ROCKFALL HAZARD PROCESS ASSESSMENT

FHWA/MT-17-008/8239-001

Final Report

prepared for
THE STATE OF MONTANA
DEPARTMENT OF TRANSPORTATION

in cooperation with
THE U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

October 2017

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Prepared for:

Montana Department of Transportation
Helena, Montana

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FINAL PROJECT REPORT

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16. Abstract

After a decade of using the Rockfall Hazard Rating System (RHRS), the Montana Department of Transportation (MDT) sought a reassessment of their rockfall hazard evaluation process. Their prior system was a slightly modified version of the RHRS and was implemented in 2005. This reassessment included an update of their existing rockfall database, review of developments in slope management systems, and a set of implementation tools to help guide their decision making and project development process.

The new MDT Rock Slope Asset Management Program (RAMP) includes a number of new enhancements. RHRS score components have been recombined to create sub-scores to isolate specific evaluation attributes. The slope's Condition is calculated as a function of rockfall history and ditch effectiveness and scored using a 100 (good, like new condition) to 0 (poor or failed condition) linear score. Five new Condition State categories facilitate deterioration modeling and risk analysis. Evaluation of rockfall event records will allow estimation of rockfall event likelihoods based on slope dimensions and condition for use in risk calculations. Programmatic cost estimates to improve the slope, also based on slope dimension and condition, allow rapid network-wide estimation of improvement costs. Performance Measures and Decision Support Tools help guide the planning process. Tools that leverage MDT's cloud-based GIS services permit collection of rockfall events and maintenance activities across multiple computing platforms.

Fiscal analyses indicate that the 997 inventoried and assessed rock slope assets represent a value of approximately 4 billion dollars to build again today; a value worthy of notice. Unchecked slope deterioration limits an average slope's life span to approximately 104 years. A 'Good' condition slope has a 50% likelihood of deteriorating to 'Fair' in 36 years, with another 41 years to deteriorate further to a 'Poor' condition slope.

Getting slopes that have deteriorated back to a modern, state-of-the-practice, 'Good' condition would require approximately 700 million dollars. Including slope preservation efforts into a funding plan that maintains network conditions rather than relying solely on comprehensive reconstruction efforts can save MDT 19% for the same outcome, or $7 million dollars annually for a fully funded Rock Slope Asset Management Program.

17. Key Words
Slope stability, Erosion, Geological activities and processes, Slope failure, Performance measurement, Evaluation and assessment, Rock slopes, Rockfalls, Rating systems, RAMP, GAM, Risk assessment, Hazards, Deterioration by environmental action, Life cycle analysis, Ratings, Return on investment, Geotechnical asset management, RHRS

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Executive Summary

Thousands of rock slopes are adjacent to Montana's Highway System as part of their transportation network. Together, this network permits commerce and facilitates mobility and contributes to the Department fulfilling its mission to *"...serve the public by providing a transportation system and services that emphasize quality, safety, cost effectiveness, economic vitality, and sensitivity to the environment."* However, construction methods of the 1940's to 1970's often prioritized minimal excavation quantity and speed of construction, leaving states nationwide including Montana with legacies of marginally performing rock slopes. Many of the Department's older slopes were constructed during this period, and these slopes are more subject to rockfall. When rockfall occurs, road users have to quickly maneuver around rock in the road to avoid the sudden hazard.

The Montana Department of Transportation (MDT) began actively managing their rock slopes in 2005, with the completion of the Rockfall Hazard Classification and Mitigation System. At that time, MDT implemented the Rockfall Hazard Rating System (RHRS) for its rock slope assets (Pierson, et al., 2005). The RHRS was a valuable tool for the Department, and it used the rating information as an informal tool in decision making processes. However, a decade after implementing the RHRS program, MDT's geotechnical personnel sought to update the database, make the data more accessible to users, and integrate advancements in management and technology.

In particular, recently finalized federal rules have mandated that state Departments of Transportation develop risk-informed Transportation Asset Management (TAM) systems for their bridge and pavement assets. As agencies become increasingly aware of these new tools, there is growing interest in applying them to other DOT assets. Even though this is not required by federal law, it represents smart business practices that fulfill goals of cost effectiveness. Therefore, as part of this research project, the team worked to make the new Rock Slope Asset Management Program (RAMP) a TAM-compatible program, to the extent practicable.

This document is the deliverable for the final task for the research project "Rockfall Hazard Rating Process Assessment" (Project No. 15-3059V) and is a final synthesis and review of the work performed under the various tasks. As part of these tasks, the research team visited hundreds of rock slope sites, concentrating on the Interstate network and higher volume highways, testing various condition and risk assessment approaches. Researchers performed economic investigations that provided life-cycle cost analysis, estimated replacement costs, and investigated trade-offs.

The RAMP program incorporates all existing data from the previous RHRS program. The solid foundation of the RHRS (Pierson, 1990; Pierson & Van Vickle, 1993) has served DOTs and geotechnical professionals well over the preceding 30 years. The concepts are well entrenched in the minds of geotechnical personnel, but it did not extend outside this realm into other highway professions until the advent of asset management. The RAMP endeavors to bridge the gap between transportation disciplines by packaging rock slope data and decision-making models that are useable by a variety of executives, planners, maintenance, and engineering professionals.

To support management of these slopes that represent a significant department asset, a number of decision support tools, including performance measures and accompanying performance classes; design approaches focused on incremental risk reduction; condition metrics for personnel with a variety of expertise; and benefit / cost approaches to assist in corridor and project selection. Slope condition is expressed in a variety of methods, with 'Good', 'Fair", and 'Poor' descriptors with the most broad appeal, statewide distribution of which is exhibited in Figure ES-1. A key component of

the new system is the inclusion of risk whereas in the current approach accident and interruption likelihoods are zero until an event proves otherwise. A series of sites on I-90 west of St. Regis, Hwy 191 in the Gallatin Canyon, and Highway 2 east of West Glacier were evaluated as critical sites through use of the developed decision support tools, with many sites exhibiting favorable benefits relative to the mitigation costs.

The research team found that in order to maintain the current rock slope network condition, with a value of roughly $4 billion dollars to rebuild today, an investment of $35 million annual would be required. This value does not include any efforts for preserving the sites well before failure. With preservation before failure, the forecast cost to maintain network conditions would decrease to $28 million, an annual cost savings of $7 million to achieve the same network-wide outcomes. The research revealed that the return on investment for preservation activities is 114%; or for every dollar spent, an additional $1.14 is returned to the Department and its road users. Other brief statistics (Figure ES-2) offering valuable insight on this billion-dollar asset along with photo examples of slopes (Figure ES-3) gathered from the research are presented on the following pages.

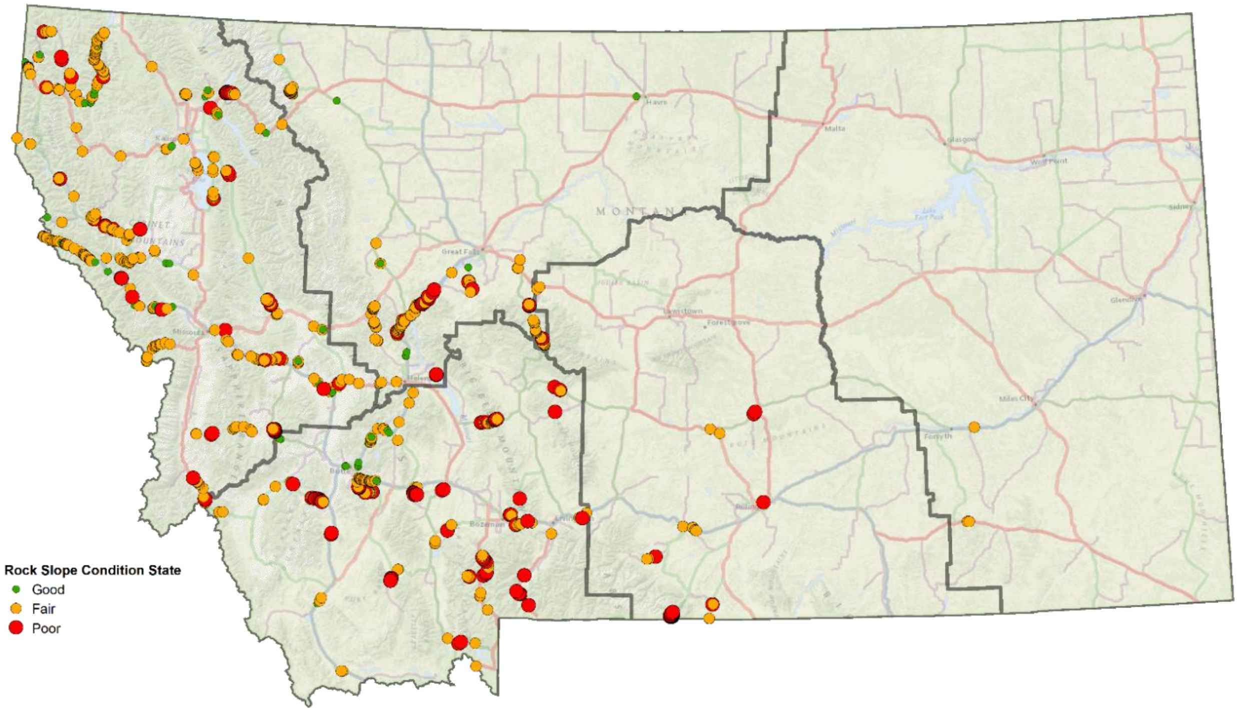


Figure ES-1: Statewide distribution of Good, Fair, and Poor condition rock slopes.

$4 Billion
Replacement value of assessed rock slope inventory

997
RAMP sites on the Interstate or are High Hazard

63 / 100
Average rock slope Condition

27
Number of significant rockfall events forecast to occur annually

$35 Million
Estimated value lost to slope deterioration annually.

36 years
Time for a 'Good' slope to deteriorate to 'Fair' without preservation

$3.5 Million
Estimated annual risk cost, including mobility and safety consequences for MDT and road users

$7 Million
Annual savings realized by preservation

114%
Return on preservation Investment

6.2 Million
(13%)
Rock slope area (sf) in 'Good' Condition

31.4 Million
(63%)
Rock slope area (sf) in 'Fair' Condition

12.1 Million
(24%)
Rock slope area (sf) in 'Poor' Condition

Figure ES-2: Statistics from the RAMP Program.

‘Good’ Condition Slopes exhibiting stability and an effective ditch.

‘Fair’ Condition Slopes with smaller, less effective ditches and with more rockfall activity.

‘Poor’ Condition Slopes exhibiting high levels of activity and ineffective ditches.

Figure ES-3: Photo Exhibits of ‘Good’, ‘Fair’, and ‘Poor’ rock slopes.

1 Introduction

The Montana Department of Transportation (MDT) completed implementation of a Rockfall Hazard Rating System (RHRS) in 2005. This program compiled data on Montana's rock slopes and their relative hazards, expressed as an RHRS score. Higher scores indicated a higher relative risk and/or hazard. MDT found the RHRS to be a valuable tool when performing comparisons between sites, and applied the ratings in an informal process. In the decade since the RHRS was implemented, MDT has compared RHRS ratings to event occurrences, maintenance needs, and rockfall mitigation project selection.

The goal of the new research project was to assess changes in MDT's rock slope assets since 2005, gather additional data, and develop new hazard and risk assessment tools that would allow MDT to develop an updated management program. This includes determining critical sites, incorporating benefit/cost analysis, and forecasting future asset condition based on various budget scenarios.

Since this initial implementation, significant changes have occurred in the means by which transportation agencies manage their assets. In particular, the Moving Ahead for Progress in the 21st Century (MAP-21) legislation, along with recently finalized federal rules (25 CFR Parts 515 and 667, 2016), require that states apply Transportation Asset Management (TAM) principles to their bridge and pavement assets. At this time, inclusion of geotechnical assets, such as rock slopes, in state TAM plans is not mandatory but application of TAM principles to other ancillary assets is encouraged. To facilitate this while not overly burdening forward-thinking DOTs, the regulations promulgated under MAP-21 and the Fixing America's Surface Transportation Act (FAST Act) provide for reduced TAM Plan requirements for assets other than NHS pavements and bridges "at whatever level of effort is consistent with the State DOT's needs and resources." (25 CFR Parts 515 and 667, 2016; Stanley & Anderson, 2017).

MDT has long recognized the benefits of TAM and decided that evaluating possible incorporation of TAM principles into rock slope management would be smart administration. The Department wanted to add value to the existing program by reassessing select slopes, incorporating current asset management methods to develop new rating approaches and decision support tools. This desire to reassess its approach to managing rock slopes and evaluating the incorporation of TAM principles into an updated rockfall hazard identification and risk assessment database led the Department to develop a new program. Work began on what would become the Rock Slope Asset Management Program (RAMP) in 2015.

An overview of the TAM process as applied in the RAMP program is shown in Figure 1-1. Specific aspects developed in the previous seven tasks over the last two years fit under the broader umbrella and are discussed in the following sections. The remainder of the report discusses how the RAMP program can be utilized to better align rock slope performance with MDT's goals.

1.1 Project Scope

Researchers implemented a phased approach consisting of eight tasks. Individual reports were prepared for Tasks 1 through 7 and have already been made available to the public by MDT. Each of the seven task reports are contained in the appendices of this report, numbered A through G for Tasks 1

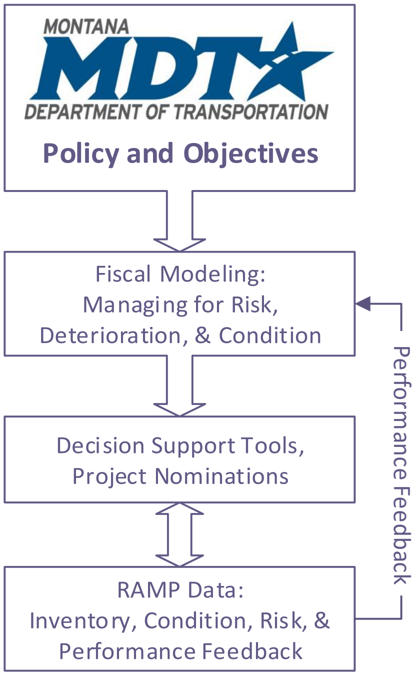


Figure 1-1: Diagram for using the RAMP once established.

through 7, respectively. The intrinsic nature of research permitted the flexibility required to tailor tasks as the project progressed into the present RAMP program. Each task had its own report prepared as a stand-alone document. Research methods and results are presented in their respective reports and are not duplicated in this final report. The component tasks of this research project included:

Task 1 – Literature Search and Information Technology Review (Appendix A)

- Reviewed rockfall ranking and management systems currently in use by other North American transportation agencies;
- Evaluated changes in data collection and management techniques since initial work on the RHRS program; and
- Reviewed recent developments in the application of asset management principles to rock slope assets, particularly in the context of decision support tools.

Task 2 – Review of Mitigated Sites (Appendix B)

- Visited and assessed rock slope sites that were new, mitigated, or otherwise significantly altered since the 2004 ratings (29 sites statewide); and
- Tested potential new combinations of RHRS evaluation criteria and the degree to which they capture change between the 2004 and new ratings.

Task 3 – Rock Slope Asset Management Program (Appendix C)

- Developed Performance Measures for rock slopes based on MDT’s existing roadway Functional Classifications;
- Developed Condition State metrics that are compatible with RHRS scoring criteria;
- Developed an approach to quantitatively calculate risk based on rock slope condition; and
- Applied the resulting performance measures and criteria to the updated rock slope asset dataset.

Task 4 – Rock Slope Assessments (Appendix D)

- Field assessed 362 rock slopes selected from the RHRS dataset, including 126 previously-unrated slopes along Interstate routes;
- Tested revisions to the RHRS rating system, TAM-compatible asset condition equations, and initial risk calculations; and
- Tested a newly developed Excel workbook and ESRI’s Collector App for utilization in future field work and database management.

Task 5 – Determination of Critical Sites (Appendix E)

- Applied selection tools from Task 3 to develop a list of Critical Sites and Critical Corridors;
- Visited selected Critical Corridors and developed conceptual mitigation designs and cost estimates in the field; and
- Combined these conceptual mitigation costs, conceptual mitigation costs for 2004 RHRS work, and data obtained from MDT’s bid tabs to estimate rock slope improvement costs per unit area

Task 6 – Develop Benefit/Cost Approach (Appendix F)

- Determined average annual maintenance costs per square foot of rock slope face based on asset condition using annual maintenance cost data at the maintenance section level;
- Estimated highway user costs due to potential rockfall-related delays;
- Estimated safety risk to users due to failures of rock slope assets;
- Aggregated resulting costs and user benefits for use in site or corridor selection tools;

- Developed deterioration curves for rock slope assets;
- Calculated life cycle costs and the return on investment from rock slope preservation and mitigation; and
- Developed an investment curve of ten-year condition outcomes vs preservation and mitigation expenditures, showing what can be purchased for a range of investment levels.

Task 7 – Evaluate TAM Compatibility (Appendix G)

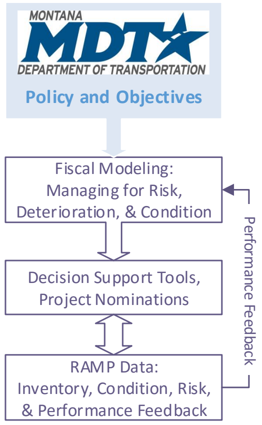
- Reviewed the IT infrastructure of MDT's current RHRS system and
- Identified additional requirements for incorporation of rock slope assets into MDT's TAM plan.

Task 8 – Final Reports and Presentations

This report documents the reassessment of the RHRS (now RAMP) and provides a final synthesis and review of the work performed under the various tasks set out above.

In addition to the project tasks, members of the research team have also communicated the results of the research while in progress, giving presentations twice at professional meetings (2016 Northwest Geotechnical Workshop, Helena, Montana; 2017 Highway Geology Symposium, Marietta, Georgia) and publishing four research papers in professional journals or conference proceedings incorporating data and knowledge gained through Montana's rockfall and related research programs (Beckstrand D. , Mines, Thompson, & Benko, 2016; Beckstrand & Mines, 2017; Beckstrand D., et al., 2017a; Mines, et al., 2018).

2 The Role of Rock Slopes in Achieving Policy Objectives



MDT's highway system encompasses 12,946 centerline miles with approximately 76% of the state's 9.3 billion average vehicle miles travelled (AVMT) on MDT roadways. Supporting this road network are about 25,000 lane miles of pavement and 2,936 bridges. Managing these assets by proactively forestalling deterioration, eventual failure, and adverse, road-closing events help the Department in achieving its mission to *"…serve the public by providing a transportation system and services that emphasize quality, safety, cost effectiveness, economic vitality, and sensitivity to the environment."* As with bridge and pavement assets, MDT's 1,873 inventoried rock slopes facilitate corridor function and reliability. Without regular attention, rock slopes deteriorate and corridor function is threatened. While bridge failure is rare in Montana, rockfall activity is likely to affect and block portions of MDT's road network multiple times per year.

When poorly performing rock slopes are adjacent to the roadway, they adversely affect each aspect of MDT's mission:

- *Quality*. Rock slopes that produce frequent rockfall where the roadside ditch is not sufficient to capture all the falling rock, are of questionable quality, at best. In the RAMP program, these slopes are rated in Fair or Poor condition. Of these inventoried 1,873 slopes, 850 of them are in Fair or Poor Condition and do not meet modern design objectives of low rockfall activity and proper ditch effectiveness. The remaining slopes are either in a known Good condition or have not been evaluated in detail, but are generally considered low risk and likely in Good condition.
- *Safety*. Rockfall reaching and/or coming to rest in the roadway affects users by introducing sudden and unexpected obstacles requiring quick reaction to avoid. Sudden swerving also can force road users off the road or into oncoming traffic. Additionally, through the research team's experience with rockfall-related legal claims, falling rock entering vehicles at highway speeds is a principal cause of rockfall-related fatalities. Poor condition slopes increase safety related risks to the road user and maintenance crews.
- *Cost Effectiveness*. Based on research results, there are approximately 60 million square feet of assessed rock slopes under MDT's responsibility. This area is distributed across the 997 slopes that have been assessed in detail. A replacement cost for these slopes is estimated at four billion dollars. Improving each slope to a 'Good' condition from their current state is estimated to cost $700 million, with the costs increasing as the slopes deteriorate. Effectively managing these slopes as critical infrastructure assets utilizing a preservation-aware TAM approach can effectively reduce costs to achieve the outcome of maintaining network-wide slope condition. When ignoring preservation efforts, the cost to maintain network condition is $35 million annually. With preservation in mind, the costs drop to a forecast $28 million.
- *Economic Vitality*. A robust and resilient highway network facilitates the state's $46 billion (2016) Gross Domestic Product (Bureau of Economic Analysis: US Department of Commerce, n.d.). Rockfall activity leads to about 23 service disruptions annually, with annual mobility, safety, and maintenance impacts estimated at nearly $10.7 million dollars. Prioritizing rockfall mitigation projects to reduce risk where the most benefit is realized maximizes the return on each dollar spent.
- *Sensitivity to the Environment*. Rockfall-related mobility interruptions could force road users on an average detour length of 42 miles and added time of 49 minutes, increasing the tailpipe emissions of greenhouse gases, particulates, etc. Other factors include disposal of rockfall debris, temporary impacts of noise pollution, community impacts, and limits on recreation. These things could cloud Montana's 'Big Sky' and negatively impact users when in travelling along MDT's scenic roadways.

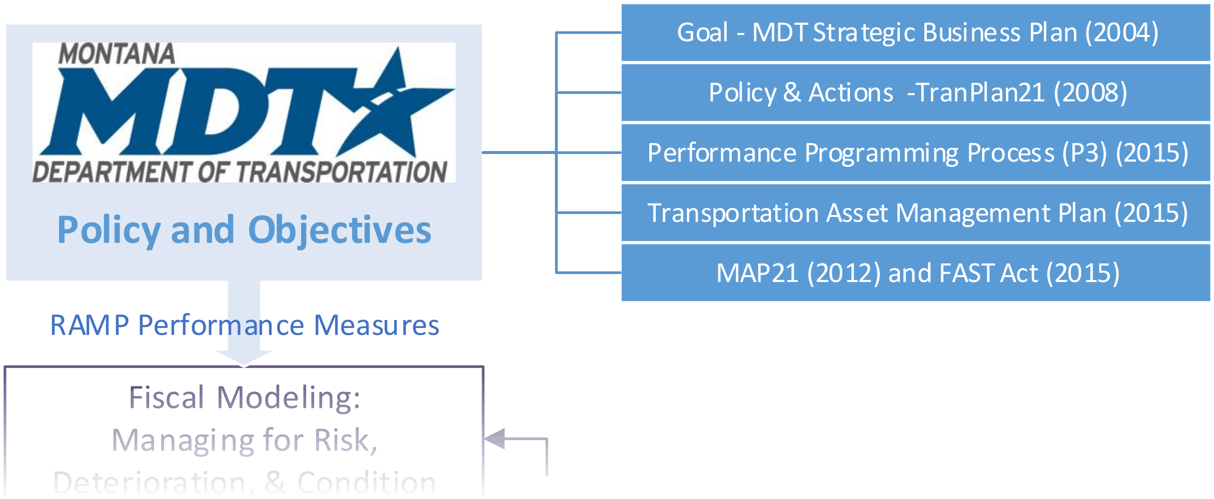


Figure 2-1: MDT's Guidance Documents for Goals, Policy, and Objectives and accompanying Performance Measures.

To counter such possible impacts, MDT has set forth goals, policies, and objectives in addition to MAP-21 that also apply to rock slopes (Figure 2-1). These documents, outlined below, describe objectives applicable to rock slopes and are discussed in additional detail in Task Reports for Task 3 (Appendix C) and Task 7 (Appendix G).

MDT Strategic Business Plan summarizes the Department's major goals, such as 1) ensuring that investment decisions consider policy directions, system performance, and availability of resources and funding; 2) enhance traveler mobility; 3) reduce crash rates; 4) improve operation effectiveness and efficiency; and 5) communicate standards, guidelines, policies, and expectations throughout MDT.

TranPlan21 Policies (Montana Department of Transportation, 2007). Three policy goals that 1) establish priorities for roadway improvement, 2) preserve mobility, and 3) improve productivity.

