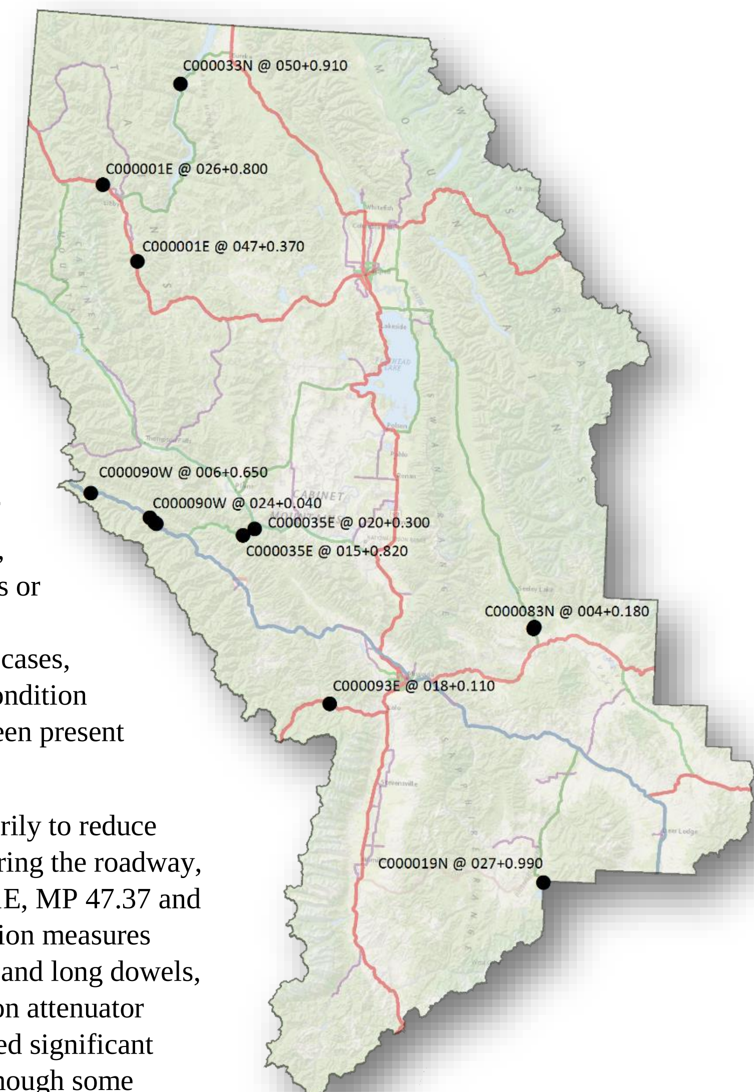


Figure 2: Sites Visited in D1 - Missoula

The two sites located between St. Regis and MT200 (C000035E at MP 15.82 and 20.30) are included as examples of slopes that may have worsened in the years following rating, one of which may be included as part of an annual monitoring survey.

The last remaining slope, between Libby and Eureka adjacent to Lake Koocanusa (C000033N, MP 50.91) had one problematic area that eventually toppled out of the slope. Like the Lolo Pass failure, the rockfall activity slightly reduced the likelihood of rockfall and was reflected in the evaluations.

Table 3: Missoula District Re-rates and Test Approach Results.

| Feature, Highway, Corridor & Mile Post | RHRS and % change | MDT #1 and % change | MDT #2 and % change | #3 Slope rating & % change | #3 Vehicle Risk and % change | #3 Impact and % change | Mob. & safety risk cost of 30 yr loss* | Condition Index & % change** |
|---|---|---|---|---|---|---|---|---|
| Hwy 37 C000033N 50.91-51.15 | 368 / 387 +5% | 108 / 106 -2% | 237 / 239 +1% | 105 / 104 -2% | 87 / 91 -5% | 3 / 2 +19% | $35 / 31 -11% | 63 / 75 +19% |
| Libby Wedge Hwy 2, C000001E 26.90-27.02 | 499 / 354 -29% | 196 / 115 -41% | 302 / 169 -44% | 171 / 92 -46% | 19 / 19 0% | 25 / 22 -10% | $734 / 367; -50% | 43 / 75 +74% |
| Libby Ck. S. Hwy 2, C000001E 47.37-47.60 | -- / 296 NA | -- / 85 NA | -- / 169 NA | -- / 76 NA | -- / 97 NA | -- / 9 NA | -- / $20 NA | -- / 75 NA |
| Hwy 135 C000035E 20.3 | 423 / 338 -20% | 139 / 61 -56% | 244 / 145 -41% | 127 / 51 -60% | 29 / 102 250% | 12 / 10 -20% | $91 / 20 -79% | 53 / 88 +66% |
| I-90 C000090W 6.5 | -- / 361 NA | -- / 108 NA | -- / 142 NA | -- / 52 NA | -- / 19 NA | -- / 56 NA | -- / 17,047 NA | -- / 88 NA |
| I-90 C000090W 22.36-22.45 | 379 / 310 -18% | 151 / 94 -38% | 212 / 155 -27% | 92 / 35 -62% | 75 / 86 +15% | 59 / 59 0% | $16,090 / 11,745 -27% | 50 / 92 +84% |
| I-90 C000090W 24.04-24.19 | 551 / 432 -22% | 176 / 127 -27% | 314 / 210 -33% | 117 / 72 -38% | 107 / 88 -18% | 59 / 56 -5% | $24,214 / 15,341 -27% | 53 / 78 +47% |
| I-90 C000090W 24.59-24.72 | 564 / 406 -28% | 217 / 113 -48% | 342 / 201 -41% | 158 / 57 -64% | 89 / 107 +20% | 59 / 56 -5% | $24,215 / 13,864 -43% | 43 / 80 +86% |
| Clearwater Jct. Hwy 83 C000083N 4.18-4.22 | -- / 190 NA | -- / 46 NA | -- / 116 NA | -- / 26 NA | -- / 116 NA | -- / 20 NA | -- / $47 -- | -- / 92 NA |
| Clearwater Jct. Hwy 83 C000083 4.66-4.72 | 118 / 111 -6% | 59 / 44 -25% | 89 / 68 -23% | 42 / 25 -41% | 44 / 21 -53% | 17 / 20 +14% | $37 / 55 +48% | 63 / 100 +59% |
| Lolo Pass Hwy 12 C000093E 18.11-18.20 | 564 / 429 -24% | 124 / 92 -26% | 282 / 230 -18% | 112 / 85 -24% | 127 / 127 0% | 12 / 7 -42% | $155 / 66 -58% | 69 / 63 -9% |
| Flint Ck. Hwy 1 C000019N 27.99-28.44 | 683 / 539 -21% | 269 / 126 -53% | 427 / 285 -33% | 261 / 121 -54% | 132 / 132 0% | 8 / 5 -33% | $1,670 / 230 -86% | 16 / 63 +294% |

* in thousands.

** Note that positive percent increases denote an improvement for Condition assessments.

## 3.2 D2 – Butte

The Butte District had seven slopes evaluated, four on the Interstate system, and three on Highway 191 (C000050N), as shown on Figure 3. Table 4 contains a summary of the re-ratings and improvements observed (when available) for the Butte District.

Two sites were recently reconstructed at mileposts 146.05 and 146.32 on Interstate 15 North. The mitigation work was part of general highway improvement projects where scaling and ditch improvements were part of the mitigation measures utilized.

Mitigation measures focused on stopping falling rock originating from more resistant rimrock on a mid-slope ditch at MP 350.69 on Interstate 90E. Maintenance personnel have reported significant decreases in the amount of rockfall that reaches the roadway; however, recent increases in rockfall activity above the mid-slope ditch will eventually require this ditch to be cleaned, which will likely require a significant effort.

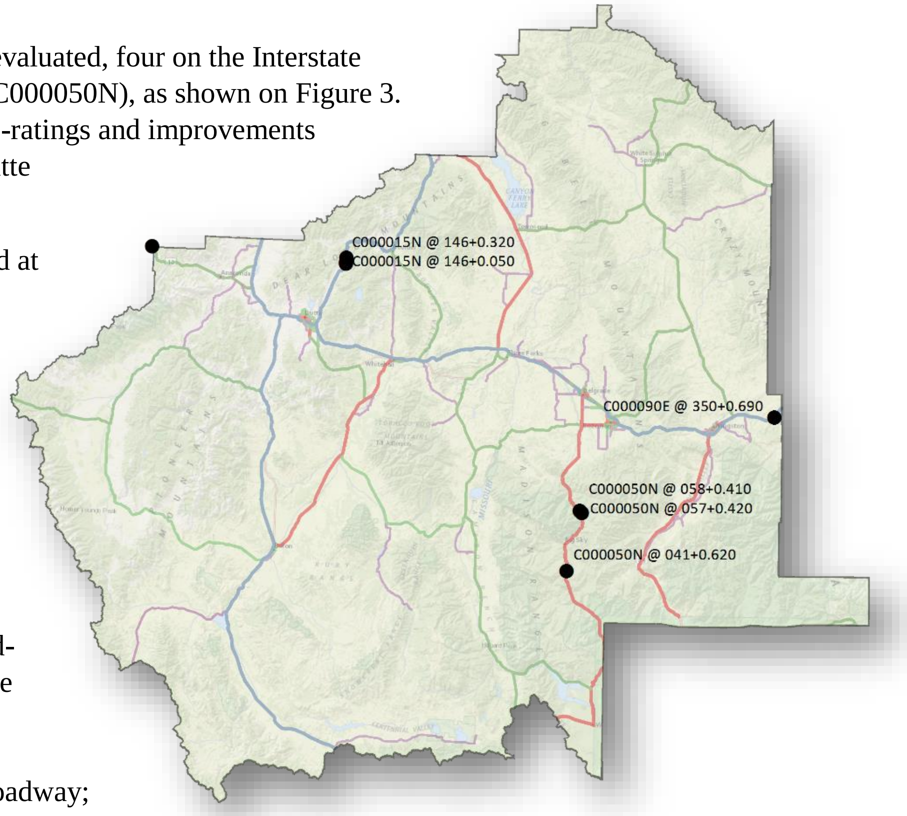


Figure 3: Sites Visited in D2 - Butte

On the three Highway 191 slopes, recent reconstruction efforts have enlarged the ditches and constructed cut faces with controlled blasting (presplit) techniques.

Table 4: Butte District Re-rates and Test Approach Results.

| Feature, Highway, Corridor & Mile Post | RHRS and % change | MDT #1 and % change | MDT #2 and % change | #3 Slope rating & % change | #3 Vehicle Risk and % change | #3 Impact and % change | Mob. & safety risk cost of 30 yr loss* | Condition Index & % change** |
|---|---|---|---|---|---|---|---|---|
| Red Cliff US 191 C000050N MP 41.62 | 269 / 195 -28% | 84 / 42 -50% | 144 / 71 -51% | 59 / 28 -52% | 43 / 14 -67% | 25 / 14 -45% | $64 / 18 -71% | 68 / 88 +29% |
| Swan Creek US 191 C000050N MP 57.42-57.47 | 320 / 137 -57% | 132 / 68 -49% | 199 / 112 -44% | 96 / 29 -70% | 76 / 42 -45% | 37 / 39 +7% | $278 / 113 -59% | 50 / 92 +84% |
| Greek Creek US 191 C000050N MP 58.41-58.45 | 425 / 224 -47% | 208 / 62 -70% | 271 / 108 -60% | 171 / 22 -87% | 58 / 50 -14% | 37 / 39 +7% | $689 / 250 -64% | 30 / 100 +233% |

| Feature, Highway, Corridor & Mile Post | RHRS and % change | MDT #1 and % change | MDT #2 and % change | #3 Slope rating & % change | #3 Vehicle Risk and % change | #3 Impact and % change | Mob. & safety risk cost of 30 yr loss* | Condition Index & % change** |
|---|---|---|---|---|---|---|---|---|
| E. Springdale I-90 C00090W MP 350.69-350.89 | 365 / 214 -41% | 153 / 91 -41% | 193 / 122 -37% | 76 / 26 -65% | 19 / 37 +93% | 77 / 65 -16% | $32,422 / 18,206 -44% | 56 / 92 +64% |
| I-15 C000015N MP 146.1-146.3 | 308 / 193 -37% | 101 / 51 -50% | 186 / 83 -55% | 74 / 27 -64% | 22 / 19 -13% | 27 / 24 -14% | $6,973 / 3,627 -48% | 71 / 92 +30% |
| I-15 C000015N MP 146.5 | 270 / 270 0% | 79 / 53 -34% | 130 / 706 443% | 52 / 29 -44% | 49 / 105 +114% | 27 / 24 -14% | $5,286 / 3,470 -34% | 66 / 88 +33% |
| I-15 C000015N MP 147.5 | -- / 208 NA | -- / 54 NA | -- / 675 NA | -- / 30 NA | -- / 44 NA | -- / 24 NA | -- / $3,433 -- | -- / 88 NA |

* in thousands.

** Note that positive percent increases denote an improvement for Condition assessments.

## 3.3 D3 – Great Falls

The Great Falls District provided three sites that had been partially or fully mitigated in the previous 10 years, two on Interstate 15 North and one near Havre on Highway 2 (Figure 4). A summary of rating changes is contained in Table 5.