Performance Programming Process (P3) Objectives and System Performance Measures (Montana Department of Transportation, 2015). Defines objectives, performance measures, and targets for pavement, bridges, congestion, safety, and maintenance.

Transportation Asset Management Plan. For pavements and bridges, the 2015 TAM Plan recognizes that the federal emphasis on long-term cost and fiscal constraints is intentional and valuable.

MAP-21 and the FAST Act. MDT's goals are mirrored in the federal level, with similar objectives and codification of improving safety, condition, sustainability, economic vitality, and reliability while reducing congestion and project delivery delays for select asset classes.

In addition to these high-level goals, objectives, and policies demonstrated above; this project has developed new Performance Measures (PMs), RAMP Performance Classes, and Decision Support Tools that will facilitate management of these slope assets to meet the Department's broader goals. Agency staff should review, adapt, and adopt the PMs that were prepared during the RAMP research program. They are designed to reflect both the high-level agency policies and the lower level needs of agency sections and subsections to effectively manage rock slopes.

These goals and objectives as applied to the RAMP are carried out through the application of research products that include life cycle costs, deterioration rates, return on investment, and funding levels necessary to maintain the current condition of the network's rock slopes.

2.1 RAMP Performance Measures

A common theme for implementing MDT goals and policies is the development of Performance Measures and decision support tools that gauge rock slope performance, at both the network and asset level.

As part of Task 2 and Task 3 work, researchers considered how best to describe a rock slope's condition, and how best to incorporate this into decision support tools. Because the RHRS is a well-established rating system and users are already familiar with the rating categories, researchers wanted to avoid making drastic changes to the detailed rating categories themselves. This choice ensured backwards compatibility with the data presented in 2005. Instead of altering MDT's RHRS rating system, researchers looked at potential modifications that would give more weight to factors that best describe slope performance and risk. The new rating methods can be used to supplement detailed RHRS ratings, making MDT's geotechnical data more accessible to users who are not intimately familiar with rock slope assessment.

Prior to starting Task 2, MDT geotechnical personnel developed three proposed rating methods. The research team also added the Condition State rating method developed as part of geotechnical asset management (GAM) research for Alaska's Department of Transportation (AKDOT&PF) (Beckstrand, et al., 2017b) where the concept was proof-tested prior to use in Montana. Section 5.1 within this report summarizes these various evaluation methods. By focusing on the rating categories that best reflect slope performance, as opposed to those like AADT (over which the Department has little control), these new rating methods can spotlight mitigation-related improvements and/or diminished performance over time if preservation funding is not available. The 'Condition Index' and 'Condition State' methods developed during the Alaska research was adopted for use in MDT.

During Task 2 and Task 4, all rock slopes received ratings using the original RHRS and these new methods. The new methods were retroactively applied to the detailed ratings collected in 2005. In particular, using a rating method that simplifies asset condition into one of three TAM-compatible condition categories (Good, Fair, and Poor) can help the Department share information with planners or the general public in an easy-to-grasp format. As an example, all rated sites in the RAMP database are mapped in Figure 2-2 with symbols showing Condition State as green, orange, or red icons illustrating condition. The weighted average condition of MDT's rock slopes is Fair. However, corridors where the majority of rock slopes are in Poor condition, like Beartooth Pass, stand out on the map. These asset-level descriptions feed the performance measures, risk assessments, improvement costs, decision support tools, and overall network condition.

Where condition data is utilized for fiscal modeling, Condition Index (100 to 0 scale, good to poor) and Condition State categorizations (1 to 5, good to poor) are used as described in the respective task reports. Network-level performance measures are expressed as percentages of the network in Good, Fair, or Poor condition.

2.1.1 Performance Classes for Rock Slopes

Building on the evaluation methods described in Task 3 and applied throughout the project, the research team developed RAMP performance classes, similar to Levels of Service used elsewhere, using slope rating and condition data, and proposed minimum acceptable conditions. These examples built upon existing MDT data, particularly the Department's current functional classification for roadways. Different RAMP performance classes were developed for the different route function classifications, in order to capture varying public expectations for the performance of each type of corridor. The final breakdown is summarized in Table 2-1. The 'Target' and 'Minimum Acceptable' performance classes are used to indicate the potential difference between the Department's aspirational goals and what can realistically be achieved within existing budget constraints.

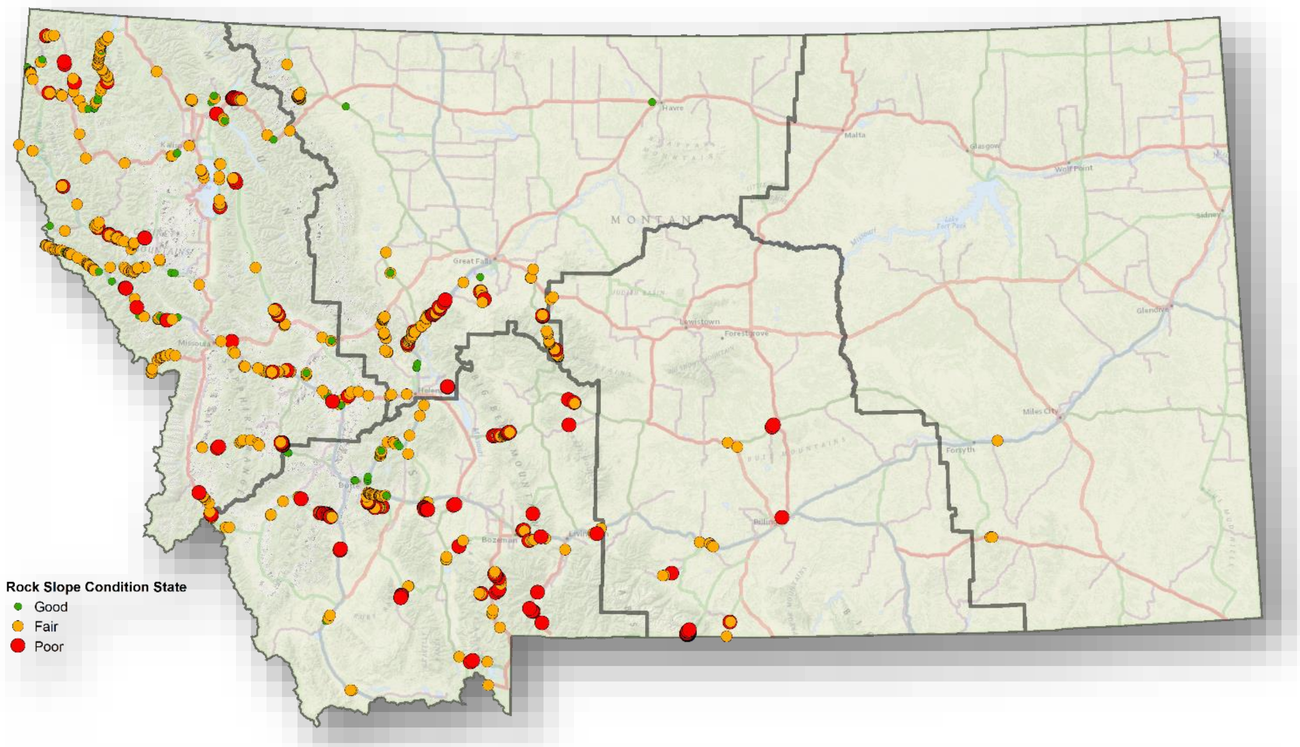


Figure 2-2: All sites in the RAMP database which have received a detailed rating as of 2016. The Condition State shown for each rock slope was calculated using the methods developed in Alaska's GAM Program research project.

Table 2-1: Functional Classification and RAMP Performance Class

Roadway Functional Classification	Example	Target RAMP Performance Class	Minimum Acceptable RAMP Perf. Class
Principal Arterial – Interstate	I-90, I-15	A	B
Principal Arterial – Non-Interstate	US 2	B	B
Minor Arterial	MT 56 Troy to Noxon	B	C
Major Collector	Rt 421 Joliet to Columbus	B	C
Minor Collector	MT 200 to US 2	C	C

2.2 RAMP Performance Targets

At the network level, performance targets are a critical component that gauges an asset's performance and can also be used to support changes in course when the asset class is not performing as expected. Targets can be either 'aspirational' and reflect the ultimate target for rock slopes; or 'fiscally-constrained', a scenario that reflects economic reality. Sample performance targets are illustrated below in Table 2-2 and warrant additional modeling and vetting if the RAMP is incorporated into MDT's TAM Plan. The low numbers in 'Good' condition reflect the original construction methods, where even newly constructed rock slopes would have been considered to be in a 'Fair' condition when compared to modern design approaches. Today’s design goals of low rockfall activity and good ditch effectiveness result in ‘Good’ rock slopes that have shown to be more cost effective in reducing service disruptions with lower overall life cycle costs.

Table 2-2: Sample Aspirational and Fiscally-Constrained Performance Targets.

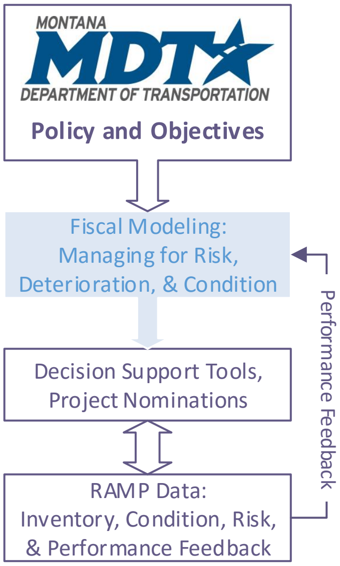
Sample *Aspirational* Targets

RAMP Performance Class	Minimum Percent ‘GOOD’	Maximum Percent ‘POOR’
A	70%	1%
B	45%	2%
C	30%	5%

Sample *Fiscally-Constrained* Targets

RAMP Performance Class	Minimum Percent ‘GOOD’	Maximum Percent ‘POOR’
A	50%	1%
B	35%	3%
C	20%	7%

3 Fiscal Modeling: Managing Risk, Deterioration, and Condition



Understanding the asset's value, deterioration rates, and investment returns allows setting budgets to achieve performance targets in the long-term planning process. These analyses integrate the data collected during the RAMP research project, (asset condition, corridor importance, etc.) into a single metric supporting straightforward and defensible project prioritization. The need for this prioritization arises from the funding limitations faced by every agency, where the total cost of all deserving projects always exceeds the available funds. These calculations enable planners to consistently determine the maximum benefit achievable for a given amount of funding. In a final list of projects, those that provide maximum benefit with available funding will be prioritized higher when allocating budget resources.

A number of parameters that feed into the network-level investment models required development as the project progressed, as illustrated in Figure 3-1. These models consider maintenance and repair costs, deterioration rates, and treatment application rates. These are used to formulate life cycle cost analyses, the return on investment for rock slopes, and achievable network conditions given various funding levels. Risk factors include the annual likelihood of deteriorating from one Condition State to the next as well as road-user risk factors affecting mobility and safety.

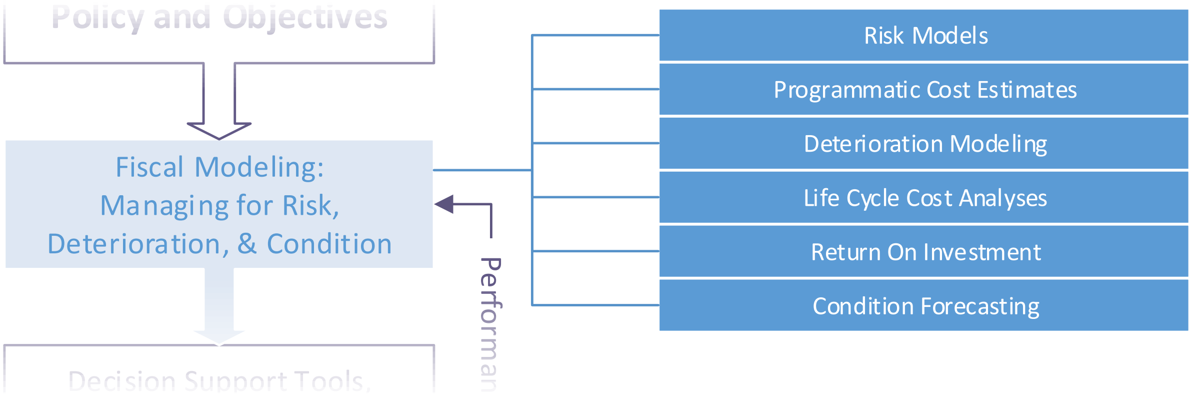


Figure 3-1: Data models required for fiscal planning.

3.1 Risk Modeling

Initial work on correlating mobility and safety risks with rock slope condition was discussed in the Task 3 report (Appendix C) and was refined and finalized for use in Task 5. They are described in the Task 6 report (Appendix F).

In early 2016, MDT administered a questionnaire to District geotechnical personnel, requesting information on adverse rockfall events that had affected the transportation system. These impacts included road closures, traffic slowdowns, property damage, and injury. Respondents provided the highway and milepost where the event occurred, the RAMP section number (where available), the event data, and a breakdown of event consequences. Respondents also provided specific event dates and information when available. For those sections of the highway where events occur on a near-annual basis, the range of RAMP sections and average impacts were provided instead. Data from District 1 (D1) was the most complete and facilitated development of a correlation between rock slope condition and rock slope event likelihood. It was then applied to rest of MDT's network.

Several edits and judgements were made to the final data set in order to generate discrete event models from recollection, as described in the Task 6 report (Appendix F). D1 also provided enough information on vehicle/property damage to develop a correlation between slope condition and likelihood of an event resulting in monetary damages, but the event sample size was too small for application of statistical modeling. The research team set the likelihood of an accident per square foot of rock slope face at 50% of the risk of a service disruption, because property damage was a reported component of 49% of events in the survey. The final likelihoods per square foot based on rock slope Condition State are presented in Table 3-1.

Table 3-1: Condition States and final rates of Adverse Events likelihoods for MDT rock slopes, derived from 2004 rating data and 2016 adverse event data provided by MDT.

Condition State (CS)	Annualized Risk of Service Disruption per sq ft of rock face (AR_{mob})	Annualized Risk of Accident per sq ft of rock face (AR_{acc})
1	1.19E-08	5.94E-09
2	4.75E-08	2.38E-08
3	3.91E-07	1.96E-07
4	1.26E-06	6.31E-07
5	2.02E-06	1.01E-06

3.2 Cost Models

3.2.1 Unit Maintenance Costs

As part of the life-cycle cost analysis, the research team developed initial unit maintenance costs based on rock slope condition. A brief overview is provided here, but the methods are discussed in greater detail in the Appendix F Task 6 report.

In early 2017, MDT provided the researchers with reported annual costs for the two job codes that contained work associated with rockfall activity, subdivided by Maintenance Section. The two codes were 1203 (Debris Removal) and 3106 (Clean/Shape Ditches). Annual costs were provided from 2009 to 2016. These job codes were not specifically rockfall-related. For example, Debris Removal, in addition to clearing rocks, covered removing deceased wildlife, tire debris, and post-winter gravel clean up, among other things. In the initial examination of average annual costs per maintenance section, some sections in eastern Montana had relatively high charges to these job codes, but there were no inventoried rock slopes in these sections.

At a March 2017 meeting, participants discussed the likely percentage of each maintenance code spent on rockfall-related maintenance. A former maintenance supervisor for the Wolf Creek Station reported that approximately 75% of his 3106 costs, and about 20-30% of his 1203 costs, were related to rockfall. Starting with this information, the researchers developed a correlation between prevalence and condition of rock slopes in a maintenance section with the percentage of 3106 or 1203 costs that the section spends on rockfall-related maintenance. The researchers also surveyed Maintenance Section supervisors visited during Task 5 fieldwork (Lookout Pass, West Glacier, and Bozeman sections) and used their rough estimates of the percentage of dollars spent on rockfall-related maintenance as a check on the predicted percentages. The supervisor responses correlated very well with the predicted values for 3106. The correlation was somewhat weaker for 1203, but the linear correlation equation was nonetheless utilized as a starting point.

Using approaches described in Task 6, the researchers calculated annual maintenance costs per square foot for each maintenance section, and then averaged these costs statewide. The resulting maintenance costs are presented in Table 3-2 on the following page.

Table 3-2: Estimated annual maintenance costs per square foot of rock slope face captured by maintenance codes 1203 and 3106.

Condition State	**Relative Weight in Maintenance Work**		**Annual Maintenance cost/sq. foot**		
	Code 1203	Code 3106	Code 1203	Code 3106	Total
Good	1	1	$0.0015	$0.0006	$0.0021
Fair	5	4	$0.0086	$0.0046	$0.0132
Poor	50	16	$0.0127	$0.0077	$0.0204

3.2.2 Unit Mitigation Costs

As part of research work for Alaska’s GAM project, the researchers used MDT’s 2005 conceptual mitigation costs and rock slope ratings for the ‘Top 100’ sites to develop a linear correlation between rock slope condition and improvement costs per square foot (Beckstrand, et al., 2016). In 2017, the researchers revised that earlier work to incorporate the additional 75 conceptual mitigation plans developed as part of Task 5. The 2005 unit costs for various mitigation items were also updated, and some mitigation items were changed to reflect changes in practice since 2005. For example, where double and triple-rail guardrail were commonly recommended in 2005, concrete barriers would now be recommended. Sixteen sites which received a conceptual mitigation design in 2005 were revisited in 2017. For these sixteen sites, only the newer 2017 conceptual design was used in the final dataset and the 2005 sites left out. The final dataset ultimately consisted of 159 sites.

In 2005, there were very few Condition State 1 and Condition State 2 sites in the conceptual mitigation dataset and the researchers developed general mitigation designs to fill the gap. Because the 2017 work was done on a corridor basis, multiple new Condition State 1 and Condition State 2 sites were added, particularly along I-90. The general mitigation designs developed for the Alaska research project were removed from the new 2017 dataset. Every site used in the unit mitigation cost analysis now has a site-specific conceptual mitigation design developed by senior geotechnical personnel. For those Condition State 1 slopes where “maintain ditch” was the only recommended mitigation work, the annual unit maintenance cost described in Section 3.2.1 was applied. This final dataset was analyzed using the methods described in a research paper prepared for the Transportation Research Board (Beckstrand, et al., 2016). The revised estimated mitigation unit cost for Montana’s rock slopes is $8.20/sq ft, to improve a slope one Condition State, which includes a 105% overhead rate. The ‘overhead rate’ approximates other costs associated with rockfall mitigation projects, such as design, mobilization, traffic control, construction engineering, etc.

A replacement cost for a slope was estimated at twice (2x) the cost to mitigate a slope from Condition State 5 to Condition State 1, or $65.60/sq ft. A rock slope ‘replacement’ could be combinations of significant roadway realignments and/or major re-excavations to drastically reduce rockfall activity and increase the ability of the ditch to retain rockfall. These high ‘replacement’ ballpark cost estimates also reflect the assumed additional environmental permitting, utility, roadway design, and etcetera that may be necessary when more drastic actions may be required.

3.3 Deterioration Modeling

The simplest possible deterioration model using Condition State data is a Markov model, which expresses deterioration rates as probabilities of transitions among the possible Condition States each year. This type of model is used in nearly all bridge management systems and in a few pavement management systems, as well. For long-lived assets, a Markov model can be expressed as the vector of median transition times from each state to the next.

In the absence of detailed condition histories, a method of expert judgment elicitation has been developed to estimate reasonable transition times. Almost every state transportation agency used this method when first getting started with their bridge management system, in order to begin applying asset management system procedures prior to long term data collection. Many states have used this method more recently for developing life cycle cost analyses for all their TAM Plans.

The method entails dividing the inventory into relatively uniform groups of slopes with similar conditions, represented as Condition States for this RAMP study. For each group, the Condition States are considered separately by asking the assembled experts the following question:

> *Imagine there are 100 assets in the indicated Condition State. After how many years will 50 of them have deteriorated to the next Condition State or worse, if no maintenance or corrective action is taken?*

This question was posed to the near entirety of MDT's Geotechnical staff and select rock slope designers, along with the research team, in a March 2017 meeting in a Delphi-style process (Boadi & Amekudzi, 2014; Helmer-Hirschberg, 1967). The group of 10 experts with extensive experience with Montana's rock slopes participated in a discussion about the questions and each person records their answers individually. Then the group discusses the answers and the members have an opportunity to change their answers. After discussion, a final estimate of the median transition times for each Condition State, from which condition vs. time deterioration curves are prepared.

The methods for developing and using these models are documented in NCHRP Report 713 (Thompson, et al., 2012). Table 3-3 shows the models that were developed for geotechnical assets using the data garnered from the expert elicitation process.

Table 3-3: Markov deterioration model for MDT rock slopes based on expert elicitation exercises.

Deterioration model	**Markov model - starting condition state**				
	State 1	State 2	State 3	State 4	State 5
Transition time (years)	36.0	25.0	15.9	8.6	
Same-state probability	0.9809	0.9727	0.9573	0.9226	1.0000
Next-state probability	0.0191	0.0273	0.0427	0.0774	0.0000

In this table the transition time is the number of years that it takes for 50% of a representative population of assets to deteriorate from each Condition State to the next-worse one; for example, from state 1 to state 2. The same-state probability is the statistical probability in any one year that a given asset will remain in the same Condition State one year later. The next-state probability is then the probability that a given asset will deteriorate to the next-worse state.

3.4 Life Cycle Cost Analysis

For the initial cost analysis, a single generic treatment was defined for each Condition State, to represent the combined effect of all feasible mitigation and preservation activities that may be applicable to a given site. Each generic treatment was associated with an improvement by an integral number of Condition States. In the life cycle cost analysis, three types of treatments are represented as: 1) Routine maintenance (ditch cleaning, rock debris clean-up), 2) preservation action (scaling, bolting, draped mesh), and 3) reconstruction of the slope and/or realignment of the road.

Table 3-4 summarizes the unit costs and application rates modeled in the life cycle cost analysis. Application rates indicate the fraction of sites, in a given Condition State, receiving each treatment each year. A rate less than 1 indicates that a site may remain in the indicated Condition State for more than a year before corrective action is taken, or that some sites never receive corrective action. A rate greater than 1 indicates that some sites receive more than one application in a year.

The life cycle cost analysis and investment analysis depend on assumptions about the allocation of agency effort among various types of preservation activity. In general, the Department chooses from among maintenance, preservation, or reconstruction approaches, and applies them to assets in the five Condition States, based in part on site-specific or policy factors that are not addressed in the investment model. The combined effect of these factors is represented in Table 3-5 in a summary fashion using application rates which vary by treatment category and Condition State. In this example, the rightmost column of Table 3-5 is a calculation of the total preservation costs (excluding reconstruction and maintenance costs) that would be incurred this year ($6,572,000) based on current conditions, if the indicated unit costs and application rates are applied.

Table 3-4: Maintenance treatment unit costs and application rates.

Routine maintenance	**Percent acted upon each year, starting in each state**				
	State 1	**State 2**	**State 3**	**State 4**	**State 5**
Debris removal - $/sq. ft.	0.0003	0.0056	0.0056	0.011	0.011
Percent acted upon	0.42%	3.16%	10.55%	105.47%	210.93%
Ditch cleaning - $/ sq. ft.	0.0006	0.0046	0.0046	0.0077	0.0077
Percent acted upon	7.60%	15.20%	30.41%	80.58%	190.05%

Table 3-5: Mitigation treatment unit costs and application rate model.

Corrective action	**Percent acted upon each year, starting in each state**					**Unit cost**	**Total cost**
	State 1	**State 2**	**State 3**	**State 4**	**State 5**	**$/sq.ft**	**$k/year**
Improve by 1 state		0.00%	0.99%	1.30%	5.00%	8.20	2,922
Improve by 2 states			0.01%	0.37%	0.01%	16.40	660
Improve by 3 states				0.98%	0.00%	24.60	2,584
Improve by 4 states					0.84%	32.80	405
Total % improved	0.00%	0.00%	1.00%	2.65%	5.85%		6,572
Reconstruct/relocate	$ 65.60/sq.ft						

For communication using simple graphs, it is common with Condition State data to compute a condition index as a normalized, weighted average of the distribution of the full inventory among Condition States. Figure 3-2 shows the combined effect of the deterioration and treatment models, expressed as a condition index where 100 is a new asset and 0 is the worst possible condition. This example reconstructs the asset when the probability of Condition State 5 reaches 50%, and has periodic mid-life corrective actions. The weight given to each Condition State was proportional to the mean Condition Index found in each Condition State, as computed individually for each site in the inventory. As a result, the computation gives an estimate of future Condition Index values likely to be found in the field during future inspections.

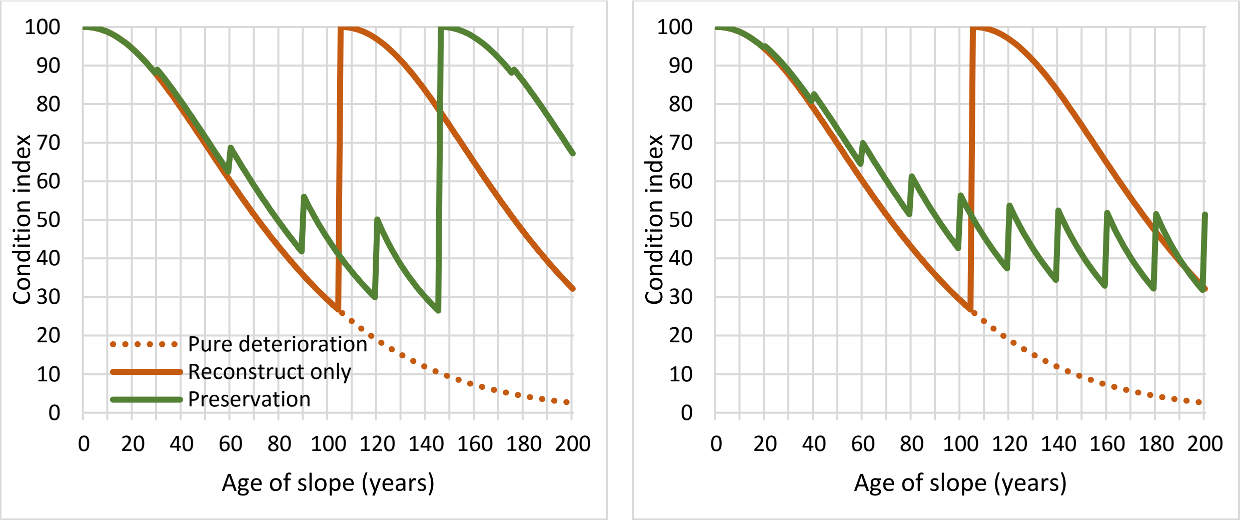


Figure 3-2: Deterioration, preservation, and reconstruction. The two plots differ by using a 30-year corrective interval on the left plot and a 20 year preservation interval on the right plot. Using longer 30 year preservation interval postpones reconstruction efforts (the big jump in the curves) for 41 years and 20-year interval on the right postponing reconstruction efforts for greater than 100 years. Reconstruction trigger is at a Condition Index of 25 points, a Poor Condition.

3.5 Return on Investment (ROI)

In a life cycle cost analysis, the deterioration model forecasts conditions from year to year over an extended period. In each year, the forecast conditions determine routine maintenance, corrective action, and reconstruction treatments with their costs and effects. Forecast condition also determines the likelihood of service disruption and therefore the expected value of economic consequences.

Costs that are assigned to future years are discounted according to accepted net present value methods. The discount rate reflects the value to the Department of postponing these costs, thereby making the money available for other, higher-priority needs. Reconstruction costs are especially large, so there is particular value in postponing these costs as long as possible. Model details are described in the Appendix F Task 6 report.

The ROI analysis compares life cycle costs between a worst-first reconstruction-only policy, and a policy featuring timely corrective action. The annual budget for both scenarios is set at a level that maintains current conditions over ten years, in other words, an equivalent network-level outcome for both funding levels. Table 3-6 summarizes the ROI results for these example scenarios.

Table 3-6: Life-cycle cost and return on investment summary, comparing worst-first to preservation-inclusive models.

	Worst-first reconstruction only	**Preservation *and* Reconstruction**
Annual Budget ($Millions)	$35.4	$28.1
Current Average Condition Index	63	63
Condition Index after 10 years	63	63
Life Cycle Cost ($Millions)	$1,577	$1,279
Preservation percent of budget	0	18%

Result Comparison	
Life cycle cost (LCC) savings by including preservation	$298 million
LCC savings as % of worst-first	19%
Annual benefit of preservation	$0.11 per sq ft
Return on preservation investment	114%

These ROI figures are calculated based on the entire inventory, including roads which may have very low traffic volume and/or detour length. The portion of life cycle cost associated with mobility benefits is proportional to traffic volume and detour length, so the social cost savings and the ROI are higher than these averages for roads which have higher AADT and longer detours.

The funding level of $28 million is found to be sufficient to maintain the current statewide slope condition index of 63 after ten years. It is noted that this figure includes not only projects identified explicitly as slope mitigation and reconstruction work, but also work affecting rock slopes that are built within other corridor rehabilitation projects, and not necessarily broken out separately. At this level, preservation and risk mitigation work would represent 18% of the slope management budget with reconstruction making up the rest. Compared to a strategy where no preservation work is done, the desired preservation investment reduces life cycle costs by 19%, a savings which is 114% of the preservation investment over the 10-year period.

This model, which considers preservation, indicates that each $1 spent improving rock slopes not only pays for itself, but returns an additional $1.14 to the Department and its road users.

3.6 Trade-off Analysis

A by-product of the life cycle cost analysis described above and detailed in the Task 6 report (Appendix F) is a forecast of condition states each year. These conditions will vary depending on the budget constraint selected, since the budget affects the amount of corrective action and reconstruction that can be performed.

TAM Plans require the establishment of fiscally-constrained targets for condition after ten years. The models can provide a reasonable estimate of ten-year condition outcomes at any feasible budget level, which may form the basis for condition targets. This kind of parametric analysis is often called a Tradeoff Analysis.

A desired funding level of $28 million, which incorporates preservation, is sufficient to maintain the current statewide slope Condition Index of 63 after ten years. Figure 3-3 below exhibits the trade-off analysis results, including the funding level to maintain network conditions as exhibited by the highlighted point. At this level, the ten-year performance targets for TAM Plan purposes would be 30% Good and 20% Poor. The total 10-year funding requirement, including inflation, is $319 million.

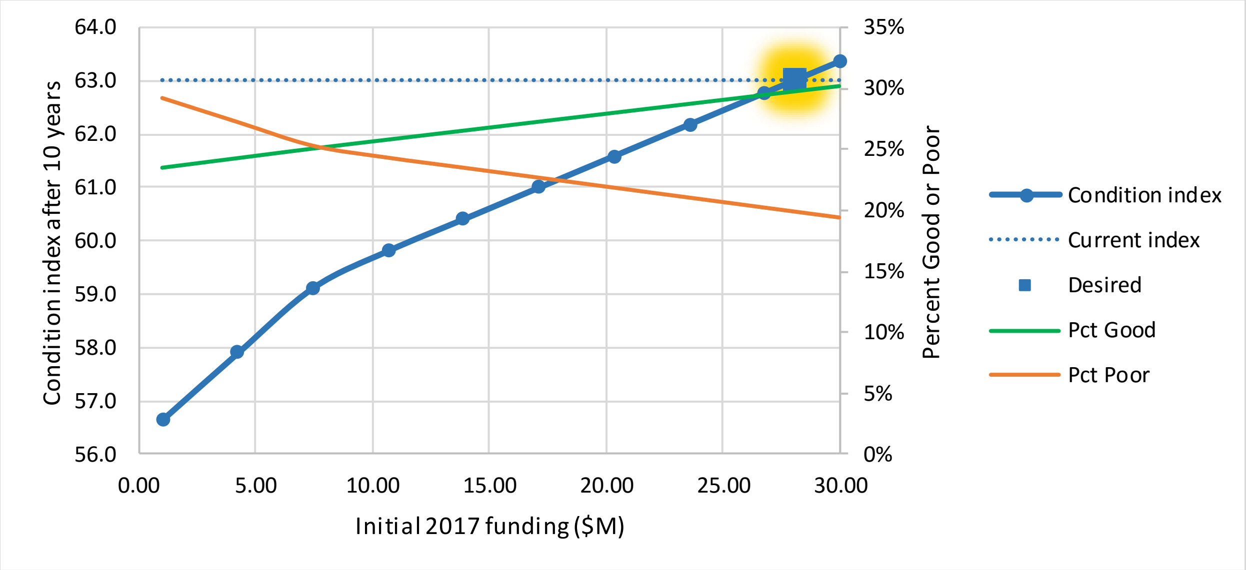
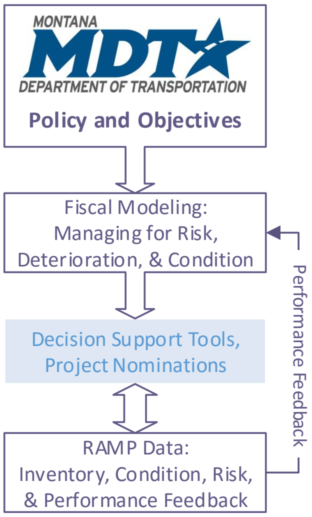


Figure 3-3: Network-level RAMP condition index versus funding after 10 years with preservation considered.

4 Decision Support with RAMP Tools



If MDT opts to begin managing its rock slopes using a TAM approach and the fiscal models outlined above to achieve risk reduction and lower life cycle costs, decision support tools have been prepared to assist with selecting the sites and/or corridors to maximize the investment benefits. Planning personnel are likely to turn to Geotechnical personnel to provide candidate sites, and these geotechnical-driven tools are intended to satisfy the objectives of risk reduction and cost effectiveness. Understanding how to best budget annual mitigation funding is critically important.

Application of the tools developed during the RAMP research project will depend on the type and purpose of the funding mechanism. Some reconstruction and 'worst-first' projects will still have to be considered. In the same sense that a bridge with settling bents even on a very low volume road will require repair or reconstruction; rock slopes that regularly produce road closing events on a low volume road will also require attention. Reacting to extreme events will always be required. The tools available for MDT's use are described below and illustrated in Figure 4-1.

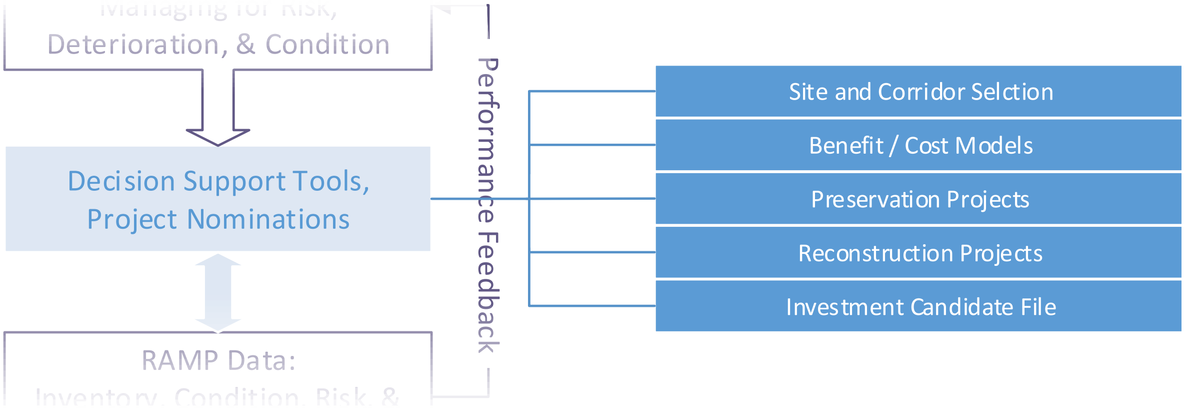


Figure 4-1: Components of decision support leading to project nominations.

4.1 Site and Corridor Selection

To assist with these efforts, the research team proposed RAMP Performance Classes for various functional classifications. Once target performance classes were set (Table 2-1), the research team developed minimal acceptable conditions for each class and potential condition assessment calculation method (Table 4-1). The performance measures for the various classes included individual site condition and corridor risk components.

As applied to the RAMP database, these tools generated a list of candidate rockfall corridors that were described in that Task 5 report (Appendix E). Applying 'Minimal Acceptable Conditions' standards for individual slopes identified 40 locations that did not meet minimal acceptable conditions under any of the rating methods proposed. These 40 sites could be considered for inclusion in a 'Investment Candidate File.' To identify high-risk corridors, the researchers estimated average slope condition, event likelihood, and monetary risk costs for MDT's roadways at 1-mile segments. By combining both of these layers in a single map, the researchers was able identify relatively high risk corridors with poorly performing rock slopes. Eleven corridors, spread throughout mountainous regions of the state, were identified for inclusion in an 'Investment Candidate File' that was presented to MDT geotechnical personnel at a meeting in March 2017. The development of the Critical Site and Critical Corridor Candidate Investment Files is discussed in detail in the Appendix E Task 5 report.

Table 4-1: Example Decision Support Tools for project selection using minimum acceptable conditions for rock slopes based on roadway Performance Class

RAMP Corridor Class	Definition	Individual Asset Condition Target	Corridor Segment Risk Target
A: Very high performance level.	Roads require only routine maintenance to remain open.	Individual sites scoring in the worst 15th percentile for the various rating methods are considered for mitigation • Condition Index/Condition State: <35/Poor (4/5) • Total RHRS Score: >450 • Method 1: >175 • Method 2: > 280 • Method 3 Slope Rating: >160	Target corridors for improvement projects where the annual likelihood of **user delays ≥ 1% per mile**
B: High performance level	User delays occur on an annual to biannual basis.	Individual sites scoring in the worst 10th percentile in the various rating methods are considered for mitigation • Condition Index/Condition State: <30/Poor (4/5) • Total RHRS Score: >485 • Method 1: >190 • Method 2: > 305 • Method 3 Slope Rating: >175	Target corridors for improvement projects where the annual likelihood of **user delays ≥ 5% per mile**
C: Minimum acceptable level	Event causing user delays occur multiple times yearly, and may be seasonally concentrated.	Individual sites scoring in the worst 5th percentile in the various rating methods are considered for mitigation • Condition Index/Condition State: <25/Poor (5) • Total RHRS Score: >550 • Method 1: >215 • Method 2: > 345 • Method 3 Slope Rating: >200	Target corridors for improvement projects where the annual likelihood of **user delays ≥ 10% per mile**

Working with Landslide Technology (LT), MDT Geotechnical personnel reviewed the candidate lists, and decided that developing conceptual mitigation costs for all sites in a critical corridor, instead of selecting individual critical sites throughout the state, would allow research team personnel to visit the maximum number of sites within the constraints of the existing schedule and budget. Ultimately, MDT selected the four corridors shown in Figure 4-2 for site-specific conceptual mitigation cost estimates. A total of 74 sites were evaluated at locations along I-90, US 2, and US 191.

Applying these criteria at other locations utilizing the RAMP GIS database will facilitate future planning and decision support beyond the work performed as part of Task 5. The RAMP database can and should be used by various divisions within the Department to alert roadway planners and designers to the presence of inventoried and assessed ‘Fair’ and ‘Poor’ condition rock slopes. These slopes should then be included in corridor and safety improvement projects, maximizing the benefit to improving rock slopes from adjacent projects, their permits, and funding sources.

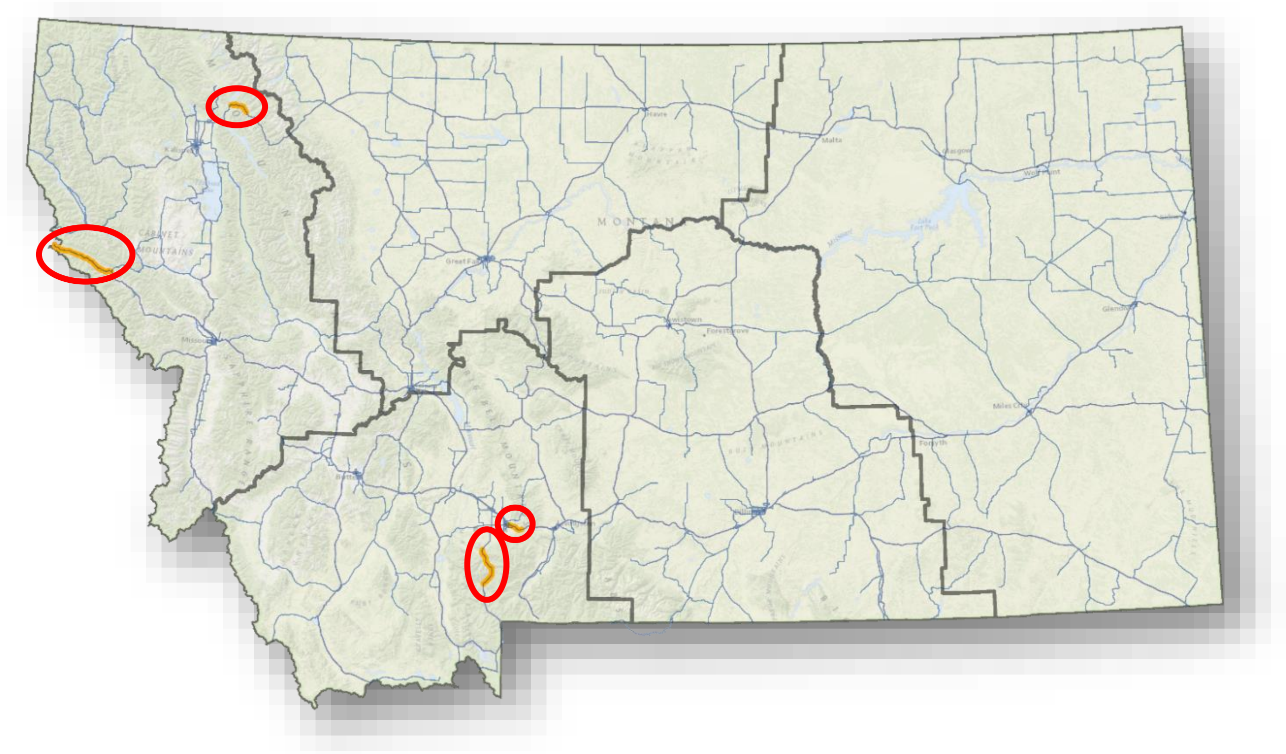


Figure 4-2: Location of the four high-risk corridors selected for detailed conceptual mitigation design and cost estimation work in 2017.

4.2 Benefit / Cost Decision Support

In a transportation agency's capital programming process, a prioritization process results in a set of projects that together maximize total benefits to all stakeholders (including road users and taxpayers), for any given level of annual funding. The project selection process for a transportation agency can be complex, with many factors, including risk management and performance management considerations, benefit/cost analysis, regional or corridor grouping, availability of funds, immediate safety concerns, etc.

The tools developed for the RAMP program help the decision making process by describing an incremental priority setting approach where a list of candidate projects eligible for advancement within certain budget constraints are advanced this year and those that should be postponed to following years.

A second approach is intended to improve upon past geotechnical practice of weighing the incurred departmental cost of ownership (long-term maintenance costs plus incurred safety consequence costs such as legal settlements) divided by the cost of a mitigation project. An improvement to this approach by factoring in risk to both the road user and Department is proposed. It equates the value of risk reduction over three decades to the cost of mitigating the slope to a certain extent. In this approach, it is assumed that a ratio above 1 is a favorable outcome worthy of consideration in that the cost to reduce risk (the denominator) is less than the potential risk cost (the numerator). Both are described in Section 8 of the Task 6 report (Appendix F) and are summarized below.

4.2.1 Incremental Priority Setting

Not all mitigation projects result in improvement to Condition State (CS) 1, due to cost or other constraints. Many mitigation projects, particularly those for Poor condition sites (CS 4 or 5) result in improvement to Fair Condition (CS 2 or 3). This approach allows planners to compare mitigation projects that will result in different levels of improvement at various sites around the state.

This approach is an “incremental priority setting” tool because the numerator is an increment of benefit (taken out of the total life cycle project benefit) and the denominator is an increment of cost (taken from the annual agency budget). But in common practice the term “benefit/cost ratio” is used, with the understanding that if it is used for annual priority-setting then the numerator must be one year deducted from the project’s total benefit, and the denominator must be the cost deducted from one year of the agency’s total budget. Since the annual numerator benefit is small and not extended out to the lifespan of the mitigation measures while the cost to implement the mitigation in any given year is its full mitigation cost, a beneficial ratio does not necessarily need to be above 1.

4.2.2 Benefit/Cost Ratio for Geotechnical Personnel

The incremental approach described above is more appropriate for setting priorities between a variety of different projects and types of projects worked on in a given budget cycle. This approach differs from the technique more familiar to the geotechnical divisions of many DOT’s. When the expense of maintaining and paying out the consequence of failures becomes more expensive than mitigating the site, the ratio is above one and mitigation work becomes justified. Unfortunately in practice, this often requires an incurred accident and associated settlements to justify rock slope work. In this approach accident likelihoods are zero until an event proves otherwise, ignoring risk.

Using the risk research (Section 3.1), user mobility and safety consequences, and applying them on a site by site basis the numerator becomes the change in expected risk costs from the current condition state to an improved condition state over the lifespan of the improvement. In these examples, the lifespan of the mitigation is assumed to be thirty years, although that could vary based on the measures selected.

This approach was applied to the 75 sites visited as part of Task 5 and tested by both improving the site by one Condition State and then improving the site to Condition State 1. Table 4-2 presents a summary of results. Averaging site-specific results across an entire corridor segment can help illustrate the benefits that are reached and this can be used to compare alternative corridor investments, especially when applying incremental improvements of one or more Condition States. On Hwy 191, 72% (8 of the 11 evaluated) of the sites evaluated for improving one Condition State provided a benefit / cost ratio above 1.0 for the improved geotech-focused approach. Only on I-90 west of St. Regis did a full improvement to Condition State 1 yield favorable results.

Table 4-2: Corridor averages utilizing the geotechnical benefit/cost approaches.

	Average Improved Geotech Benefit / Cost Ratio	
Highway Segment	**Improved to CS 1**	**Improved by 1 CS**
I-90 West of Regis MP 0 to 30 (37 of 49 sites in Fair Condition)	0.6 (9 sites > 1.0)	1.1 (14 sites >1.0)
I-90, E. of Bozeman, 2 sites	0.3 (0 sites > 1.0)	0.8 (0 sites > 1.0)
Hwy 191, Gallatin Canyon, 11 sites	0.4 (0 sites > 1.0)	1.5 (8 sites > 1.0)
Hwy 2, East of W. Glacier, 13 sites	0.1 (0 sites > 1.0)	0.2 (0 sites > 1.0)

4.3 Decision Support Example

Based on the sites visited as part of Task 5, the following approach may be warranted to achieve various goals proposed for the project:

- *I-90 West of St. Regis* - a stand-alone, corridor-based risk reduction project utilizing STIP funding mechanisms similar to the I-15 D3 rockfall mitigation project. Of the 49 sites present, 37 are in a Fair condition and have experienced a number of failures in recent years. Based on Table 4-1 - RAMP Performance Class ‘A’ targets, two sites do not meet condition targets, 20 of the 31 miles have greater than 1% likelihood of user delays per mile (due to the large slope sizes and their Fair condition), and up to 14 of the sites exhibit a favorable benefit cost outcome. These efforts may be considered as preservation rather than reconstruction.

- *Highway 191* in Gallatin Canyon, nine of the 11 slopes evaluated that do not meet RAMP Performance Class 'B' goals, 6 miles have an annual likelihood of service disruption greater than 5%, and up to eight of the sites demonstrate favorable benefit cost outcomes. Due to the Fair and Poor nature of the slopes, this may be considered reconstruction and be funded through the STIP process. Alternatively, opportunity to expand the tentative guardrail upgrade project NH 50-2(83)56 to reduce risk should be considered as a preservation project with different design goals. Note that some needed environmental work may have already been accomplished through a Finding of No Significant Impact (FONSI) in project STPHS 50-1(14)8: Gallatin Canyon: Slope Flattening/Widening.
- *Highway 2 east of West Glacier* could be programmed through a Highway Safety Improvement Project (HSIP) rather than strictly on cost-basis alone. While no sites possessed a ratio above '1', eight of the 13 sites evaluated did not meet Class 'B' goals and three of the four miles evaluated had an annual likelihood of disruption greater than 5%.