Rockfall activity has forced partial mitigation at two sites on I-15. Limited controlled blasting was utilized as the primary mitigation method at both locations. Both sites will receive further mitigation

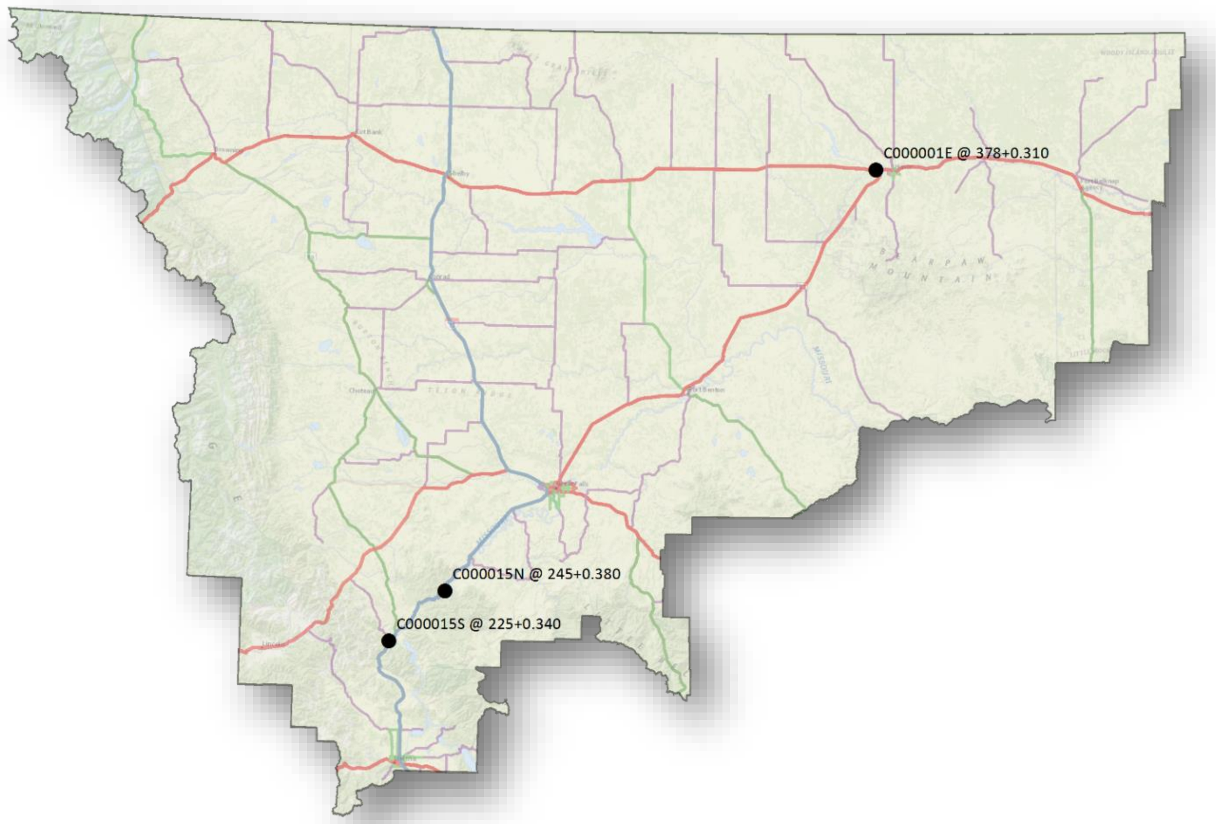


Figure 4: Sites Visited in D3 - Great Falls.

measures as part of the ongoing D3 rockfall mitigation project during the 2016 construction season. At Highway 2, MP 378.31, unstable rock blocks near the top of a tall butte adjacent to the roadway were also mitigated using controlled blasting techniques. The Highway 2 site is fully mitigated.

Table 5: Great Falls District Re-rates and Test Approach Results.

| Feature, Highway, Corridor & Mile Post | RHRS and % change | MDT #1 and % change | MDT #2 and % change | #3 Slope rating & % change | #3 Vehicle Risk and % change | #3 Impact and % change | Mob. & safety risk cost of 30 yr loss* | Condition Index & % change** |
|---|---|---|---|---|---|---|---|---|
| I-15 C000015N MP 225.4 SB | 466 / 422 -9% | 149 / 130 -13% | 274 / 254 -7% | 120 / 94 -22% | 65 / 118 +81% | 29 / 36 +23% | $7,884 / 7,277 -8% | 60 / 54 -10% |
| I-15 C000015N MP 245.5 NB | 453 / 386 -15% | 165 / 134 -19% | 255 / 238 -6% | 128 / 99 -23% | 83 / 83 0% | 36 / 35 -4% | $5,726 / 4,628 -19% | 44 / 50 +14% |
| US 2 C000001E MP 378.31 | 394 / 175 -56% | 157 / 58 -63% | 243 / 75 -69% | 137 / 27 -80% | 30 / 10 -66% | 20 / 31 +60% | $111 / 77 -30% | 43 / 88 +105% |

* in thousands

** Note that positive percent increases denote an improvement for Condition assessments.

## 3.4 D4 – Glendive

The Glendive District is the least mountainous district and provided two mitigated rockfall sites, both on Highway 12 west of Forsyth (Figure 5). The sites have been mitigated using blasting and excavation to remove problematic blocks and lay back the slope to a flatter angle, lessening the effects of differential erosion. Table 6 contains the summary of rating changes for these two slopes.

Table 6: Glendive District Re-rates and Test Approach Results.

| Feature, Highway, Corridor & Mile Post | RHRS and % change | MDT #1 and % change | MDT #2 and % change | #3 Slope rating & % change | #3 Vehicle Risk and % change | #3 Impact and % change | Mob. & safety risk cost of 30 yr loss* | Condition Index & % change** |
|---|---|---|---|---|---|---|---|---|
| US 12 C000012E MP 259.07-259.12 | -- / 80<br>NA | -- / 13<br>NA | -- / 41<br>NA | -- / 11<br>NA | -- / 51<br>NA | -- / 2<br>NA | -- / $2<br>-- | -- / 100<br>NA |
| US 12 C000012E MP 265.62-265.71 | -- / 149<br>NA | -- / 13<br>NA | -- / 28<br>NA | -- / 11<br>NA | -- / 24<br>NA | -- / 2<br>NA | -- / $8<br>-- | -- / 100<br>NA |

* in thousands

** Note that positive percent increases denote an improvement for Condition assessments.


Figure 5: Sites Visited in D4 - Glendive

## 3.5 D5 – Billings

We visited five rock slope locations in the Billings District. Four on Highway 72, south of Belfry and one on Highway 12, west of Roundup. Figure 6 is a map of the District and Table 7 is a summary of the rating changes.

Reconstruction during highway improvement projects constituted the improvements at all four of the locations. Roadside concrete barriers are installed at one of the five sites (Hwy 72, MP 7.98 - 8.34). The remaining sites were reconstructed with no additional mitigation measures installed besides the roadside ditch.

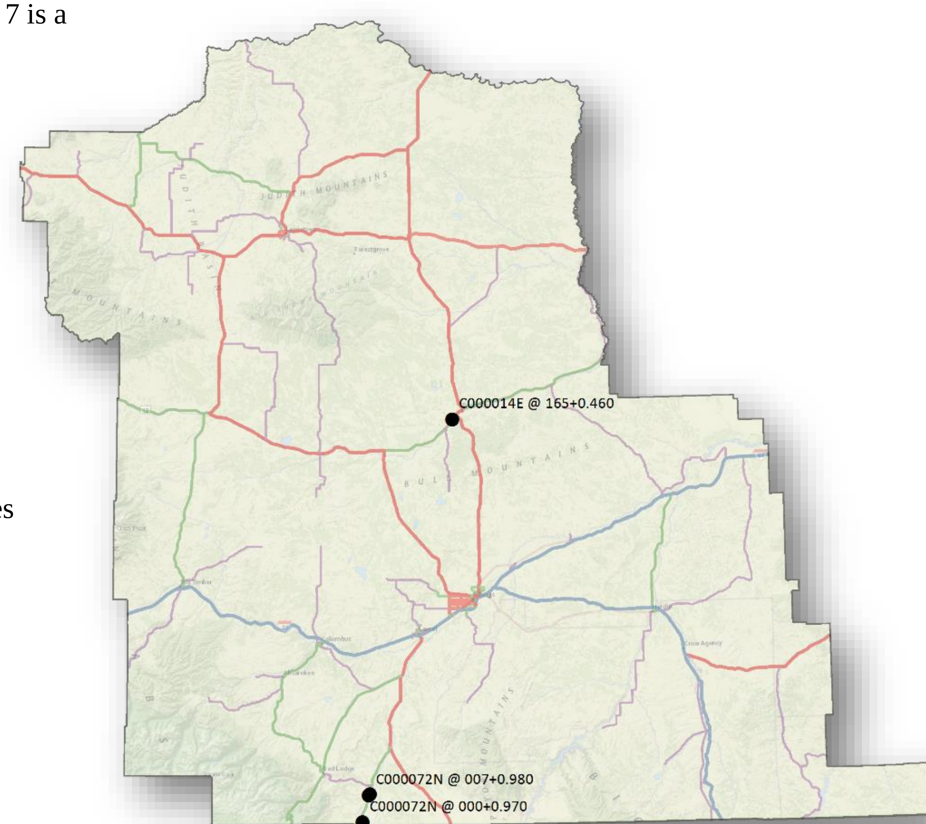


Figure 6: Sites Visited in D5 - Billings District.

Table 7: Billings District Re-rates and Test Approach Results.

| Feature, Highway, Corridor & Mile Post | RHRS and % change | MDT #1 and % change | MDT #2 and % change | #3 Slope rating & % change | #3 Vehicle Risk and % change | #3 Impact and % change | Mob. & safety risk cost of 30 yr loss* | Condition Index & % change** |
|---|---|---|---|---|---|---|---|---|
| MT 72 C000072N MP 0.97-1.07 | 271 / 150 -45% | 88 / 37 -59% | 122 / 55 -55% | 76 / 23 -69% | 25 / 10 -59% | 12 / 13 +7% | $14 / 9 -36% | 61 / 100 +64% |
| MT 72 C000072N MP 1.08-1.17 | 387 / 167 -57% | 134 / 34 -74% | 221 / 52 -76% | 122 / 21 -83% | 24 / 12 -51% | 12 / 13 +7% | $29 / 9 -70% | 58 / 100 +72% |
| MT 72 C000072N MP 7.98-8.34 | 347 / 359 +3% | 140 / 95 -32% | 197 / 198 +1% | 128 / 81 -37% | 36 / 40 +11% | 12 / 15 +18% | $18 / 22 +20% | 39 / 84 +115% |
| MT 72 C000072N MP 8.36-8.44 | 288 / 159 -45% | 112 / 47 -58% | 199 / 100 -50% | 99 / 32 -68% | 100 / 91 -9% | 12 / 15 +58% | $14 / 5 -61% | 47 / 81 +72% |
| Roundup US 12 C000014E MP 165.46-165.52 | 615 / 382 -38% | 226 / 63 -72% | 376 / 169 -55% | 222 / 57 -74% | 113 / 141 +25% | 4 / 6 +58% | $68 / 35 -48% | 29 / 88 +203% |

* in thousands

** Note that positive percent increases denote an improvement for Condition assessments.

# 4 Rating Evaluation

The eventual rating criteria selected by MDT should be able to clearly demonstrate the improvements that mitigation efforts provide for a rock slope as well as communicate general rockfall hazard. This is an important aspect for a TAM-compatible assessment system so that condition deterioration, life cycle costs, maintenance deferment costs, and other risks due to maintenance or mitigation deferment are calculable. These quantifiable improvements will also factor into future TAM Plan performance measures and help support future project selection and decision making. In general, the greater the improvements demonstrated by percentage change and assuming the mitigation measures were effective, the better the approach.

One aspect to keep in mind while examining the criteria is the ability to achieve Performance Measures developed during Task 3 (Task 3a in the original proposal document). The measures should be compatible with the Good/Fair/Poor (G/F/P) condition criteria similar to those FHWA are requiring for bridges and pavements[2]. These were developed for the AKDOT&PF GAM system and used the Condition Index and States approach to correlate FHWA G/F/P criteria (Table 1). It is important to note that all these various approaches draw from the same field evaluations (with some additional office evaluations for detour distance, incorporation of cost estimations[3], economic analyses) and all can be utilized in various ways as decision support tools, rather than using one and discarding the others. One possible way to calculate these would be to generate a rating sheet that automatically calculates these based on a routine RHRS rating with the addition of detour and likelihood scenarios.

The tables in Section 3 display the various rating criteria changes for each of the sites visited. Nearly all slopes exhibited improvements between 2004 and 2015 and only a few exhibited a 'worsening' condition depending on the calculation approaches. These were typically due to factors such as new, taller cut slopes or new rock cuts that originally was a "B" slope that had not previously received a detailed rating. Slopes that did not have any previous detailed rating information were not included in the summaries below.