4.4 Using RAMP Criteria as Design Objectives

The benefit/cost methods developed for this project utilized differing approaches to conceptualizing mitigation measures during Task 5. One approach was to marginally improve the slope's condition only one Condition State. Mitigation measures may have only improved ditch effectiveness and not involved any on-slope work. Other sites may have only included slope work with no ditch improvements due to a lack of space. These partial improvements may have only improved the site one Condition State. A second cost estimate was provided where the designer intended to perform a complete mitigation by both decreasing rockfall activity significantly and providing good ditch effectiveness. This would result in a Condition State 1, but would be more costly.

While recent practitioners have made efforts toward using similar rating systems with design objectives in mind (Anderson, et al., 2017), the general lack of federal design criteria and standards with regards to rockfall mitigation separates itself from other transportation engineering disciplines. Use of the Condition State concept ties condition, risk likelihood, fiscal constraints, and objective design goals within a comprehensive package, worthy of additional consideration and research. Research team members performing the conceptual design options during Task 5 found the concept quite useful and applicable to their needs.

4.5 Preservation Projects

The example life cycle analyses discussed in Section 3.4 allocated 18% of the 28 million dollar annual budget towards 'preservation' projects and the remaining to reconstruction projects. What constitutes 'preservation' is flexible. In terms of bridges and pavements, this would be a new coating on a steel bridge or a chip seal or overlay on pavements. Rock slope preservation projects could be ditch cleaning, barrier replacement or repair, installation or repair of flexible barriers, or on slope efforts such as scaling.

In recent history, MDT has performed some additional scaling work at MP 22 on I-90 to remove some overhanging blocks. This type of work could be considered preservation or heavy, specialized maintenance.

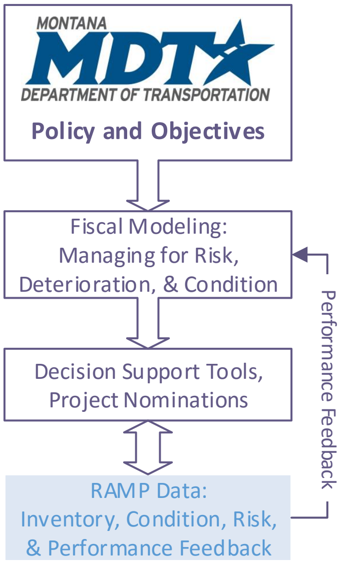
Both the above preservation projects and reconstruction projects described below can be largely programmed through the federal funding process rather than through state funding mechanisms. This has the added benefit of reducing wholly state-funded maintenance expenditures, since slopes in better condition require less maintenance.

4.6 Reconstruction Projects

Traditional rockfall mitigation projects, ones that aim to significantly reduce rockfall activity and improve ditch effectiveness for the long term, such as work on I-15 north and south of Helena (D3 and Butte rockfall projects, respectively), are considered ‘reconstruction’. Full reconstruction, with accompanying rock slope excavation and/or roadway realignment also fall within this category.

5 RAMP Data: Key in the Performance Feedback Loop

Common to all management systems is the need to provide data in order to understand what is being managed, how it is performing, and if it is meeting the Department's expectations. Database curation and continual use and updating is critical to maintaining a well-functioning Rock Slope Asset Management Program. While MDT considers inclusion of rock slope assets into its formal TAM plan, Geotechnical personnel can encourage use of the features, additions, data, and concepts that are built into the RAMP program. Figure 5-1 illustrates the role of RAMP data in communicating performance information.



5.1 Condition Data

The RAMP program incorporated all existing data from the previous RHRS program. The solid foundation of the Rockfall Hazard Rating System has served DOTs and geotechnical professionals well over the preceding 30 years. The concepts are well entrenched in the minds of geotechnical personnel, but it did not extend outside this realm into other highway professions until the advent of asset management. The RAMP endeavors to bridge the gap between transportation disciplines by packaging rock slope data and decision-making models that are useable by a variety of executives, planners, maintenance, and engineering professionals.

5.1.1 Traditional Slope Scoring

Traditional RHRS scores that grow with worsening conditions with an exponential, base-3 scoring system provides experienced rockfall professionals with a common language to quickly communicate rock slope condition, hazard, and risk.

The RAMP program reports traditional RHRS scores as well as three additional methods developed by MDT and subsequently incorporated into the RAMP. The RHRS categories of rockfall activity and ditch effectiveness are the basis of the remaining Condition States. These two criteria often supersede other site-specific categories and prompt action. Table 5-1 summaries the RHRS categories used in the different methods as detailed in the Task 2 and 3 reports, contained in Appendix B and C, respectively.

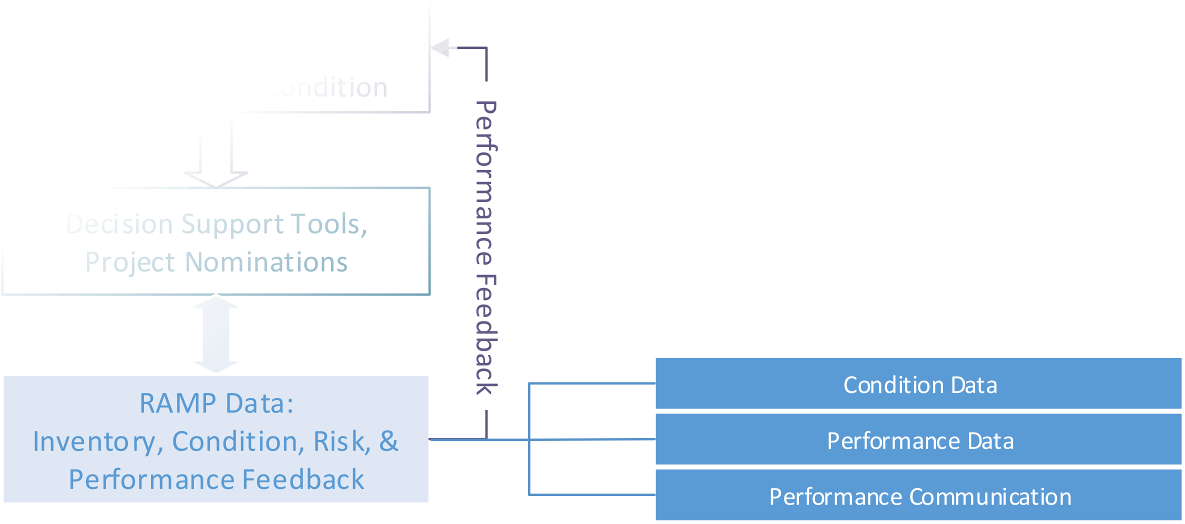


Figure 5-1: Role of RAMP Data in Performance Information.

Table 5-1: RHRS category subdivisions for various rating schemes.

MDT Method 1	MDT Method 2	MDT Method 3	Condition Index & State
• Ditch Effectiveness • Rockfall History • Block Size / Event Vol. • Geologic Character • AADT (raw value)	• Ditch Effectiveness • Rockfall History • Block Size / Event Vol. • Decision Sight Distance • Roadway Width • Geologic Character • AADT (raw value)	• Ditch Effectiveness • Rockfall History • Block Size / Event Vol. • Geologic Character • Sight Distance • Roadway Width • AADT (raw value)	• Ditch Effectiveness • Rockfall History

5.1.2 Condition State and Index

Beginning in Task 2, the research team began evaluating application of Condition State and Condition Index scoring, which use certain categories of the RHRS. To determine what a slope's 'condition' is, it needs to meet a variety of criteria: 1) is anticipated to degrade with time in an absence of maintenance or preservation efforts; 2) is expected to be independent of risk factors (like geologic condition, block size, decision site distance); and 3) is expected to be within Department control for treatment.

Like other TAM data types, Condition Index data is communicated in a linear scale from 100 (favorable, ideal, or new condition) to 0 (unfavorable, failing, or failed condition). To facilitate additional analysis and communication objectives, the Condition Index is grouped into five Condition States. These condition categorizations serve both geotechnical professionals as well as planning and other more technical personnel well. The transformation from RHRS score values to Condition Index and States is described in the Task 3 report (Appendix C).

5.1.3 Good / Fair / Poor

FHWA research (Guerre, et al., 2012) and new federal regulations (23 CFR Part 490, 2017) dictate categorizing condition assessments into Good/Fair/Poor divisions for bridges and pavements, as opposed to the purely numerical rankings like those generated by the above scoring and rating methods. In their current form, Good/Fair/Poor divisions are intended to improve FHWA's ability to assess the health of the nation's highway infrastructure and serve two primary objectives:

- Define a consistent and reliable method of assessing infrastructure health with a focus on bridges and pavements on the National Highway System; and
- To develop tools to provide FHWA and State Department of Transportation (DOT) personnel ready access to key information that will allow for a better and more complete view of infrastructure health nationally.

For the RAMP, the researchers relate the Good/Fair/Poor terminology directly to the Condition State. Table 5-2 summarizes the relation between condition classifications, duplicated here from the Task 3 report. These descriptors quickly and effectively communicate the condition of the asset in question into language easily understood across technical and non-technical personnel, as well as management and the public alike. Figure 5-2 illustrates the relation between these various ratings and condition indicators.

The assessment methods summarized above are fully described in the Task 3 report, contained in Appendix C.

Table 5-2: Condition Descriptors for Rock Slopes

Condition State	Good Fair Poor Descriptor	Cond. Index Range	Description
1	**Good**	**100 - 80**	Rock slope produces little to no rockfall and no history of rockfall 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 and performing as intended.
2	**Fair**	**80 - 60**	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 and maintain ditch effectiveness. Mitigation measures, if present, are in generally good condition, with only surficial rust or minor apparent damage.
3	**Fair**	**60 - 40**	Rock slope produces many rockfalls with some rockfalls occasionally reaching the road. Maintenance is required bi-annually or annually to maintain safety. Mitigation measures, if present, appear to have significant corrosion or damage to minor elements. Preventative maintenance or replacement of minor mitigation components is warranted.
4	**Poor**	**40 – 20**	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**	**20 – 0**	Rock slope produces constant rockfall and nearly all rockfall reaches the road. Virtually no rockfall catchment exists or, if present, it is ineffective. 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.

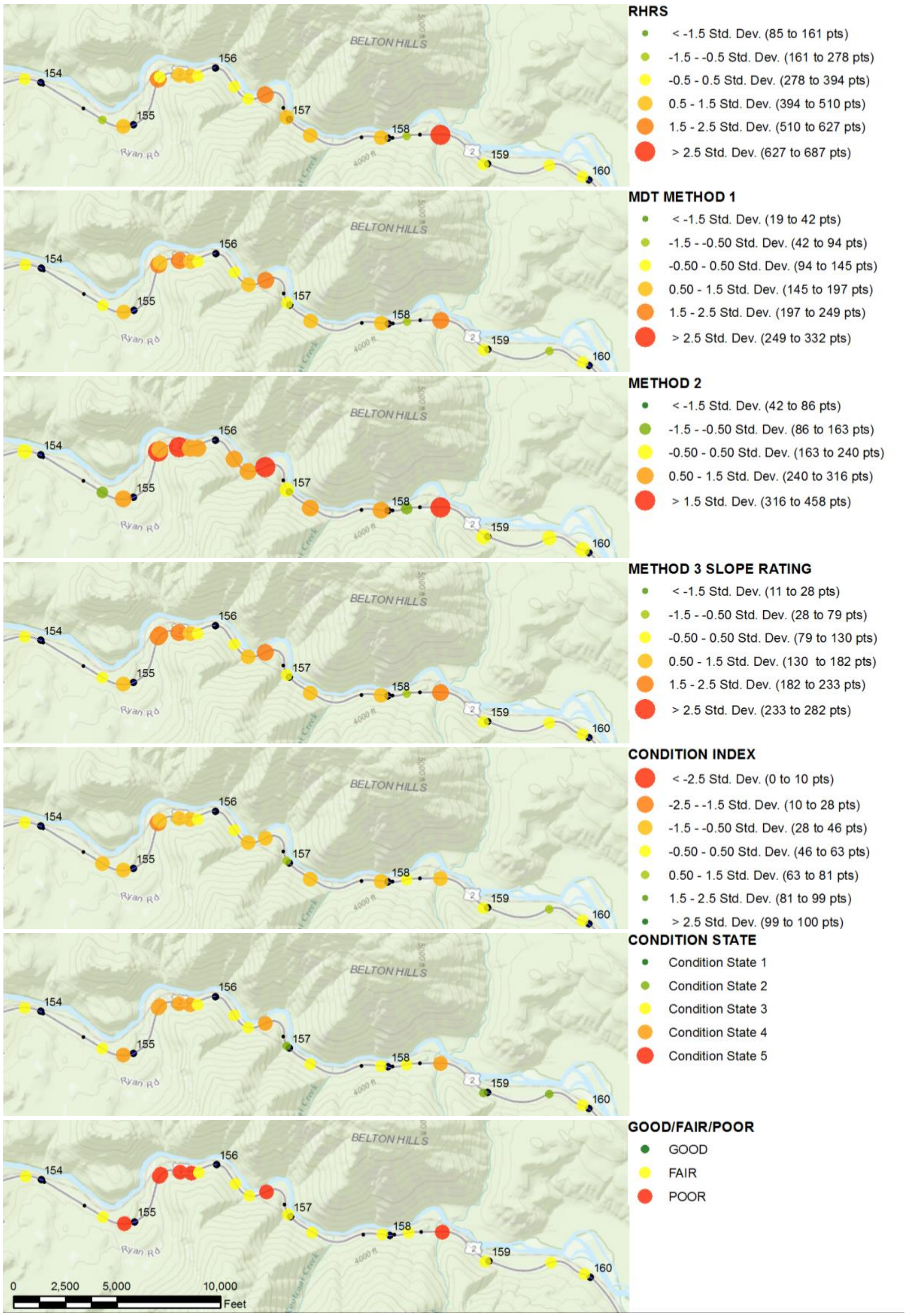


Figure 5-2: Comparison of rating methods for a six mile corridor immediately east of West Glacier on Highway 2, MP 154 to 160. Many of these sites received conceptual cost estimates as part of Task 5.

5.2 Supplying Performance Feedback

The RAMP is a living database that requires additional data to help refine models, improve system performance, and determine if the level of funding is making the changes that were forecast. This feedback is important in understanding system performance and making effective, cost conscious decisions over the life span of a slope and any mitigation measures constructed. The primary data types that are supplied by the RAMP in its current form are 1) condition data, 2) event data, and 3) maintenance data. Figure 5-3 duplicates a figure from Task 6 with highlights exhibiting where the RAMP data is input back into the models for continued improvement.

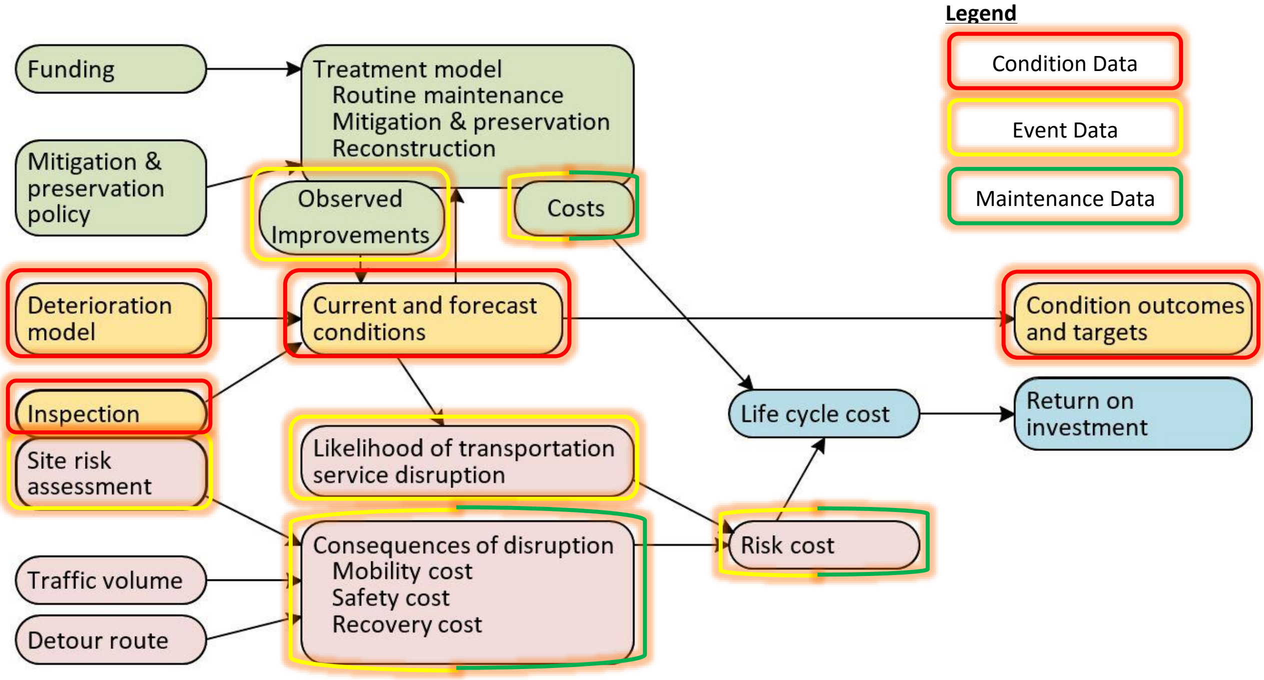


Figure 5-3: Framework for implementing the RAMP. The base figure is slightly modified from Task 6, with select items highlighted here illustrating where RAMP performance and event data are needed.

5.2.1 Condition Data

Performance data related to condition assessments should be updated when mitigation efforts or heavy maintenance (scaling, major ditch cleaning, mitigation repairs, etc.) are performed. This is done by re-rating a site with spreadsheet tools, concentrating on the aspects that were improved during mitigation efforts. The new rating data is assigned the same RAMP slope ID and input into the geodatabase, marking the status field as ‘ACTIVE’ and changing the old rating status field as ‘ARCHIVE’. These steps will display the new rating on all the maps while still storing the old condition data for future analyses. These changes should be made soon after the mitigation or maintenance measures are completed, rather than waiting for a future date when a batch of slopes are ready for input.

Newly constructed slopes should be added into the RAMP database as new entities when construction is complete.

Slopes that change status due to a change in ownership or maintenance responsibility should have their status field changed to ‘ARCHIVE’.

When making changes to rock slope ratings, consider event history and maintenance events that may have been recorded in the trackers to better inform rating categories, such as rockfall history, block size, or geologic characteristics.

At a set interval MDT should perform a condition assessment of their rock slopes. Bridges are typically inspected on a two-year interval (up to six years for low-risk assets), while pavement management systems commonly measure pavement condition annually. Ultimately, reassessing RAMP sites on an annual or biannual basis would be ideal for accurate forecasting of life cycle costs for a multi-billion dollar asset class. However, until rock slopes and other geotechnical assets are required to be part of TAM plans, this may not be realistic. Nevertheless, a five-year interval for reassessment is in keeping with the standard-of-practice for reassessment intervals and accompanying model refinement.

5.2.2 Event and Maintenance Data

Tools to track geotechnical events and maintenance activities have been developed for use by primarily geotechnical and maintenance personnel as part of an added, supplemental task. The tools request information key to understanding the frequency and consequences of rockfall events. The technology behind these tools is discussed in Section 6. The event information requested includes:

- Event type (rockfall, debris flow, landslide, avalanche, etc.);
- Weather associated with the event;
- Event volume;
- Size of rocks on the road;
- Road closure and slowdown duration;
- Resources required to respond to event;
- If there were any accidents; and
- All associated costs.

Maintenance information requested:

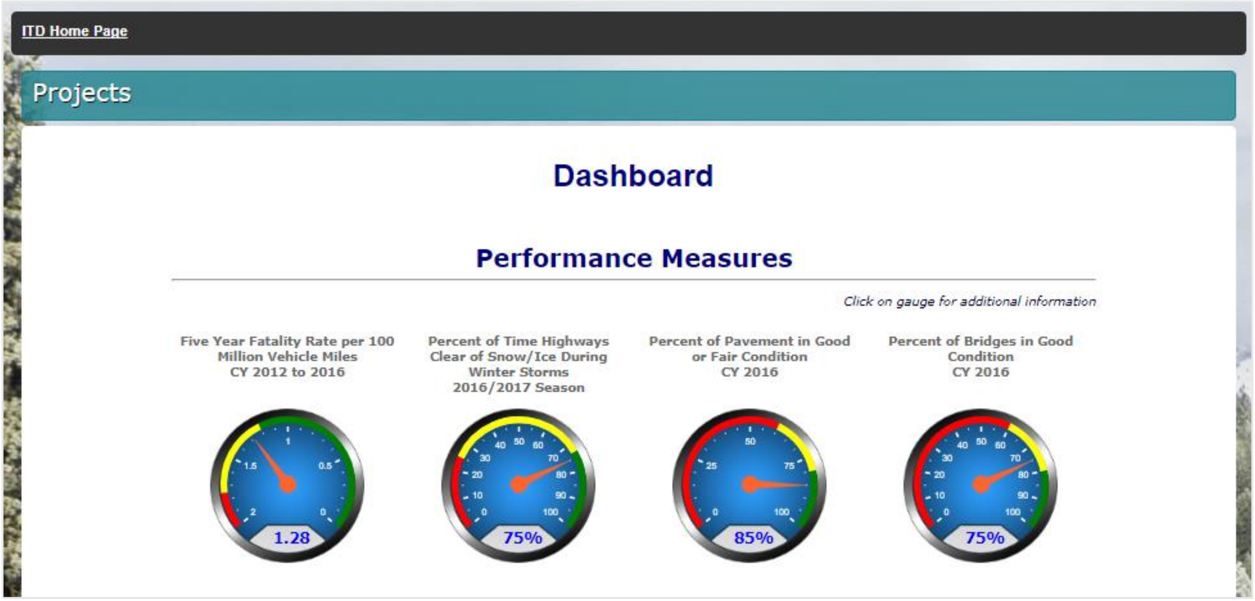
- Maintenance frequency;
- The feature requiring maintenance;
- What activity is required;
- Resources required to respond; and
- All associated costs.

This information significantly improves understanding of rockfall risks and their effects. Thorough and consistent application of these tools will provide additional risk and consequence information that will improve models over time. Field data tracked from these data items should be incorporated into the RAMP models for risk, life cycle costs, condition assessments, and deterioration rates at the reassessment interval. Over that time, tool use should be promoted regularly. Incorporation of these tools is highly recommended for inclusion into MDT's new Maintenance Management System.

5.3 Communication Tools

Many state DOTs have a 'Performance Dashboard' where key performance measures are gauged against goals and objectives measures, often in an interactive, public, web-based format. Idaho's Performance Dashboard, shown in Figure 5-4, is an example of an interactive Performance Dashboard. MDT does not yet have a public-facing performance dashboard, but one is planned based on MDT's 2015 TAM Plan. Geotechnical personnel should strive to include RAMP performance data in MDT's eventual dashboard.

In the interim, ESRI offers a software package, 'Operations Dashboard' for Windows 10, which can present performance information. The research team has conceptualized one that features RAMP data on a statewide or user-selectable basis (Figure 5-5). This example is discussed more in the Task 7 report (Appendix G).


ITD Home Page

Projects

Dashboard

Performance Measures

Click on gauge for additional information

Five Year Fatality Rate per 100 Million Vehicle Miles CY 2012 to 2016

Percent of Time Highways Clear of Snow/Ice During Winter Storms 2016/2017 Season

Percent of Pavement in Good or Fair Condition CY 2016

Percent of Bridges in Good Condition CY 2016

Figure 5-4: Portion of Idaho Transportation Department's Performance Measure Dashboard. Available at http://apps.itd.idaho.gov/apps/Dashboard.