## 4.1 Total RHRS Score

This approach compared the previous standard total RHRS score to the revised score based on the new site conditions. A lower RHRS score indicates an improvement. Typically, the improved site conditions were a result of reduced rockfall activity and enhanced ditch effectiveness. Geologic conditions occasionally improved with the removal/failure of unstable rock blocks. Sites reconstructed with a taller overall slope often resulted in a higher overall RHRS score, even though site conditions or other rating factors may have improved. The average score decrease was 28% with a standard deviation of 19%, with a concentration of reductions between 30% and 20% (Figure 7). Two site scores increased by 3 and 5%, respectively.

Overall, using an unmodified RHRS score comparison appears to underrepresent the actual improvements to the site when accounting for all the other RHRS factors that do not typically change as a result of mitigation activities.

[2] Notice of Proposed Rule Making (NPRM), 23 CFR Part 490, January 5, 2015; https://www.gpo.gov/fdsys/pkg/FR-2015-01-05/pdf/2014-30085.pdf

[3] Beckstrand, D., Mines, A., Thompson, P. (2016) Development of Mitigation Cost Estimates for Unstable Soil and Rock Slopes Based on Slope Condition; Transportation Research Board

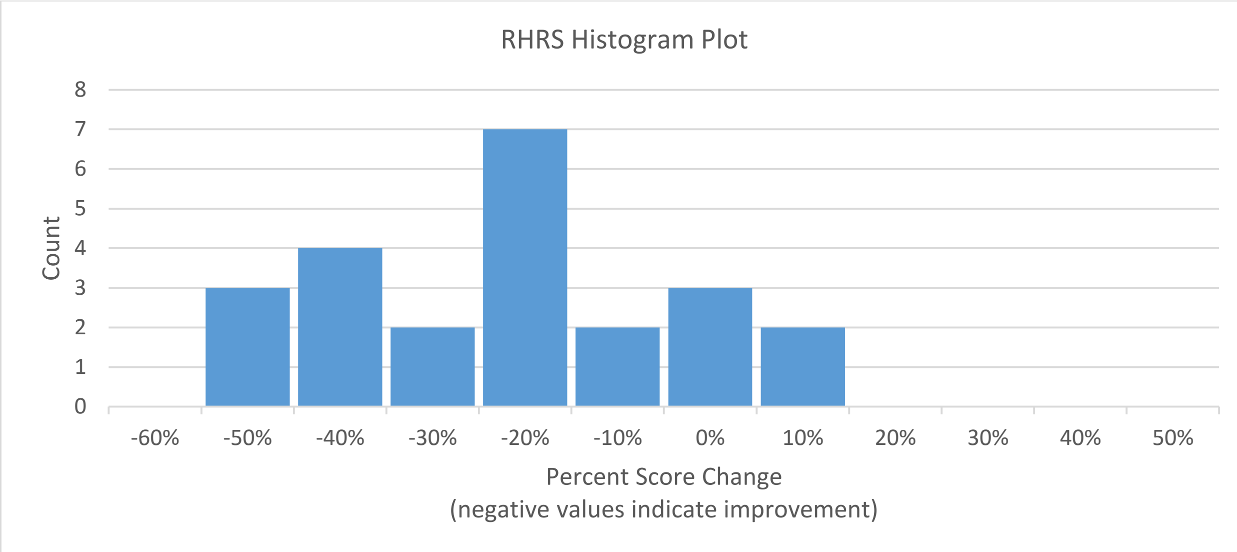


Figure 7: Histogram plot of RHRS percent change between 2004 and 2015 ratings.

## 4.2 MDT Rating Method 1

This method assessed a site's ditch catchment effectiveness, potential traffic impacts, rockfall history, and failure potential (as function of geologic character and block size or volume), as discussed in Section 2.2. This method exhibited a greater change as result of mitigation activities, with improved conditions measureable by a decrease up to 74%. Like with the RHRS scoring, this approach uses standard RHRS exponential rating criteria with higher scores indicating a worse condition where the greatest percentage decrease possible is 100%.

This method resulted in an average score decrease of 43% with a standard deviation of 19% and a range between -2 and -74% (Figure 8). The greater average decrease than that observed from the standard RHRS score approach better captures improvements realized through mitigation activities than the standard RHRS score method permits.

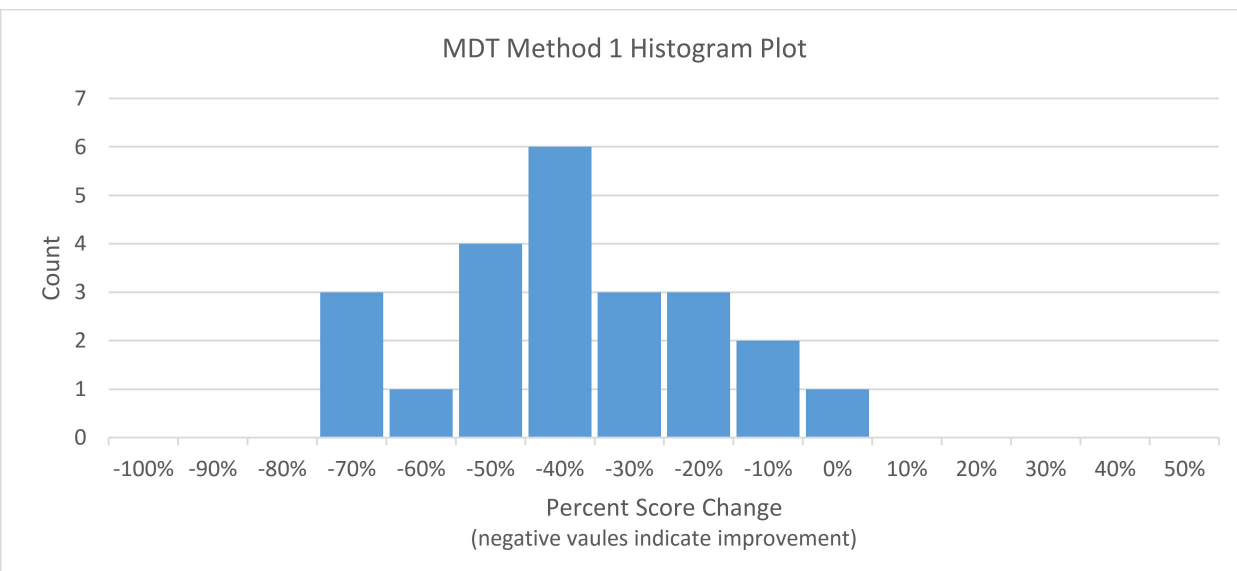


Figure 8: Histogram plot of MDT Method #1 percent change between 2004 and 2015 ratings.

## 4.3 MDT Rating Method 2

The second rating method provided by MDT assessed a rock slope's ditch effectiveness, potential traffic impacts, immediate hazard, failure potential, scale of the potential threat, and rockfall history, as discussed in Section 2.3.