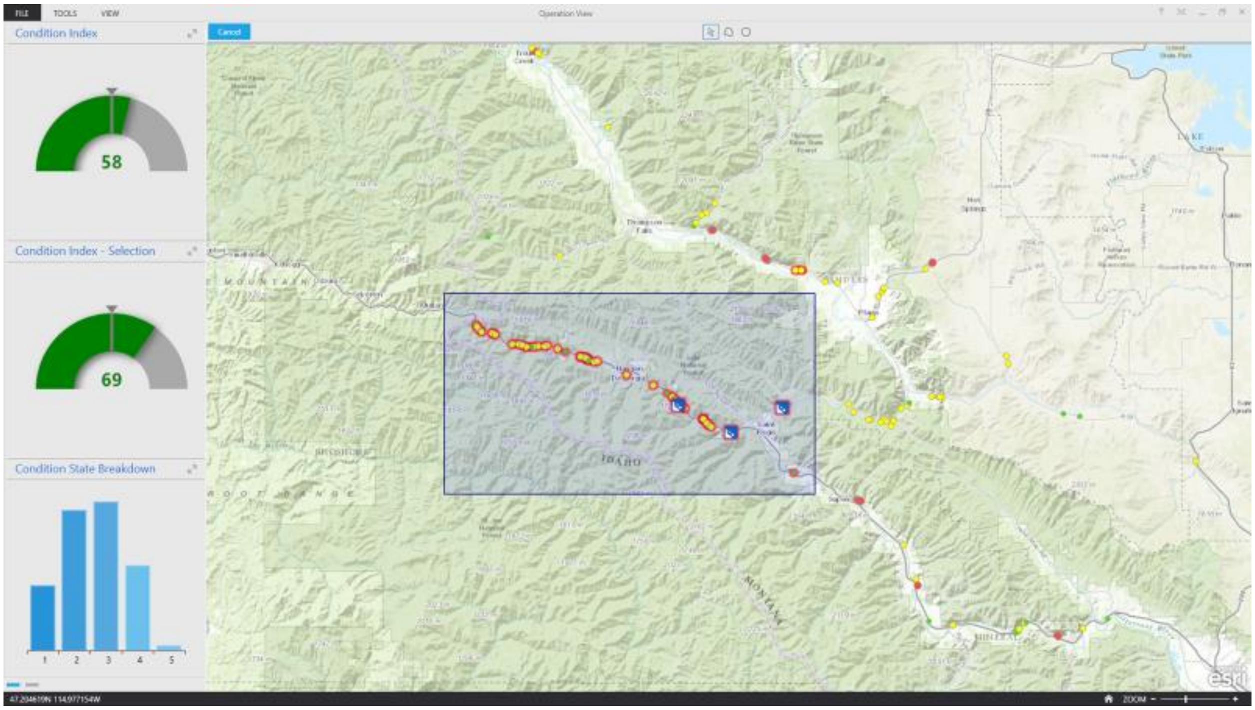


Figure 5-5: Prototype Map-Based Performance Dashboard. This exhibits a site selection process and gauges indicating an unweighted Condition Index for a larger network (top gauge) and then for the selected features (middle gauge). The bar chart is a historgram of network Condition State breakdown for a corridor segment.

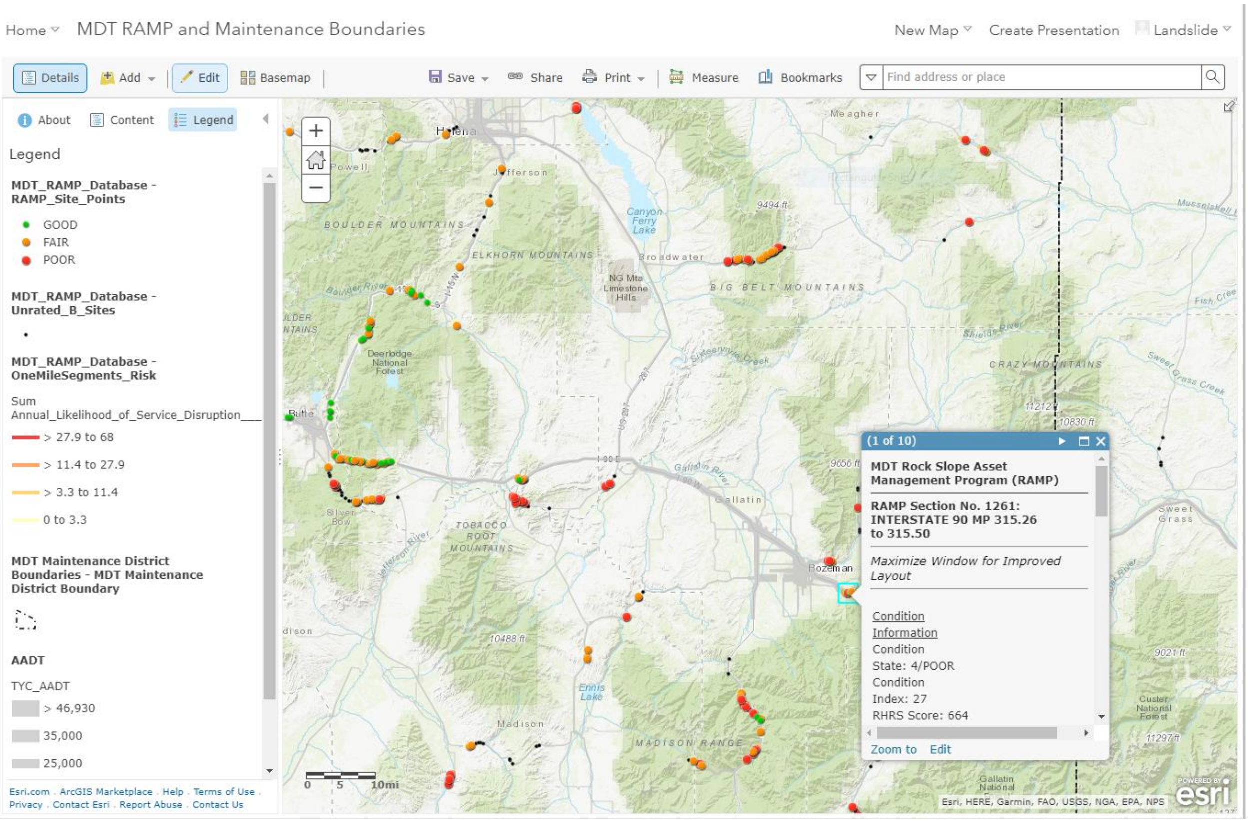
6 Data Tools

As part of the research project, RAMP geodatabases were created and are hosted on MDT’s ArcGIS Online (AGOL) portal (https://mdt.maps.arcgis.com/home/). This platform permits plotting, mapping, and analysis through both an easy-to-use online mapping platform as well as a more traditional desktop GIS platform. These mapping tools are compatible with MDT’s planned Information Services upgrades in the coming years. Additionally, a planned upgrade to the state’s Maintenance Management System (MMS) will be incorporating remote, offline-capable data collection platforms for collecting maintenance data in the field using ESRI’s Collector App for iOS, Android, or Windows 10 devices.

Data layers are available as REpresentational State Transfer (REST) APIs, critical to future integration with MDT Information Services planned future upgrades.

The research team developed several maps to present RAMP data for various purposes. The map shown in Figure 6-1 below contains all inventoried rock slopes, the Geotechnical Event Tracker, and the Geotechnical Maintenance Tracker. It has a “click-to-access” functionality for accessing data, with integrated hyperlinks to photos and is available to select personnel (those belonging to the ‘Rockfall Management’ AGOL group within MDT) at http://arcg.is/1uvb0O. With an adjustment in the map permissions, this map can be shared with the public via embedment in a website.

The Event Tracker and Maintenance Trackers are available to those in the Rockfall Management group and are available by clicking the links above. AGOL geodatabases, maps, and apps are delineated in Table 6-1.



Legend

MDT_RAMP_Database - RAMP_Site_Points

- ● GOOD
- ● FAIR
- ● POOR

MDT_RAMP_Database - Unrated_B_Sites

•

MDT_RAMP_Database - OneMileSegments_Risk

Sum Annual_Likelihood_of_Service_Disruption___

- > 27.9 to 68
- > 11.4 to 27.9
- > 3.3 to 11.4
- 0 to 3.3

MDT Maintenance District Boundaries - MDT Maintenance District Boundary

AADT

TYC_AADT

- > 46,930
- 35,000
- 25,000

(1 of 10)

MDT Rock Slope Asset Management Program (RAMP)

RAMP Section No. 1261: INTERSTATE 90 MP 315.26 to 315.50

Maximize Window for Improved Layout

Condition Information

Condition State: 4/POOR

Condition Index: 27

RHRS Score: 664

Figure 6-1: Screenshot of current MDT RAMP map showing MDT rockfall sites in the web-based GIS interface.

Table 6-1: Files supporting the RAMP program currently hosted on AGOL.

File Name	**File Type**	**Type of Data**
MDT_RAMP_Database	Hosted Geodatabase	
RAMP_Site_Points	Point	All sites in the RAMP Program; Basic and Detailed Rating information for A sites, Basic information for unrated B-sites
Ramp_Site_Extents	Polygon	Site extents for rock slopes visited during 2015/2016 field work with basic condition information
OneMileSegments_Risk	Line	Summary of Condition, Risk, and Mitigation Costs for all rock slopes in a one-mile segment; contains only segments with risk > 0. *Note: information in both SystemSegments_Risk layers are identical, and reflect different requirements for data storage and analysis*
Unrated_B_Sites	Point	Basic location and site information for unrated B-sites
Geotechnical_Event_Tracker	Hosted Geodatabase	Framework database for geotechnical event tracker app
Geotechnical_Maintenance_Tracker	Hosted Geodatabase	Framework database for geotechnical maintenance activity tracker app
MP Labels	Annotation	Milepost labels for Collector App
Site Labels	Annotation	RAMP site labels for Collector App
On_System_Routes	Line	Copy of MDT 2015 on-system route layer for offline use with the Collector App
AADT	Line	Copy of MDT 2014 AADT data for offline use with the Collector App

7 Conclusions and Recommendations

In order for this research project to provide the maximum possible benefit to the Department, it should be maintained and integrated into planning and decision making. Implementation and maintenance recommendations are summarized in the following sections. The Implementation Report, prepared separately for this project, summarizes eight implementation recommendations, discussed below.

7.1 Integration into Department Planning and Design

MDT is currently developing its federally-mandated TAM plan. Currently, TAM plans are only required to include pavements and bridges. Incorporating other assets is not required, but using modern tools to manage department assets is smart business. This is especially the case for rock slopes, a $4 billion group of assets that has numerous individual assets in poor condition. The RAMP is TAM compatible, but because integration is not required, MDT has a great deal of flexibility in how they incorporate the new program into department planning and budgeting. Development of the RAMP in a TAM compatible format will ease future integration into the TAM Plan.

The research team recommends that the Department integrate the RAMP into the planning workflow, so that potential improvements to existing Fair and Poor condition rock slopes can be addressed early in the NEPA and project selection process. Further, MDT should develop STIP and HSIP line items in the state budget for stand-alone rock slope mitigation projects, such as the D3 rockfall mitigation project currently underway on I-15. These projects reduce corridor risks, improve user safety, and help slow overall asset deterioration, as measured at the statewide level. The RAMP is capable of providing the necessary data to support decision-making for geotechnical elements of highway projects or for stand-alone rock slope mitigation.

The budget forecasting tools proposed in the RAMP can also be used to help MDT ensure adequate spending to maintain rock slopes in acceptable condition and reduce risk and life cycle costs over a multi-year period. The preliminary tools in this research report provide an estimate of the amount required to maintain existing conditions. This includes both maintenance costs and potential mitigation project costs.

The research team recommends initiation of an annually funded STIP item for maintaining, improving and updating the RAMP program and collecting data in a periodic inventory and re-assessment program. The re-assessment at a 5-year interval could be conducted with, for example, 1/3 of slope assets per year, prioritized by corridor or district priority.

Utilize the Condition State approach in conjunction with percent retention for developing rock slope design goals. For instance, a design goal of all new slopes of Condition State 1 and percent retention of 95% would yield a rock slope that produces little rockfall and an effective ditch.

7.2 Maintenance of Existing Data

In order for the RAMP program to be a useful planning tool, the database must be maintained and data kept current. Currently, the RAMP data is stored using ESRI's AGOL program. Because MDT already maintains a subscription to this service, it will be easy to get any necessary IT support, either from within MDT or from ESRI. Using AGOL also means that the format of RAMP maps and layers will already be familiar to users, and will make using the database more efficient and less intimidating. It will also be easy to incorporate other RAMP layers into other AGOL maps, such as those showing proposed STIP projects or rockfall event locations and shared with planners or the public. Most importantly, ESRI constantly maintains and improves its AGOL software and platforms so the RAMP data is unlikely to become trapped in an obsolete system. However, we recommend that MDT occasionally backup the geodatabase to an offline location, in case the subscription lapses or MDT decides to transition to a different program and cancel its ESRI license. This will require some degree of coordination with the staff in charge of MDT's AGOL licensing, to make sure they are aware of the RAMP. This will help reduce the risk that the RAMP layers are accidentally deleted from MDT's AGOL server.

In addition to the AGOL server, site photographs are stored on MDT's internal server system. These photos can be accessed via hyperlinks in the RAMP site information layer. MDT selected this method of photo management because storing the photos on ESRI's servers requires additional service credits, and would be too expensive. By storing the photos in files on MDT's server, MDT geotech personnel can also easily add new photos to a site's folder, capturing adverse events, mitigation work, or other changes.

Data stored within the RAMP database should also be kept up to date. Currently, data can be edited within the online space, a desktop environment, or in the field through the use of ESRI's Collector App. Rock slopes should be re-rated after any significant mitigation project or rockfall event. New rock slopes that meet the acceptance criteria should also be inventoried and rated as appropriate. On a broader level, MDT should conduct another large-scale assessment, similar to that performed in 2016, in 5 to 10 years. This assessment will capture changes in statewide conditions, and provide the Department with feedback to improve the rate of deterioration and life cycle models used in budget forecasting.

7.3 Incorporate Event Tracking Tools and Collection of New Data

To improve the quality of data used in risk and cost estimates, MDT should also encourage use of the event tracking tools developed as part of this research project. The rockfall event tracking tool is a simple question form hosted on AGOL that can easily be accessed from any computer with an internet connection. The form has intentionally been kept as brief as possible, to encourage busy maintenance supervisors or district geotechnical personnel to fill it out. Using the event tracker will help the department visualize where emergency maintenance is concentrated, track associated costs, and update predicted unit maintenance costs, as needed. It can also be added to the rockfall activity survey conducted by MDT for this project, and used to update the risk forecasting tools.

7.4 Conclusion

The MDT Rockfall Hazard Rating System is a robust and successful program that has served a useful purpose over the last 10 years as a means to collect data and rate hazards related to Montana rock slopes. Advancements in data collection and analysis, transportation asset management processes, and the advent of geotechnical asset management have made possible improvements to modernize the RHRS. This has allowed the RHRS to be transformed into the Rockfall Asset Management Program and the formation of a connection between the Geotechnical group and the Planning staff in the decision-making process for MDT project selection. The RAMP has the potential to improve the MDT transportation system by improving rock slope condition over time through lifecycle cost-based project decisions; safety by risk reduction through selective project development; and to reduce the life cycle cost of MDT slopes.

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Appendix A

TASK 1 REPORT – LITERATURE AND IT REVIEW

October 2015

Montana Department
or Transporation

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

Task 1 Report
Literature Search and Information
Technology Review

LANDSLIDE
TECHNOLOGY
A DIVISION OF CORNFORTH CONSULTANTS

Prepared for:

Montana Department of Transportation
Helena, Montana

ROCKFALL HAZARD PROCESS ASSESSMENT

TASK 1 REPORT

STATE OF THE PRACTICE LITERATURE SEARCH AND INFORMATION TECHNOLOGY

October 7, 2015

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Executive Summary

This document is the deliverable for Task 1 of the Montana Department of Transportation (MDT) research project “Rockfall Hazard Rating Process Assessment” (Project No. 15-3059V). The purpose of the review is to provide a synthesis of current knowledge and state of the practice of existing and newly developing systems for rockfall hazard management and their application in transportation asset management programs. MDT’s objective for the project is to obtain an evaluation of the existing rockfall hazard rating process and recommend updates as necessary for a more effective asset management system for their rock slopes. The updates are intended to be used as a planning device to provide guidance to MDT on selection and advancement of rockfall mitigation projects. This guidance is developed for use by MDT geotechnical staff as decision support tools to advance appropriate projects to the design and construction phases, either on a District or Statewide level.

The previous rockfall management project implemented the nationally and internationally utilized Rockfall Hazard Rating System (RHRS), with only minor adjustments to the climate categories. Implementing the RHRS consisted of visiting 2,653 rockfall sites; and performing detailed ratings, where 13 criteria are evaluated, at 869 of those sites. Of these detailed rating sites, a cutoff score of 350 points (of a total possible score of 1,100 points) was established to define highest-hazard, or ‘A’-rated sites. This resulted in a total of 368 A-rated sites on the evaluated MDT highway system (Figure 1).

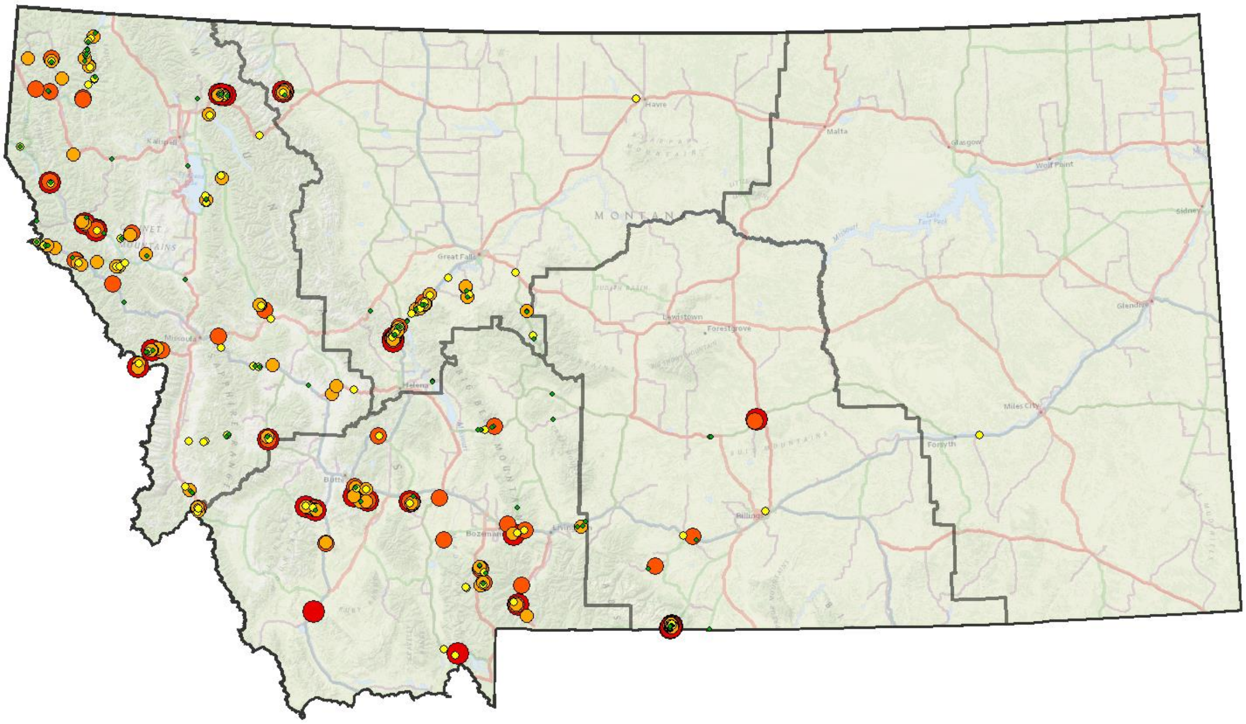


Figure 1: Map of 368 'A' rated slopes from 2005.

Based on this literature review, the most widely used rockfall ranking and management systems in North America are variations or modifications of the Rockfall Hazard Rating System, developed in 1993 (FHWA Publication No. FHWA SA-93-057). Other similar hazards rating systems, such as those for landslides, use a similar exponential scoring system as found in the RHRS (Liang, 2007). The DOTs of New York, Ohio, Utah, Washington, Alaska, Tennessee, and Missouri are all examples of agencies that along with MDT have utilized RHRS-based systems for ranking and evaluating rock slopes. In a 2008 survey (TRB, 2012), 25 U.S. State or Canadian Provincial transportation agencies utilize a management system to track rock slope data and most of these (88%) are based on the RHRS. Most of these agencies have made modifications to the RHRS to meet departmental goals and objectives, such as Montana's relatively minor modification for climatic criteria.

There have been two primary modifications of the RHRS in recent years. The first comes from the province of Ontario, Canada. In their Ontario Rockfall Hazard Rating System (RHRON), the rating categories are subdivided and grouped into four Factors to approximate 1) magnitude, 2) instability, 3) reach, and 4) consequences. Each of these categories are evaluated on a 0 (good) to 9 (bad) scale. This system uses categories from the RHRS and adds additional lab testing or estimations to further assess certain rock characteristics. Concepts in the RHRON system may be applicable to MDT's goals of identifying slopes with possible rockfall concerns in the short-term future and assist with ways to prioritize those sites.

The second set of modifications are the result of ongoing research into developing concepts of geotechnical asset management (GAM) by the Alaska Department of Transportation. The purpose of this research project is to develop a comprehensive plan to manage geotechnical assets, focused on rock slopes, unstable soil slopes and embankments, retaining walls, and material sources. The research includes development of a GAM Plan, inventorying assets, developing rating systems, conducting field ratings, developing condition states, deterioration curves, programmatic cost estimations, and modelling funding scenarios on maintaining these assets. The nearly completed project will be a comprehensive asset management program for geotechnical assets compatible with Alaska's Transportation Asset Management (TAM) plan. This project has demonstrated how to adjust RHRS-like inventory and rating programs into TAM-compatible systems based on condition states, which can be utilized for deterioration modeling and life cycle cost analyses to support efficient and cost-effective management.

The advent of readily available and inexpensive GPS-capable mobile computing platforms in the past five years has made inventory, mapping, and analysis more accessible to geotechnical personnel and planners. Utilizing these platforms would modernize the IT interface and make the use of the data less challenging and more intuitive, therefore increasing its use at more technical and managerial levels within MDT.

Major developments in the field of laser scanning and photogrammetry have occurred or become more widespread in the last 10 years. The use of aerial and ground-based laser scanning have made landform interpretation and monitoring much more accessible and accurate. Advancements in photogrammetry now make it possible to remotely measure rock joint orientations for engineering analysis, zoom in with greater detail for visual inspections, and generation of detailed surface models for change detection and volume calculations for quantitative analysis of rockfall activity.

The maturation of rockfall hazard management programs through alignment with asset management systems has been partially driven by the 2012 Moving Ahead for Progress in the 21st Century Act (MAP-21) and partially by increasing agency awareness of advances in management and technology. Through these advances, the process to inventory and assess slope condition and risks will be much improved. A modernized rockfall management system should meet the goals of MTD's developing asset management program and improve safety, mobility and efficiency for the road system. The MAP-21 law requires a streamlined and performance-based and risk-based transportation program for bridges and pavements but also encourages similar management practices for other types of transportation assets. The goals of this current project align with both the objectives of federal mandates and with MDT's goals and objectives.

1 Introduction

As transportation agencies modernize their infrastructure data collection and usage, they increasingly look for ways to improve the integration of data and analysis into routine decision making. This effort is intended to maximize the value of the data, to clarify what data items are needed and for what purpose, to establish expectations for quality and timeliness, and in the end, to help agencies make well-informed decisions. Transportation Asset Management (TAM) is the framework commonly used by state Departments of Transportation (DOTs) for these initiatives.

The Task 1 Report provides a background synthesis of existing and newly developing systems of rockfall hazard assessment, field data collection techniques, and a literature review of TAM and its application to rock slopes. Using rockfall data in an asset management program is a new concept, and therefore relies to some extent on studies that are underway and not yet published, as well as literature focused on asset classes other than rock slopes. Development of new concepts in this area is advancing rapidly, pushed by federal initiatives, increased concern about changed site conditions related to climate, and a growing realization that cost-effective management based on performance and risk management is needed to meet agency goals and objectives such as safety, mobility and efficiency. Agencies realize they must do more with less given the increasing intensity of road network usage and lower funding levels for added capacity, network redundancy and preservation of current service levels and asset condition.