Applying this method to the Task 2 sites resulted in a lower average percent improvement (36%) and larger standard deviation (22%). This approach also resulted in two apparent worsening scores of 1% where small evaluation changes resulted slightly different scores; these very small changes are not considered significant. See Figure 9 for the histogram plot. The ability to quantify improvement are not as well represented in this approach as in Method 1, but better than the RHRS score-only approach.

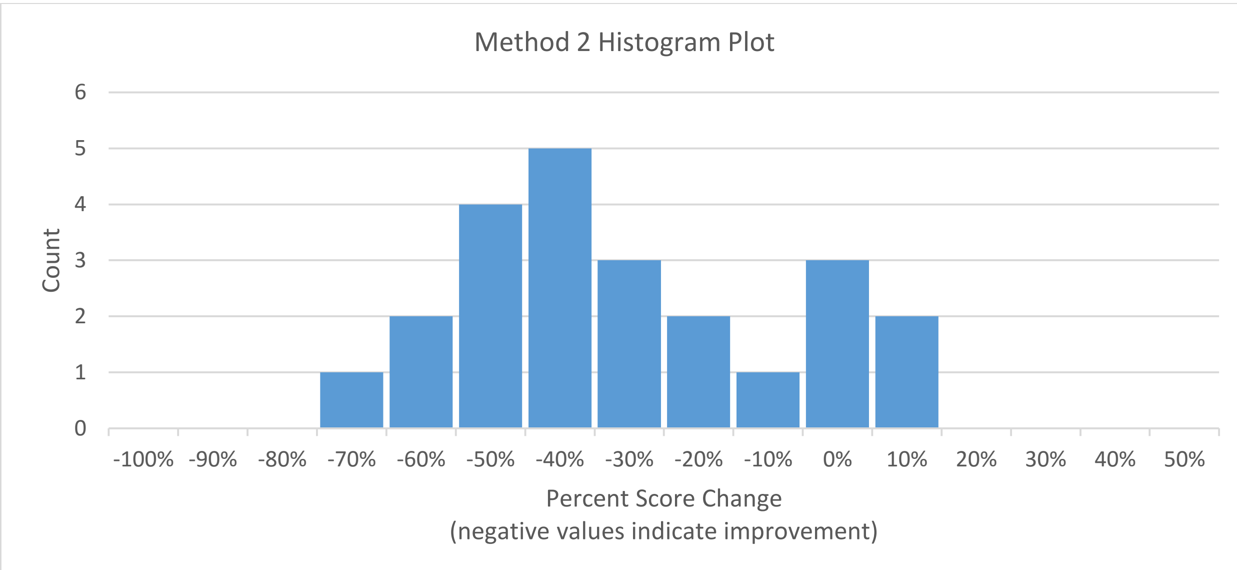


Figure 9: Histogram plot of MDT Method #2 percent change between 2004 and 2015 ratings.

## 4.4 MDT Rating Method 3

Unlike Rating Methods 1 and 2, Rating Method 3 generates three distinct sub scores – Slope Rating, Vehicular Risk (or ability to avoid a rock in the road), and Impact to Traffic, as discussed in Section 2.4. The Slope Rating Score comprises Ditch Effectiveness, Potential for Failure, and Rockfall History. The ditch effectiveness and rockfall history scores are obtained directly from the RHRS rating categories, while the potential for failure is derived using the same equation applied in Method 1. The Vehicular Risk Score is the sum of the Sight Distance and Roadway width category scores. The final component of Method 3, the Impact Rating, currently consists of only an AADT-based score. See Figure 10 for a histogram of the three different criterial evaluated in this method.

The Slope Rating component of Method 3 exhibits the greatest percent improvement in slope condition due to the reduced number of incorporated factors, with an average percent decrease in score of 53% and a standard deviation of 22%. This approach exhibits the greatest improvement in slope rating of the three MDT methods. This approach is also closest to the TAM-compatible Condition Index and State approach summarized in the following section, which considers only the ditch effectiveness and rockfall activity. It also benefits from the fact that typical rockfall mitigation measures address these rating components more than others.

Change in the vehicular risk (or hazard avoidance) scores exhibited a wide spread due to some sites exhibiting changed site condition, typically resulting from a changed sight distance. Site changes that could impair site distance include the vegetation changes or installation of a concrete barrier that blocked previously open sight distance or a narrower roadway. Improvements may have been the result of improved sight distance due to vegetation removal or a repaved, wider roadway. Average change was +9% with a 69% standard deviation. This result was heavily influenced by the four outlier values where worsening sight distance changes coupled with the exponential scoring system resulted in scores that more than doubled from their previous values.

AADT changes averaged out to be minimal, but observed individual changes ranged from +60% to -45% where traffic pattern changes were more significant. The average change was +1%, with a standard deviation of 25%. This criteria is useful as a risk-exposure tool, particularly if combined with the vehicular risk criteria.

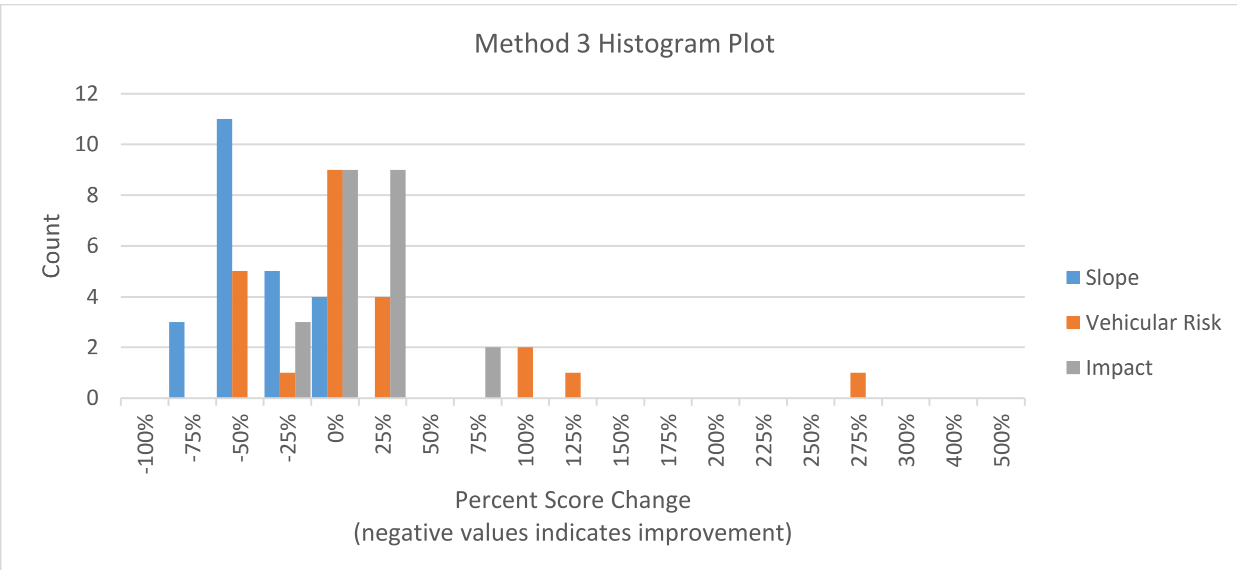


Figure 10: Histogram plot of the percent change of MDT Method 3 rating components between 2004 and 2015 ratings.

## 4.5 TAM Condition Indexes and Condition States

One of the features common to a TAM compatible system is linear evaluation criteria with a new or like-new (Good) condition indicated with a “100” and a failed (Poor) condition being “0”. Calculation of these values is directly from the RHRS categories Ditch Effectiveness and Rockfall History as discussed in Section 2.5. The Condition Index logged improvements up to a nearly 300% improvement, which simply means that a site may have possessed both a high rockfall activity with a very ineffective ditch that realized even partial improvements through mitigation. The average improvement was 80% with a 71% standard deviation (Figure 11). As an expression of Condition State (CS) (5 categories of the Condition Index, see Table 1 and Table 2), 4 of the 23 (17%) sites stayed within their previous CS, 35% improved 1 CS, and 47% improved 2 or 3 States and not always to a CS 1 (Figure 12). This is equivalent to a partial improvement to avoid greater costs if conditions deteriorated if left untreated (e.g. a chip seal for pavement preservation or a new paint coating on a steel bridge for renewed corrosion resistance).

The particular site that received such a high percentage increase was the Flint Creek site (MT 1 at MP 28, south of Philipsburg), where regular rockfalls were reaching and blocking the road from very high slopes and a ditch only a few feet wide in places. The mitigation measures (bolts, mesh, early generation attenuators) installed has significantly reduced rockfall activity from a regular occurrence (RHRS activity score of 95) to only an occasional occurrence (new score of 9). Ditch effectiveness improved only marginally, from an RHRS score of 81 (none) to 27 (limited) through effectively reducing falling rock velocities with the mesh and attenuators. The mitigation measures installed were effective in reducing rockfall activity reaching the road and brought the Condition Index up from a score of 16 (Poor) to 63 (Fair). In terms of Condition State, this site improved from a CS 5 to a CS 3.

While differing from the more familiar RHRS style scoring approaches of lower numbers indicating better conditions, the Condition Index and Condition State approach are currently being incorporated into TAM-compatible geotechnical asset management (GAM) systems with success. Initial deterioration rate approximations, programmatic cost estimations, performance measures, and condition targets have been formulated around these factors for other state DOTs. Modifications to these indices are possible and could include matching categories to one of the MDT rating criteria, particularly the slope rating approach of Method 3. Including the Condition Index and States into MDT's future Rockfall Hazard Assessment schema is recommended.

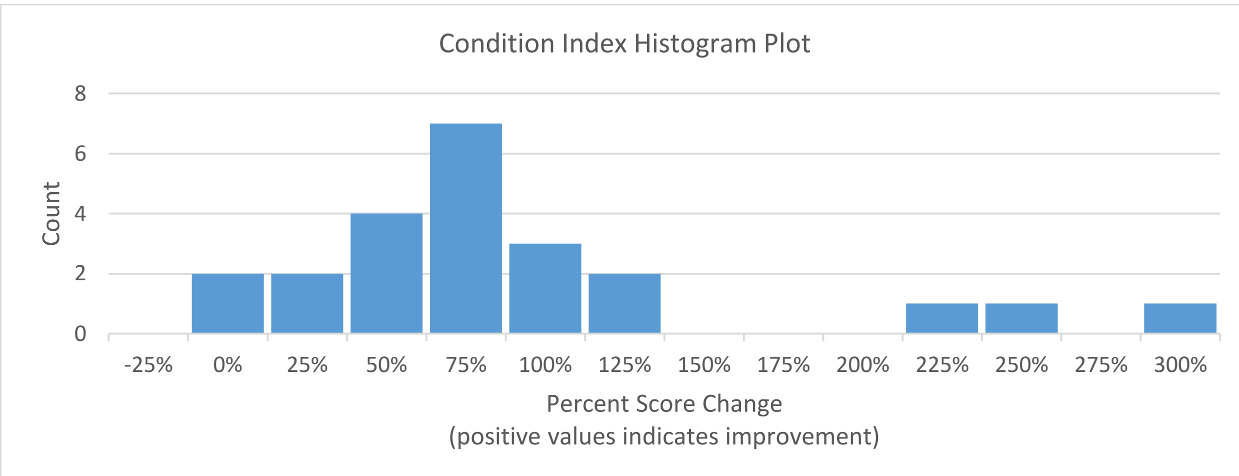


Figure 11: Histogram plot of Condition Index percent change between 2004 and 2015 ratings

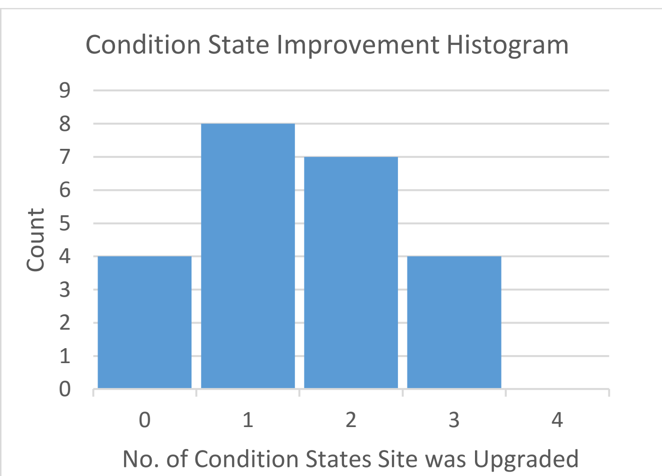


Figure 12: Histogram plot of condition state improvement between 2004 and 2015 ratings.

## 4.6 Economic Risk Factors

Following guidance from TAM systems, using factors from the AASHTO Red Book, and making initial assumptions on likelihood of adverse events, the economic savings to the public through improved mobility and safety can be factored into cost/benefit calculations. When the traffic volumes are high, such as on the Interstate Highway System and areas near cities and towns, the payoff for reducing rockfall likelihood is often significant.

Using these initial hypothetical calculations, the sample user costs incurred over the 30-year period were reduced $44 million or an average of 39% per site for the small sampling of sites visited in 2015. Note that these decreases are based on initial assumptions and can benefit from a more robust likelihood analyses from data being currently being collected by MDT on past road blocking events. Additional tools for collecting rockfall events and maintenance activities should eventually be built into the future MDT rockfall system to track costs and adverse effects on the transportation system.