In looking to the TAM literature for guidance, several important questions should be addressed:

- In what ways do rock slopes affect the performance of the transportation network?
- What properties of rock slopes change over time, causing changes in road network performance?
- What information is necessary, and can be gathered economically, to sufficiently understand and manage these effects?
- What actions can the agency take, with regard to a given rock slope, to maximize adjacent roadway performance and minimize cost over the long term?
- How can rock slope investments compete for limited funding in the same increasingly rigorous processes now being adopted for pavements and bridges?
- What is the right total level of investment in rock slopes to maximize road network performance, given fiscal constraints?
- How can stakeholders gain understanding and confidence in allocating money for the preservation and improvement of rock slopes?

For all classes of transportation assets, these questions have always been seen as highly relevant, but may have been dismissed as unanswerable except by professional judgment. Today, however, transportation agencies have the capability — in fact, are required by law — to give quantitative answers based on quality data, at least for pavements and bridges.

A major lesson learned from pavement and bridge management, and one now being learned for geotechnical assets, is that these questions are not as intractable as they may have appeared. This literature review will describe how the problem has been organized and attacked from several disciplines to construct the necessary standards, processes, and tools, which are now being applied to the management of rock slopes.

2 Rock slope inventories

One of the most established examples of a geotechnical asset inventory was developed for retaining walls in National Parks (DeMarco et al 2010, Anderson et al 2008). The Wall Inventory Program described in this manual addresses the full range of program design considerations, including inventory data fields, inspection interval, training, and field procedures. It has substantial sections devoted to the classification and qualification of geotechnical features. For example, consider Figure 2, depicting a structure consisting of placed stone on a constructed slope, with a face angle of 50 degrees. Is this a retaining wall? An embankment? A protected slope? Does it belong in the inventory at all?

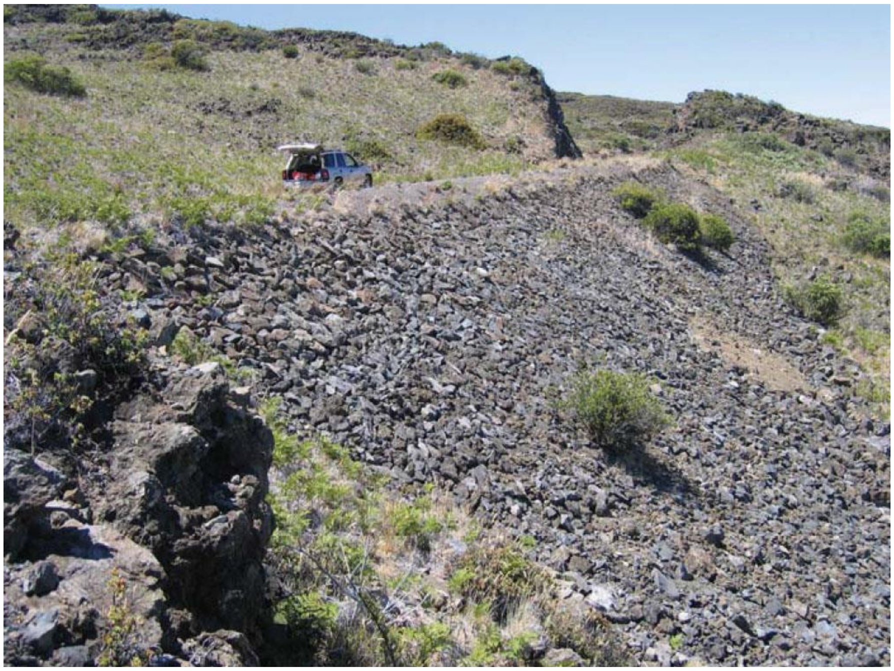


Figure 2: Geotechnical feature with ambiguous classification

The criteria for making this determination could consider any of the following:

- Does the feature impact transportation system performance, such as by presenting a failure or rockfall risk? Does a slope have to be unstable in order to be included? “Unstable” by what criteria?
- Is the feature man-made (as contrasted with naturally-occurring slopes in the vicinity of a road)?
- Is the feature wholly or partially on agency-owned or publicly-owned land?
- Is the feature historic, monumental, or culturally significant?
- Does the feature require maintenance or programmed work to ensure transportation system performance?
- Is the feature already part of a bridge or other asset managed separately (a determination made in order to avoid counting the same feature in two different inventories)?
- Does the feature satisfy geometric criteria for inclusion in the program as a whole, or in a specific asset category? Such criteria might include maximum height of the structure above lower ground, maximum change in ground level, length of the feature or structure, face angle, distance from a transportation facility (lane line, bikeway, sidewalk, parking lot, etc.), and configuration of tiered walls.

- What structure types and materials are included? What usage is included above and below the feature? For example, are culvert headwalls, protected abutment slopes, and bridge wingwalls included (if not already in the bridge inventory)? Are river banks (protected or unprotected) included as embankments or as slopes (stable or unstable)?
- Are buried or partially-buried assets included, and what inferences, if any, should be made about buried assets which affect the inclusion or classification of geotechnical features?
- It is also necessary to determine the physical boundaries of the inventory asset. For example, a rock slope is 1000 feet long, but most of it appears to be stabilized by slope angle and vegetation. However, two 100-foot sections are chutes with rockfall in evidence. Is this two short slopes, or one long slope?
- Can a structure of uniform design and material be divided into two or more asset classes, for example part retaining wall and part protected slope? How is the transition between the two parts determined?

Slope characteristics are routinely modified by maintenance crew activities or small construction projects. It may be difficult to ensure that the asset inventory is kept up-to-date with such changes. If the geometric criteria are set too low, or if the inspection interval is too long, or if inventory inclusion criteria are affected too much by natural events or inspector judgment, this can cause significant concerns about inventory accuracy. These factors are also directly related to ongoing inspection costs.

Fortunately for MDT, these criteria were largely determined during the 2005 Rockfall Hazard Rating System program implementation. The included rock slopes were delineated as follows:

- All rock slopes that were excavated as part of road construction were included for evaluation.
- Natural outcrops within ROW were included; those outside ROW, unless judged as highly active with the ability to affect the roadway, were excluded.
- Rock slopes with no ability or history of providing rocks on the road were excluded from the database as “C” slopes, rock slopes with a low hazard were included as “B” slopes, and those with a high hazard were included as “A” slopes and received a detailed evaluation. Scores from the detailed evaluation were then used as a cutoff (350 points) between “B” and “A” slopes.
- Long slopes were subdivided by either topographic depressions within the slope (e.g. gullies), geologic characteristics (jointed hard rock versus soft rock subject to rapid differential erosion), or rock slope condition and mitigation approach (basic roadside barrier versus on slope mitigation measures).

2.1 Other inventory resources

Several survey and synthesis reports have been prepared which summarize the types of inventory and condition data gathered by transportation agencies. Few of these reports address geotechnical assets at a useful level of detail for the present study, but many have useful ideas and insights that can be adapted. These reports include the following:

- FHWA has published a guide for asset management data collection, presenting the results of a survey of the states. It provides a broad overview (but not much detail) on data collection methods and data uses related to management systems for pavements, bridges, highway safety, traffic congestion, public transportation facilities and equipment, intermodal transportation facilities and systems, and maintenance (Flintsch and Bryant 2006).
- The 2006 AASHTO Asset Management Data Collection Guide provides data dictionaries for drainage, roadside, pavement and traffic assets; guidance on data collection frequencies;

describes data collection equipment options; provides an overview of data processing, storage and analysis procedures; and discusses data integration considerations. It has a short section on slopes which focuses on slope dimensions and erosion (Task Force 45, 2006).

- NCHRP Synthesis 371 provides detail on current practices for maintenance of performance and service life information for signals, lighting, signs, pavement markings, culverts and sidewalks. It is based on a survey of 35 transportation agencies as well as an extensive literature review (Markow 2007).
- NCHRP Synthesis 301 presents a methodology for collecting Global Positioning System data and integrating it into geographic information systems (Czerniak 2002).
- A 2005 FHWA report on Roadway Safety Hardware Asset Management Systems presents case studies of road feature inventories. This report includes detailed information on inventory and condition assessment methods and frequencies for selected agencies, as well as the results of a broader survey (Hensing and Rowshan 2005).
- NCHRP Synthesis 367 focuses on the management of crash data, and also includes a review of methods and technologies for collecting roadway inventory data (Ogle 2007).
- Minnesota DOT has a compendium of useful resources for management of retaining walls (CTC 2013).
- North Carolina's Asset Management Inventory process includes a treatment of embankments, slopes, and earth retaining walls (Kim et al 2009).
- The National Bridge Inventory Coding Guide (FHWA 1995) provides detailed requirements for collection and submittal of required bridge inventory and condition data items.

2.2 Other agency RHRS rockfall inventories

As part of project planning and scoping in the Alaska program, the University of Alaska at Fairbanks reviewed nine rockfall programs (Huang & Darrow, 2009). This study found these programs drew heavily on the Rockfall Hazard Rating System (RHRS) assessment categories developed in the late 1980s, but they often expanded on, altered, or replaced the initial RHRS evaluation categories to cover unstable soil slopes or to meet specific geographic or department needs, as was done in Montana. In general, the surveyed inventory programs utilized a two-stage implementation, with preliminary ratings followed by more detailed evaluations. The unstable slopes management systems surveyed and evaluated in the Phase 1 study included:

- Oregon DOT-I, 1985; an RHRS system developed to assess rock slopes across the state.
- Oregon DOT-II, 2001; a new rating system applicable to rock slopes, landslides, and debris flows, unlike the rock slope-specific 1985 program.
- Ohio DOT, 2007; a Geologic Hazards Management System (GHMS) designed to manage landslides across the state, as well as potential hazards posed by abandoned mines, karst, and shoreline erosion.
- New York DOT, 1988 and 1993; a Federal Highways Administration (FHWA) – based system for evaluating rockfall sites across the state.
- Utah DOT, 2001; a multi-phase rockfall rating system, with the rockfall hazard inventory in Phase I followed by rockfall hazard rating for select sites in Phase II. Applied Oregon DOT-I in Phase I and drew from Oregon DOT-I, Oregon DOT-II, and New York DOT to develop suitable parameters in Phase II.
- Washington DOT, 1993; a matrix-based rating system designed to rate rock slopes, landslides, erosion, and settlement.

- Tennessee DOT, 2000; a two-phase rockfall hazard rating system, using the standard RHRS in Phase I, and a detailed RHRS rating system slightly altered to meet state-specific needs.
- Missouri DOT, 2004; a two-phase rating system which organized parameters into “risk of failure” and “consequence of failure” categories, instead of the “hazard” and “risk” categories used by other DOTs.
- British Columbia Ministry of Transportation, 2000; adopted the RHRS system developed in Oregon DOT-I, but converted units to metric and Transportation of Canada (TAC) standards.

A study was undertaken in 2008 to ascertain the current state of the practice in the use of rock slope management systems within the United States and Canada. They survey result in responses in from 50 agencies (8 Canadian, 42 US). Forty-two of these respondents indicated that rockfall issues pose some level of safety concern or maintenance burden, with 36% indicating high hazards, 40% medium hazards, and 24% low hazards. Of these, approximately half of those indicating high or medium rockfall hazards exist undertake a systematic rock slope rating or ranking process, including Montana. This survey indicates that Montana is among the leading agencies in North America systematically assessing their rock slopes.

2.3 Recently Developed System - RHRON

The primary development in approach to evaluating and inventorying rockfall sites in the past 10 years, besides their integration into TAM plans, has been the development of a rockfall hazard rating system by the Canadian province of Ontario, called RHRON (Ontario Rockfall Hazard Rating System) (Franklin et al, 2013). This system, loosely based on the Oregon DOT-I RHRS, was developed to determine four primary factors, rated good (numeric score of 0) to bad (9):

F1 – Magnitude “How much rock might come down?”

F2 – Instability “How soon is it likely to come down?”

F3 – Reach “What are the chances of rock reaching the roadway and how much of it will be blocked?”

F4 – Consequence “How severe will be the consequences?”

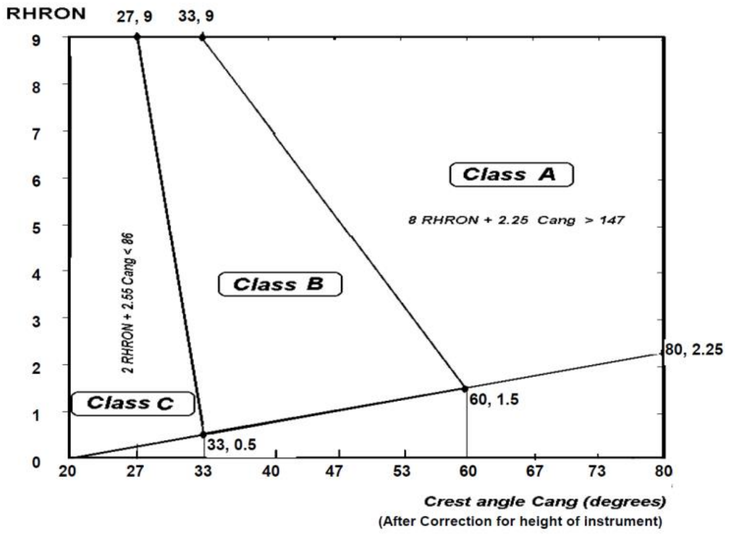


Figure 3: RHRON Classification Scheme.

Following a preliminary evaluation focused largely on the angle from the edge of pavement to the highest potentially unstable rock (termed Crest angle), those meeting “Class A” criteria (Figure 3) are the subject to a detailed rating evaluation. This crest angle evaluation effectively quantifies the relationship between slope height, slope angle, and ditch width, but neglects to account for flatter slopes resulting in additional horizontal velocity or for launch features reducing ditch effectiveness.

The detailed evaluation evaluates 20 different criteria that include those found in MDT's RHRS as well as additional categories that evaluate rock strength criteria and judgement-based estimates of the largest potential rockfall volume and a total of potential rockfall volume. Various combinations of these categories are then combined to determine the F1 through F4 criteria outlined above. A flow chart of RHRON criteria is shown in Figure 4.

The criteria that may be of the most interest to MDT is the approach to F1, Magnitude and F3, Reach. Factor 1 offers an approach to estimating the quantity of material subject to failure while components of F3 evaluates the likelihood of the material reaching the roadway. These factors may be extracted from MDT's existing RHRS with some definition modification. Coupled with possible Functional Classification cutoff, traffic volume thresholds, life-cycle cost analyses, and risk models, a variety of prioritization approaches could be formulated.

2.4 Recently Developed System – AKDOT Unstable Slope Management Program

The Alaska Department of Transportation and Public Facilities (AKDOT) has undertaken extensive research in the development and implementation of the nation's first-ever comprehensive Geotechnical Asset Management (GAM) system that is compatible with TAM systems and approaches for assessment of condition, risk, programmatic cost estimations, deterioration, and life cycle cost estimation for rock slopes, unstable soil slopes and embankments, and retaining walls. For condition assessment, the condition of rock slopes has been evaluated based on two primary criteria; rockfall activity and ditch effectiveness. Other RHRS factors, such as geologic characteristic, height, decision sight distance, etc. are measured and recorded to generate an RHRS-like exponential score, but only select few conditions are used to evaluate condition.

Ditch effectiveness, as a measurement of slope condition, is the ability of the roadside ditch, including any improvements and slope defects, to restrict rockfall from entering the roadway. This includes both improvements to the ditch and slope and also defects in the ditch or on the slope, such as launch features and full ditches, which increase the ability for rocks to reach the roadway. Geologic characteristics that affect the rockfall activity, such as high differential erosion rates or continuously oriented adverse jointing, that are evaluated in other categories are accounted for in the activity category. This is also similar to the RHRON Crest angle evaluation criteria, but also accounts for irregularities, defects, and improvements that may be in place.

The evaluation of both criteria are compared to descriptions contained in the RHRS and are combined to form a Condition Index (0-100, failed to new condition), Condition States (1-5), and Good/Fair/Poor groupings. These scoring criteria are <u>not</u> exponential like the RHRS and also are reversed for indication of good (high numbers) to poor (low numbers), but are consistent with standard approaches to slope degradation modelling and other TAM criterial. However, these can all be calculated from the exponential scoring criteria and definitions utilized in the RHRS. As discussed earlier, this approach permits for the utilization of expert judgement in the field to evaluate ditch effectiveness in light of existing launch features, narrow ditches, and the improvements from rockfall mitigation measures such as draped mesh, attenuator fences, and concrete barriers. Improvements to reduce the rockfall activity, such as rock bolts, cable lashing, and pinned mesh, will improve the rockfall activity scores and result in condition improvements from decreased activity levels.

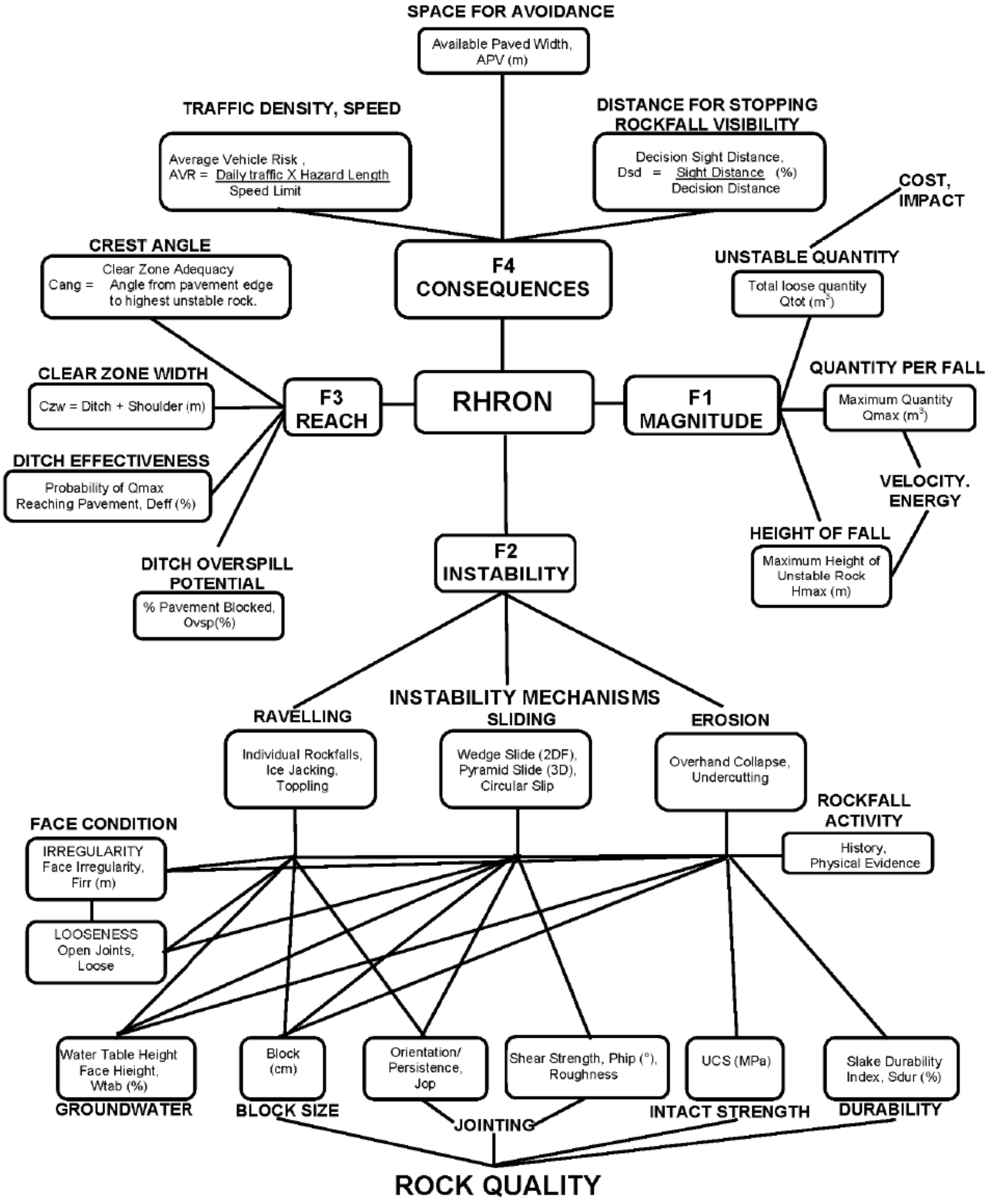


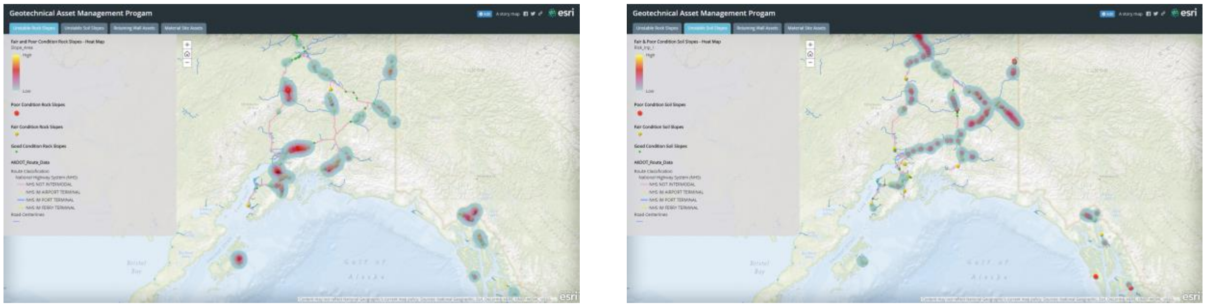
Figure 4: Flowchart for individual components of the four RHRON factors.

Table 1: Rock Slope Condition States from AKDOT (2015).

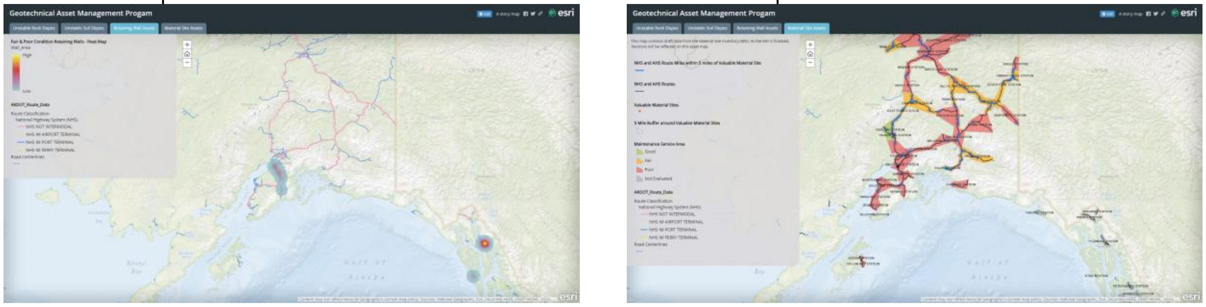
Condition State, Condition Index and Action Level	Description
1- Good (80-100) No action needed	Rock slope produces little to no rockfall and no history of rock reaching the road. Little to no maintenance needs to be performed due to rockfall activity. Mitigation measures, if present, are in new or like new condition.
2 – Fair (60-79.99) Review status at 5-year intervals	Rock slope produces occasional rockfall with a rock rarely reaching the road. Some maintenance needs to be performed due to rockfall activity to maintain safety. Mitigation measures, if present, are in generally good condition, with only surficial rust or minor apparent damage.
3 – Fair (40-59.99) Inspect at bi-annual intervals. Consider mitigation efforts.	Rock slope produces many rockfalls with a 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 damaged minor elements. Preventative maintenance or replacement of minor mitigation components is warranted.
4 – Poor (20-39.99) Inspect annually. Perform major rehab and repair efforts.	Rock slope produces constant rockfall with rocks frequently reaching the road. Maintenance is required annually or more often to maintain ditch. Mitigation measures, if present, are generally ineffective due to significant damage to major components or deep apparent corrosion.
5 – Poor (0-19.99) Perform major mitigation or reconstruction efforts	Rock slope produces constant rockfall and nearly all rockfall reaches the road. Virtually no rockfall catchment exists. Maintenance is cleaning rock off the site regularly, possibly daily during poor weather. If present, nearly all mitigation measures are ineffectual either due to deferred maintenance, significant damage, or deep corrosion.

The AKDOT GAM program is utilizing the State's ArcGIS online accounts for the presentation and distribution of rating data and exhibition of poor asset condition (Figure 5). Eventually, MDT's RHRS could be based on a similar platform, as discussed below. If additional geotechnical assets, such as landslides and retaining walls are eventually added to MDT's Asset Management system, tabbed maps can be added to the interface.

MDT has the critical elements of rock slope condition already collected and assessed through the RHRS. Due to the variable nature and the judgement involved with assessing rockfall potential, hazard, and activity, the larger variety of elements to evaluate as illustrated in the bridge examples above are not typically required for rock slopes.



AKDOT rock slopes AKDOT soil slopes



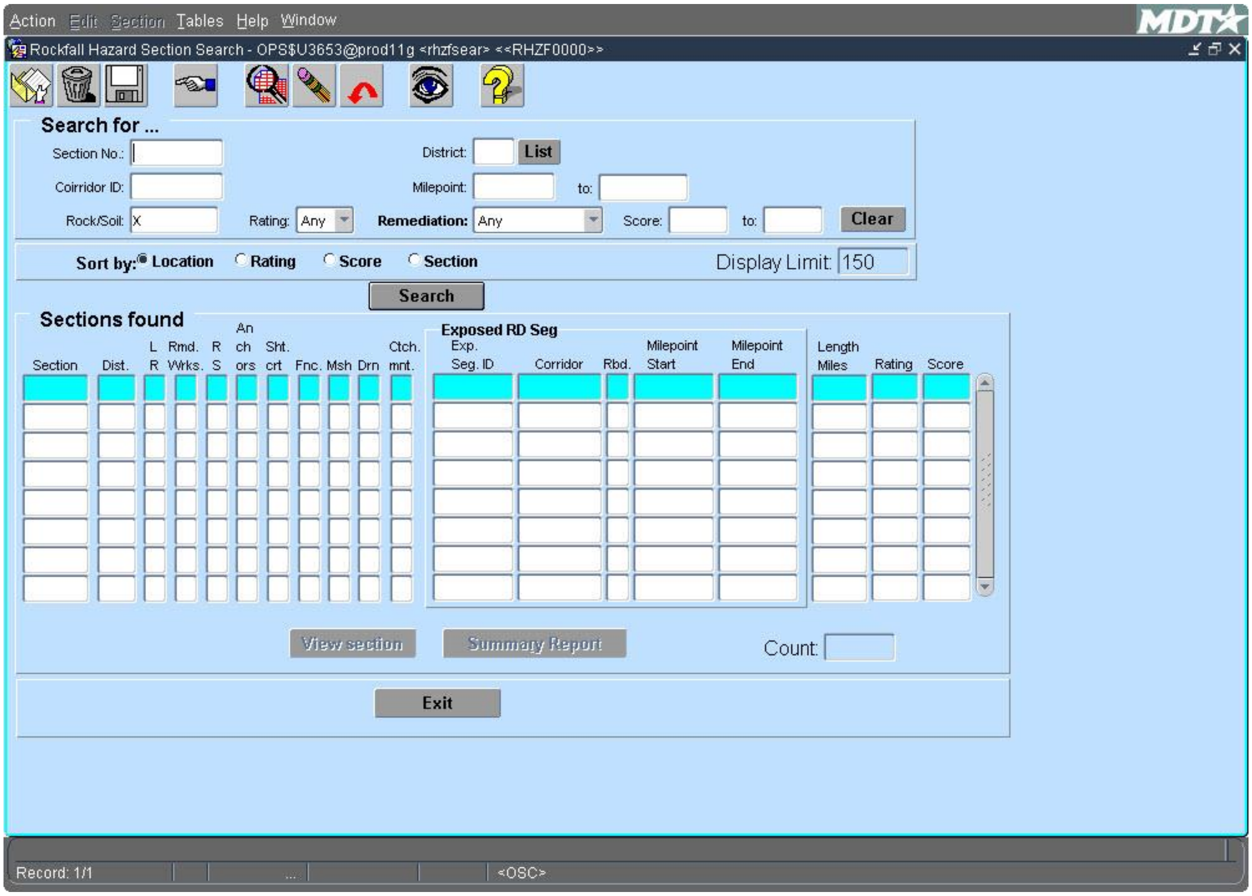
AKDOT retaining walls AKDOT material source scarcity by M&O Station

Figure 5: AKDOT ArcGIS.com interface with all geotechnical assets available from one internet portal.

3 MDT’s existing digital rockfall inventory management system

MDT has existing IT infrastructure and an Oracle system in place for storage and review of RHRS information. This system, however, would not be considered a “modern” IT implementation and is not entirely user friendly or widely used by staff.

The system consists of an Oracle instance in MDT’s enterprise database system along with an Oracle Forms application for end users. Oracle Forms is a Java based interactive “screens” platform for application development to interface with an Oracle database. It is primarily intended as data entry or basic query/review application environment. It is not a true “Rich Application Interface” that can provide users with ease of use or design features, such as streamlined mapping and geographic queries that users have come to expect in the Google era. An example search screen for the existing application is shown on Figure 6.



Rockfall Hazard Section Search - OPS$U3653@prod11g <rhzfsear> <<RHZF0000>>

Rock/Soil: X

Rating: Any

Remediation: Any

Sort by: ● Location ○ Rating ○ Score ○ Section

Display Limit: 150

Record: 1/1

<OSC>

Figure 6: Search Screen from the existing Oracle application.

Beyond the “old school” nature of the platform and accessibility, the current application provides only a few functional abilities: create new record, search, and view existing record(s). The application does not provide a functional ability to “update” existing records nor maintain any sort of “version history”. The end result is that the system is simply an inventory and “snapshot” of the original assessment information. The search mechanisms are also cumbersome to use. The application provides only basic lookup based on record identifiers (e.g. section number) that are not commonly known to end users. Spatial searches and other detail attribute searches are not available.

Another detraction to the system is that RHRS information cannot be displayed visually in conjunction with map features and other related media (pictures, video, reports, etc.). GIS integration is done ad-hoc, manually using commercial off-the-shelf (COTS) applications e.g. ArcGIS for Desktop by advanced analyst users. Even in this use scenario, there is no automated connectivity between the GIS features and the RHRS information.

3.1 Future Systems Recommendation

Leveraging the current RHRS information database environment, a modern information system and end user application environment can be constructed to meet staff needs for everyday information access and upkeep as well as provide dashboard-type overviews for program and business managers and potentially real-time connections with field data collection. This enhancement to the system can be achieved with a combination of existing vendor platforms e.g. ArcGIS.com, COTS sub products, and refined workflows. Custom application development of the “templates” provided by ArcGIS.com would be required to achieve some specialized functional abilities but the scope of work would be considerably less than a full scale custom application development project.

Integration with COTS field products like ArcGIS Collector would allow for off-line data use for staff working disconnected in the field and real-time data entry. Data accuracy and lineage would be improved, which in turn would provide staff with better information with respect to rockfall hazards.

Using GIS map services hosted with the State of Montana and ArcGIS.com, the following example web template application shows “click-to-access” functionality with integrated links to images and data:

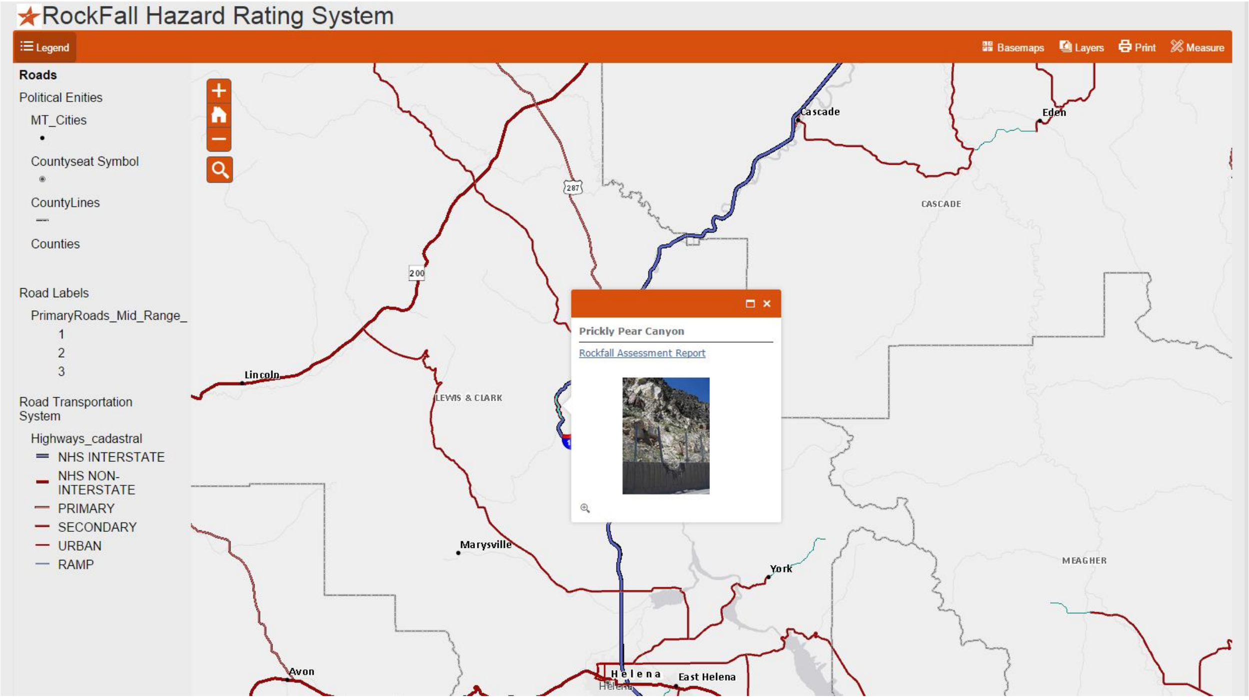


Figure 7: Mock-up of potential future MDT rockfall web-based GIS interface.

4 Data Collection Techniques

In the past decade, there has been a number of developments in the availability and use of technological advancements in consumer mobile computing platforms and in remote sensing techniques. Advances and techniques relevant for rock slope hazard monitoring and assessment are summarized below.

4.1 Field GIS and Mobile Computing

Previously, powerful computers capable of high resolution imaging and display, retrieving data from remote servers, and capable of geolocation were very high-end products and were not generally available to the public. With the advent and mass-adoption of smart phones and portable, cellular-capable tablets, the ability to collect and store data in user-friendly, affordable devices across multiple platforms and operating systems has become more realistic and cost-effective (Figure 8).

While third party or Open Source solutions are available, the most comprehensive platform that leverages new-generation devices and operating systems is ESRI. Coupled with ArcGIS online accounts, collecting GIS data utilizing Android or Apple iOS devices are possible via ESRI's Collector Application. This permits the mobile collection of data using affordable, easily replaceable devices and automated data backup onto remote servers either via a cellular network or offline data collection with nightly backup on a wireless network. The data is immediately available through ArcGIS.com online maps or Windows-based desktop computers with ArcMAP.

Landslide Technology has found these systems to sometimes be error-prone and have problems uploading data collected offline on a nightly basis, though these issues may have been the fault of configuration errors outside our control. With proper configuration and training, these mobile devices and applications have the promise to collect accurate field data with a high degree of confidence, ease-of-use, and reliability.

Figure 8: ESRI's Collector Application on Android, iOS, with Windows-based ArcMAP exhibiting field data.

4.2 LiDAR and Laser Scanning

LiDAR is an acronym that stands for light detection and ranging. LiDAR has become increasingly common for landform interpretation for geological, geotechnical, habitat, biologic assessments and many other uses. Laser light pulses are emitted and return times of each pulse are recorded, permitting the delineation of vegetation (first pulse return) to those on the ground (last pulse return). Through data processing to generate a point cloud of the last pulse returns, a vegetation-free, bare earth model can be generated and mapped for detailed geomorphic surface interpretation. This technology is used from a variety of platforms.

A drawback of all laser techniques is that it is a line-of-sight method from a single point. Features not within view of the scanner cannot be measured, potentially omitting significant features from measurement. For aerial LiDAR, rock slope overhangs are undetected. For terrestrial laser scanning, features out of view or ‘around the corner’ from steep features are not seen or measured. Mobile LiDAR exhibits similar drawbacks.

4.2.1 Aerial LiDAR

This method of Aerial LiDAR Scanning (ALS) data acquisition has been the most common and useful for geotechnical and geologic professionals over the past 10 to 15 years. The bare earth models have permitted a wide variety of landform interpretation, particularly for landslide identification and delineation. A recent example of this functionality has been utilized following the Oso, Washington landslide disaster in 2014 (Figure 9) (Haugerud, R.A, 2014).

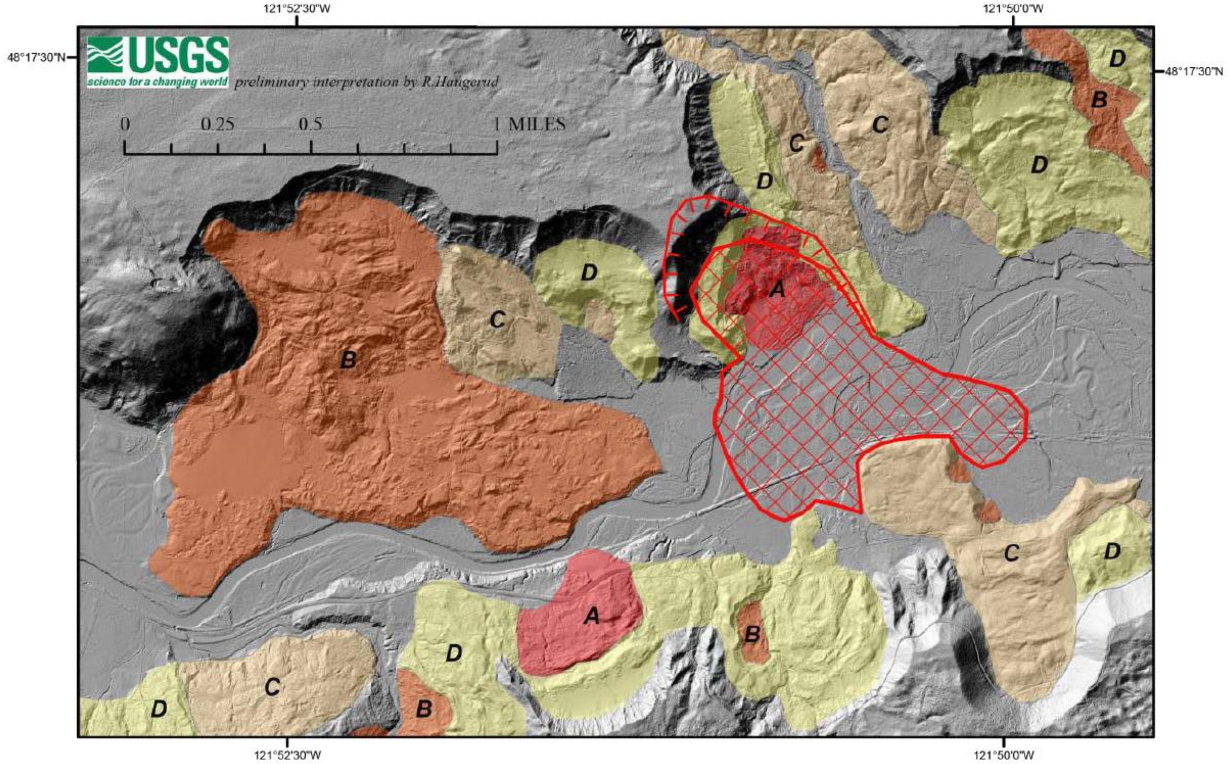


Figure 9: Landslide Interpretation following the 2014 Oso landslide.

Recently, MDT has utilized LiDAR on the D3 rockfall mitigation project on Interstate 15 between Helena and Great Falls. These detailed maps permitted detailed rockfall modeling and plans preparation. For purposes of rockfall hazard assessment, aerial LiDAR would provide detailed surface maps that may illustrate significant features that could contribute to rockfall, such as wide tension cracks, presence of large boulders, orientations of exposed, large structural planes, etc. Smaller features and those obscured by dense vegetation are typically masked and could only be identified by a detailed ground reconnaissance. Multiple, repeat LiDAR surveys can be used for surface change detection where significant block movement between surveys may be identified by subtracting the two surfaces from one another and identifying resulting anomalies. While this has been performed for landslide detection (for example, Burns et. al., 2010), this technique for has not been used for detection for the type of rockfall common to highway rock cuts.

Due to the steep nature of most rock cuts, downward facing instruments and the resulting low point density on rock cut faces, it is doubtful that ALS would prove to have the point density required for accurate change detection for rock slope monitoring, except where the slope angle is sufficiently flat. Where this method could prove useful is change detection in rockfall containment ditches that may go uncleaned for a prolonged period, such as the highly active slopes ascending to Lookout Pass on I-90. Past studies that have focused on using ALS for rock slope monitoring has been on large, mountain-scale rockslides, reinforcing that the ALS approach to small-scale rock slope movements and change detection is still tenuous on steep rock cuts (Jaboyedoff et al, 2012).

4.2.2 Terrestrial Laser Scanning

Ground-based terrestrial laser scanning (TLS) has been used to obtain highly detailed surface maps of rock cuts for monitoring on a variety of research and practical projects (Jaboyedoff et al, 2012). In this application, the laser scanning devices is set-up and georeferenced via a control survey much like a traditional theodolite. After set-up, a ‘window’ where the detailed survey is to take place is programmed into the robotic scanner and scanning begins. The subsequent point cloud is then manipulated back in the office for referencing and correction. Other analyses, such as discontinuity identification, classification, and measurement can also then take place. Multiple surveys can be compared and used for detection of movement (Figure 10)

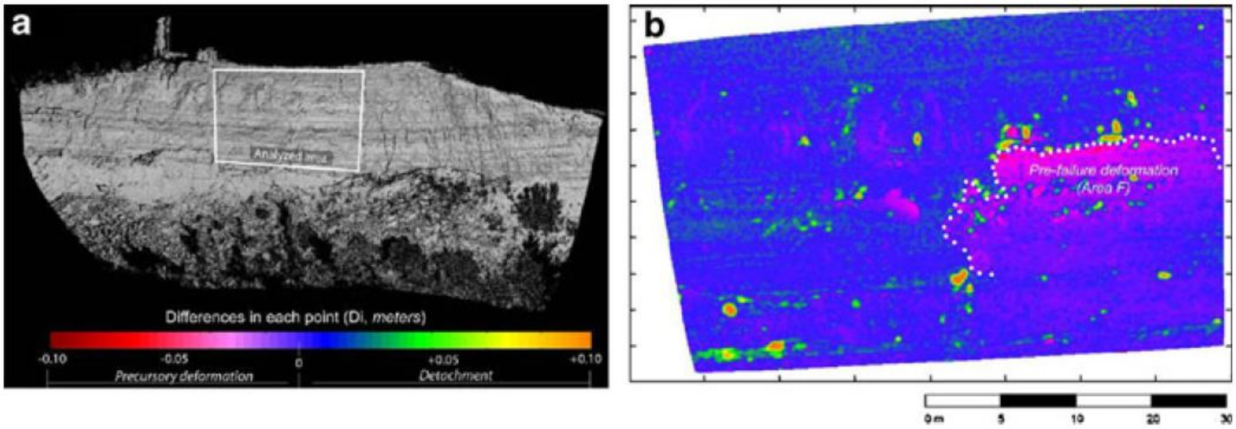


Figure 10: TLS surface comparisons used for deformation detection (Abellan et al., 2010).

These scans have been subsequently used for detection and measurement of discontinuities using a variety of computational techniques (Jaboyedoff et al, 2012). TLS has been used in Montana on the US 2 Badrock Canyon Monitoring project near Columbia Falls between 2006 and 2011 before being discontinued. These scans (Figure 11) were used to monitor for small changes in the rock blocks on the slope at certain locations. In these instances, the change detected in the blocks were smaller than the accuracy of the instrument and/or control survey. This project demonstrated that TLS has promise for monitoring rock cut faces, but that the technique of surface comparison rather than comparison of only specific points on the slope would be a better application of TLS techniques.

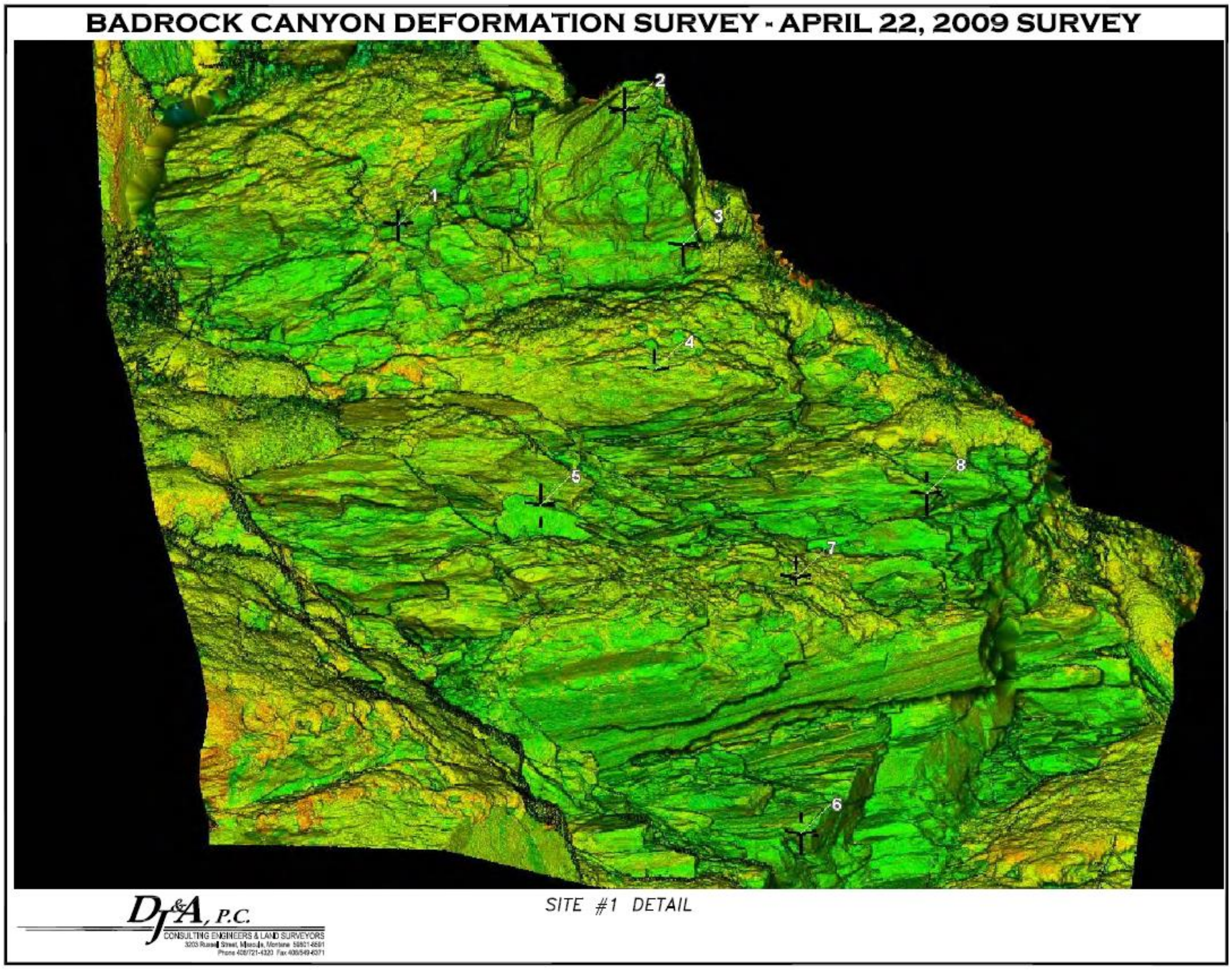


Figure 11: TLS survey on US 2 in Badrock Canyon. Numbered points indicate control point locations.