For illustration purposes, the greatest user cost reduction was $14 million at I-90 MP 350.7 Springdale West project. The low bid for construction was $3.8 million, assuming a 25% cost factor for PS&E and Construction Engineering, the total project cost would be $4.8 million which results in a $2.91 user cost savings for every dollar spent on designing and constructing the project. Reductions such as these suggest that more robust risk analyses are warrented.

While this approach bolsters support for project selection on higher traffic corridors, it would initially appear that low traffic corridors, as are typical throughout Montana, would be left out of this matrix. However, the long detour effects, emergency access, national defense, truck traffic, and other factors will still permit prioritization with this approach. Additionally, MDT's eventual performance goals and targets (e.g. 95% of all rock slopes in Condition State 2 or higher) will still facilitate mitigation of Poor and Fair condition rock slopes on low volume routes.

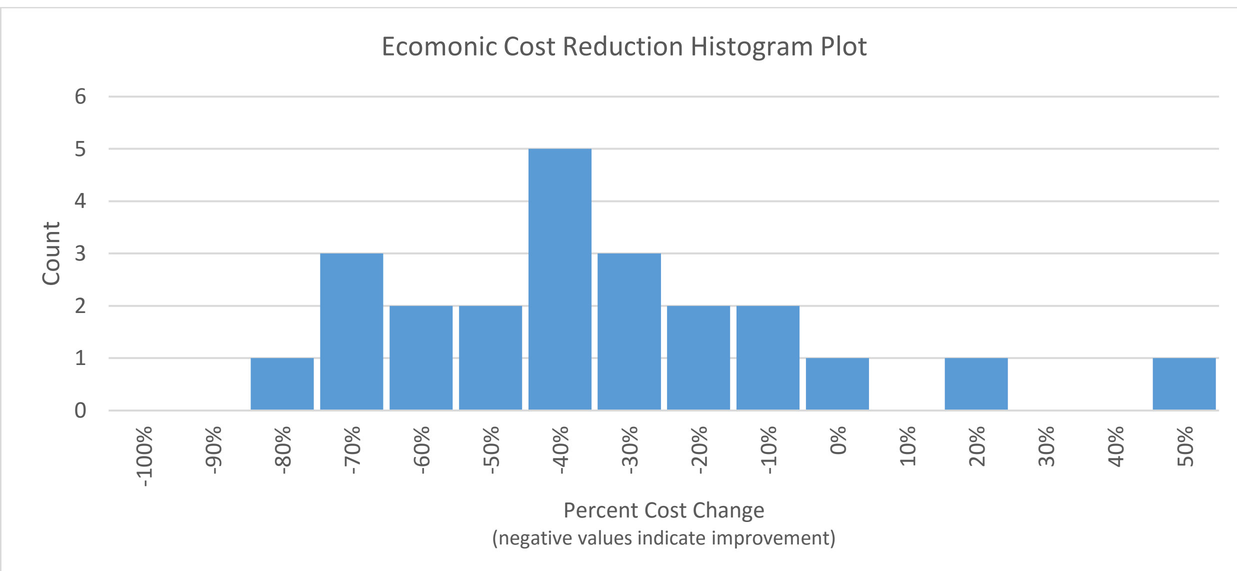


Figure 13: Histogram plot of economic cost reduction (as a percentage) between 2004 and 2015 ratings.

# 5 Task 2 Recommendations

The task consisted of applying the RHRS rating criteria to 29 mitigated, new, or ones that had otherwise significantly changed since 2004. The sites were interspersed through MDT's network and all five Districts. The new ratings were then compared to previous rating information and recombined using methods described in Section 2. Rating schemes were evaluated for their ability to facilitate future project selection and their ability to demonstrate their effectiveness of relating the value of mitigation activities. Recommendations related to each rating scheme is below.

**Total RHRS Score.** The total RHRS score is an established, internationally recognized method to indicate general slope condition and risk and should therefore continue to be calculated and reported. Mitigation measures influence RHRS scores for the positive, but cannot demonstrate as much improvement (measured as a percentage change) as the other category combinations. These criteria should continue to be utilized as a reporting measure and as part of a toolbox of project selection methods to be developed as part of a later task.

**MDT Rating Methods.** Of the three MDT provided rating schemes, the Slope Rating portion of the Method 3 produced the greatest spread in demonstrating improvements through mitigation activities and is very similar to the methods used in the TAM approach, just with an alteration in calculation approach. The vehicular risk and impact to traffic scores of Method 3 were sensitive to site changes through means other than mitigation activities, with AADT increases and decreases and sight distance changing these scores. Rating sub-scores (Impact Rating of Method 1 and 3) based solely on AADT can exhibit where risk changes due to traffic volume fluctuations. These three MDT Methods will be further evaluated in Task 3.

**TAM Condition Indexes and Condition States.** These evaluation criteria follow the formats common to bridge and pavement management systems and also have a significant degree of supporting research for follow-up performance measures, programmatic cost estimating, and deterioration rates that permit robust long-term planning and budgeting. The criteria, while using familiar RHRS categories, have served as the basis for nation's first geotechnically-focused asset management. In this research, research to generate programmatic cost estimates, which were derived from the 2004 MDT RHRS dataset for the AKDOT project[3], are used for determining the investment levels required to maintain or achieve performance targets common to TAM plans. This framework permits the modelling of various investment strategies to predict the future network-wide asset condition based on level of investment.

Consider a scenario where TAM-Plan Performance Targets are set to achieve and maintain that 85% of MDT's rock slopes are desired to be in a Good condition. Using Condition Indexes and States (both of which are derived from RHRS categories), methods are currently in place to develop mitigation programs and cost estimate models on a statewide basis. For instance, the current slope conditions (e.g. 70% of slopes are Good), deterioration estimates (2% of slopes degrade per year), and programmatic cost estimates ($7 per sq. foot for one Condition State improvement) are applied to the rock slope inventory. These factors assist in developing rock slope annual program budget estimates to improve, maintain, or limit losses associated with deferred mitigation, just as with pavements and bridges.

We recommend applying these calculations to the 2004 data as part of Task 3 and incorporating these calculations into MDT's future Rockfall Hazard Process.

**Economic Risk Factors.** These economic risk factors will assist in setting priorities and measuring the economic benefits of mitigation activities in addition to approximating MDT's and the public's risk exposure from unstable rock slopes. We recommend developing likelihood models based on MDT's known road closing events due to rockfall to more accurately estimate risk costs. This task can be performed either during the current work efforts or during a later phase. This additional task would correlate the known road closing events to slope condition prior to failure; incorporate detour lengths from either from new estimations or from known distances if already performed by MDT; then applying the factors