4.2.3 Mobile Laser Scanning

Similar to TLS, mobile laser scanning (MLS) utilizes a laser scanner, but instead of mounted on a tripod, it is mounted on a moving vehicle to rapidly obtain feature data visible from the roadway. This method relies on inertial GNSS/GPS referencing techniques and either real-time or post-processing for correct georeferencing of the point clouds. This technique has been used in pilot programs for unstable slope monitoring on the Parks Highway near Denali National Park, Alaska with promising early results for change detection on scree slopes (Figure 12). The Federal Highway Administration has sponsored a NCHRP report proposing guidelines for both TLS and MLS data collection on US Highways. (Olsen et al., 2013).

Like the TLS scanning techniques, MLS suffers from a degradation in point density the further the scanner is from the feature. Note that in Figure 12 the upper portions of these slopes are not well covered, so rockfall from these upper sources cannot be monitoring with this technique. Similar limited topographic data extent for geotechnical use has been observed in pilot projects for the Idaho Transportation Department. However, the use for managing short to moderate (<100 feet) height rock cut slopes, which are generally within full view from the roadway with light vegetation, is a promising data collection tool for comparative surveys to serve as an unbiased method for rockfall activity measurement.

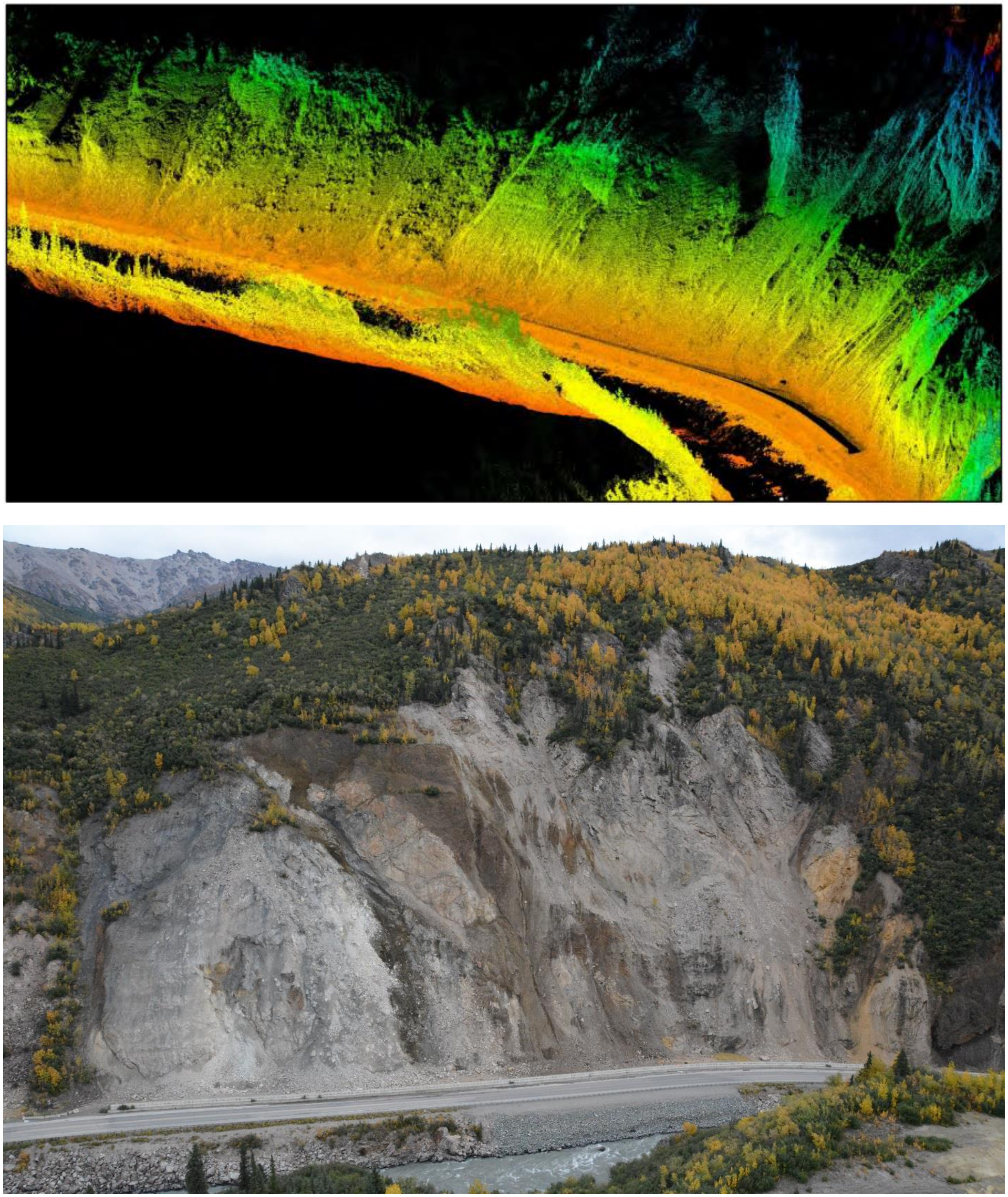


Figure 12: MLS scanning on the Parks Highway, Alaska with an aerial oblique photo from an alternate vantage point. Note the MLS data is limited to the approximately bottom third to half of this very tall slope.

4.3 Photogrammetric Techniques

Use of photogrammetric techniques for monitoring rock slopes and other geotechnical assets have recently been receiving additional attention for both highly detailed digital photographs and the ability for point cloud creation with the use of digital single lens reflex (DLSR) cameras and specialized software.

4.3.1 Gigapixel Photography

Digital cameras have simplified obtaining photographic records of rock slopes and other geotechnical features for long-term record keeping of condition and visual detection of changes. However, even most consumer digital cameras are within the 12 to 24 megapixel range. Having images easily enlarged on a computer screen versus using a loupe or magnifying glass on a film print offers a significant improvement. However, even with these new techniques, geologists and geotechnical engineers still find that they are often struggling to see change on the face of a rock slope. For these instances, obtaining a large number of photos and stitching them together using freely available tools offers the level of detail often sought after.

To create the panorama, the user first obtains a large number of photos (10 to 100 photos are typical depending on the distance to the feature and its size), ideally from one position. A DSLR with a moderate or long fixed focal length telephoto lens on a DLSR camera is ideal, though most cameras at a moderate zoom also produce acceptable results. Hardware to automate photograph acquisition are available, though not required. Next, the user then loads the individual files comprising the panorama into a software program[1] capable of creating, editing, and uploading the composite image. The image can then be used in the future as a precondition inspection record in the event of a significant rockfall or as visual record to replace minor site visits.

An example of a 630 megapixel photo composite from a Landslide Technology project in Alaska and the detail available from a maximized zoom are below and on the internet[2] is shown in (Figure 13).

4.3.2 Structural Geology Photogrammetry

The use of stereophoto pairs has long been a fundamental aspect of geologic work. The collection and use of digital stereo pairs for mapping and measuring geologic structures has recently become more accessible. The advantages of these programs (Sirovision, BlastMetrix, 3DM Analyst) are that they provide for acquisition of geological discontinuity data on slopes that are dangerous and/or difficult to access while leaving the roadway open to traffic. Other methods to collect this information require the geologist to be physically present to place a geologic compass on the discontinuity and would require either rope methods or lifts to access the slope, typically requiring full or partial road closures.

These software packages, initially formulated for the mining industry, utilize images captured by DSLRs to create three dimensional surfaces using proprietary image analysis algorithms. The surfaces are then georeferenced to either local, project, or global coordinate systems to determine distances, spacing, and orientations of critical discontinuities. These measurements can then be utilized for stereonet generation and engineering analyses. For rockfall hazard assessments, these techniques are best suited for focused study on a subset of high hazard, hard rock slopes that exhibit discontinuity-controlled (e.g. Type 1 RHRS slopes) rockfall mechanisms.

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[1] Image Composite Editor (http://research.microsoft.com/en-us/um/redmond/projects/ice/) with Photosynth.net (http://photosynth.net/) website (free) and Gigapan (http://www.gigapan.com/) (not free) are two options.

[2] https://photosynth.net/view.aspx?cid=160416b8-0d0a-475a-ac60-4e72284c5cd8

Figure 13: 630 Megapixel photograph and detailed zoom. Note 3-inch climbing anchors in the detailed zoom.

These techniques have been used for various rockfall mitigation projects for MDT on Interstates 15 and 90 in the past two years. The data has been shown to provide accurate and useful information for rockfall hazard assessment and design purposes. Sample images from the Sirovision software package from the D3 rockfall mitigation project on I-15 near the Prickly Pear Canyon entrance at Sieben is shown in Figure 14. This is a composite of 16 photos (8 stereo pairs) taken from the opposite side of the highway. An internet video demonstrating the process and use of Sirovision on the D3 project is located at http://landslidetechnology.com/rockfall-3D-Photogrammetry.htm.

The point clouds generated can also be imported into other point cloud manipulation programs for comparisons and change analysis. This technique was used on the I-90 MP 6.5 project in 2014 to approximate change in the slope configuration before and after failed wedge excavation (Figure 15).

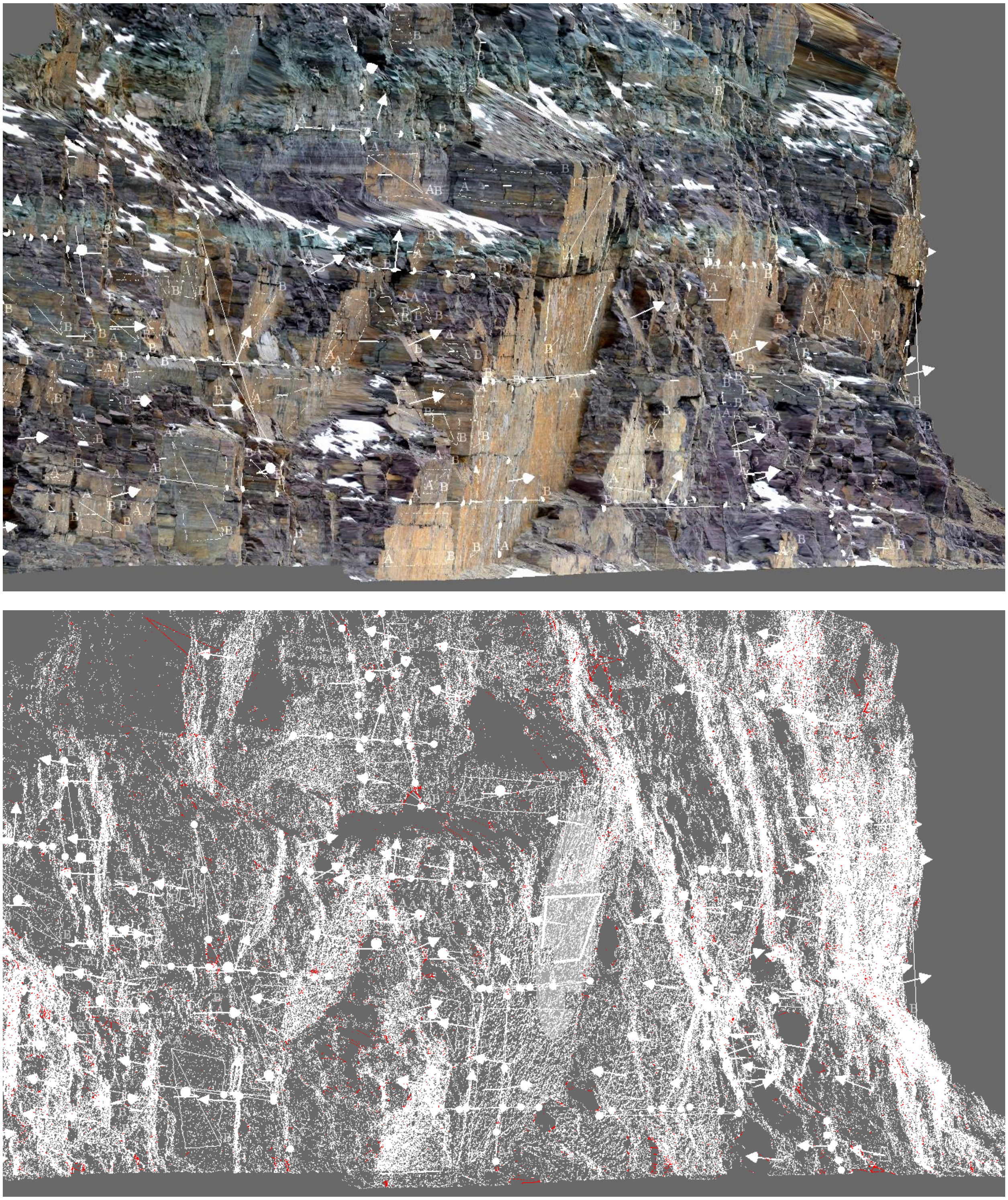

Figure 14: Sirovision-produced structural geology imagery. Photographic surface model above with the point cloud of the same region shown below.

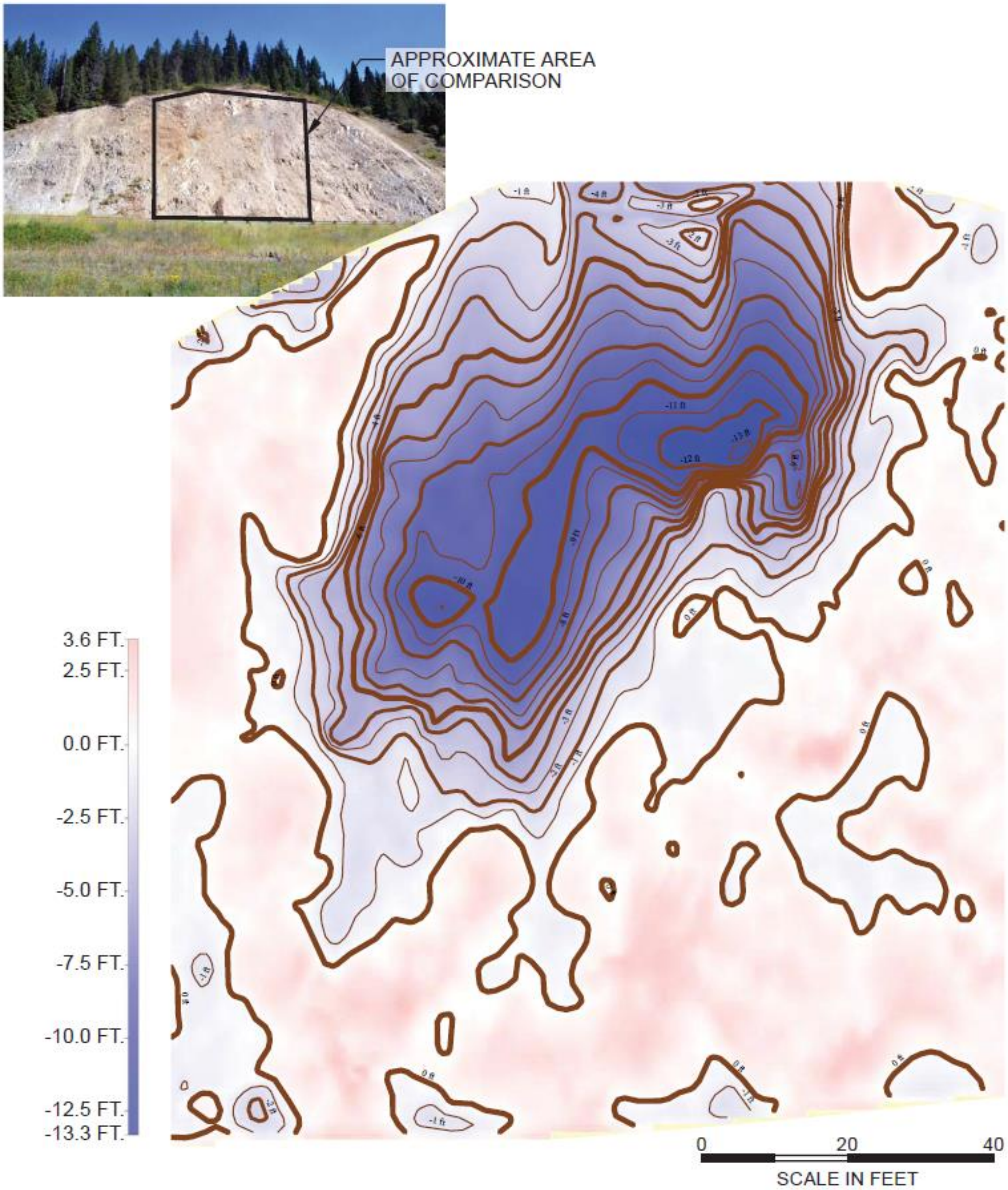

Figure 15: Surface comparison before and after slope excavation at the I-90 MP 6.5 rockfall mitigation project. Blue indicates where the most excavation took place.

4.3.3 Photogrammetric Surface Generation

A relatively new methodology for rapidly collecting and assessing hazardous rock and soil slopes above highways has been the release of professional-grade photogrammetric software. These newer software packages are intended for a wider user base (survey, cultural, Hollywood visual effects, etc.), thus making software more affordable with associated online user groups also available.

Agisoft's PhotoScan photogrammetric software has recently been used to monitor rockfall activity above rail and transportation corridors in Canada and for a pilot program for the Colorado Department of Transportation (Lato et al., 2015). This software permits the rapid creation of surface models from photos collected via aerial oblique photos or from the ground surface. Photos collected from a helicopter with its doors removed offers the most rapid data collection technique while still producing reliable and accurate results. Using this method, an entire corridor (such as I-90 near Lookout Pass) can be photographed from a helicopter in an afternoon with corresponding surface models generated and georeferenced soon thereafter. Figure 16 illustrates the surface model generated at the Parks Highway site in Alaska.

Figure 16: Parks Highway PhotoScan surface model. Blue squares indicate helicopter positions. This low density surface consists of 1.6 million points and 323,000 TIN faces.

Repeated surveys can be used to detect changes resulting from rockfall activity or mass movement. Landslide Technology recently tested the technique for AKDOT by comparing a 2011 ALS LiDAR surface to the surface model generated by PhotoScan. Following a georeferencing process in another software package (CloudCompare), the surfaces were compared with absolute differences shown in Figure 17. This comparison revealed potential landslide movement generating rockfall activity from the weak rocks present on the slope as well as more active rockfall chutes on the southern (right) edge of the slope. Note the debris accumulation indicated in ditch, signifying a concentration of rockfall activity.

These datasets illustrate a key advantage of this photogrammetric technique; the nearly normal incidence angle of the photograph to the slope face results in an even point density that stays consistent to the top of the slope. This preserves details that would otherwise be lost from road-based survey techniques and also permits observation of overhangs that would not be seen from ALS techniques.

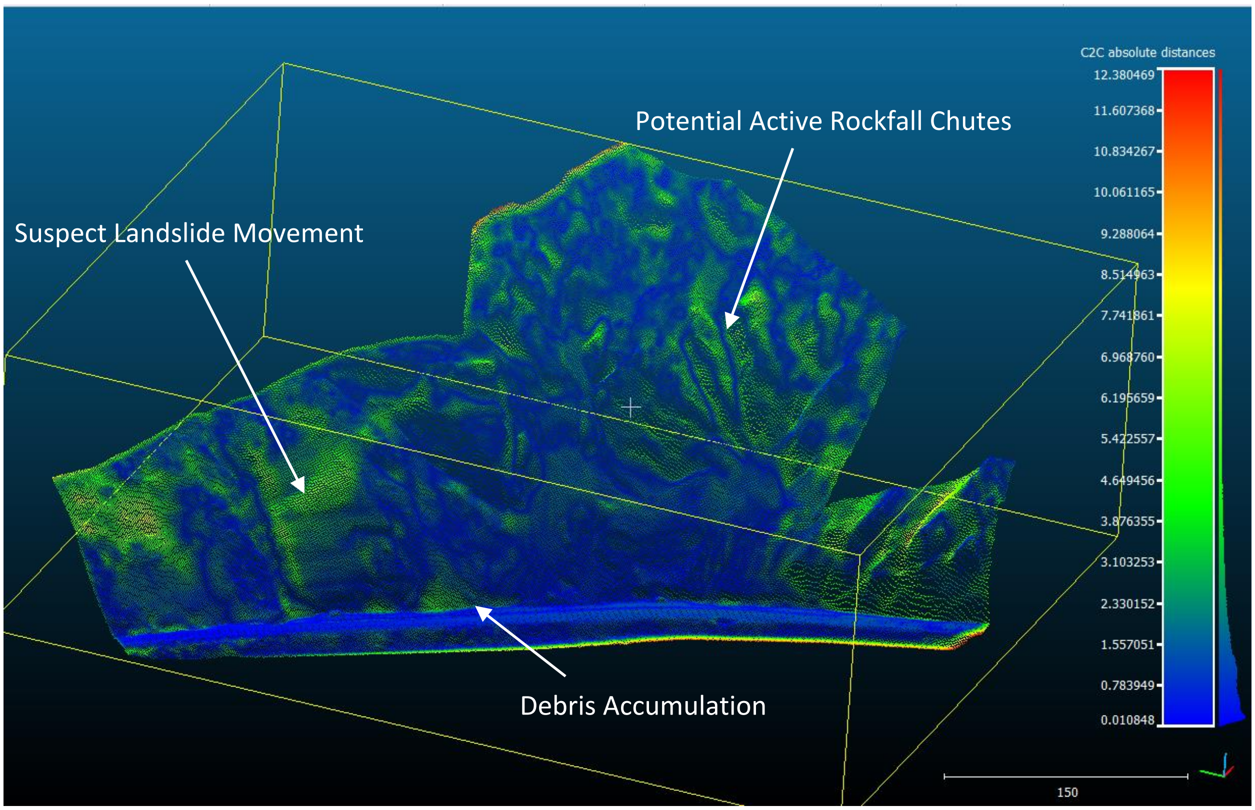

Figure 17: Surface comparison between 2011 LiDAR and 2015 PhotoScan surface model generated by CloudCompare. Greens indicate surface changes.

On a recent field visit to the US 2 Badrock Canyon site, photos were collected from the roadside and importation into PhotoScan was tested for suitability. Ninety-three (93) separate photographs were needed to create the surface model (Figure 18). A low density cloud resulted in 2.27 million points along a 450-foot section of roadway. To focus on a smaller area within the same rock cut, a smaller set of 12 photographs was used to create a high point density surface. This subset resulted in 18.35 million points over approximately a 25x40-foot area, or approximately 18,000 points per square foot in this model.

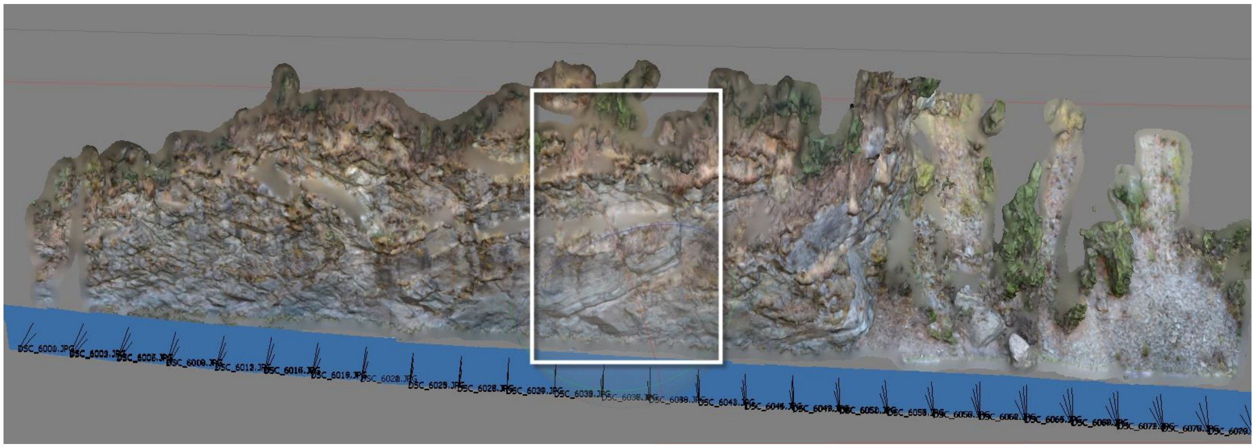

Figure 18: US 2 Badrock Canyon Model. Box indicates detailed zoom area in next figure.

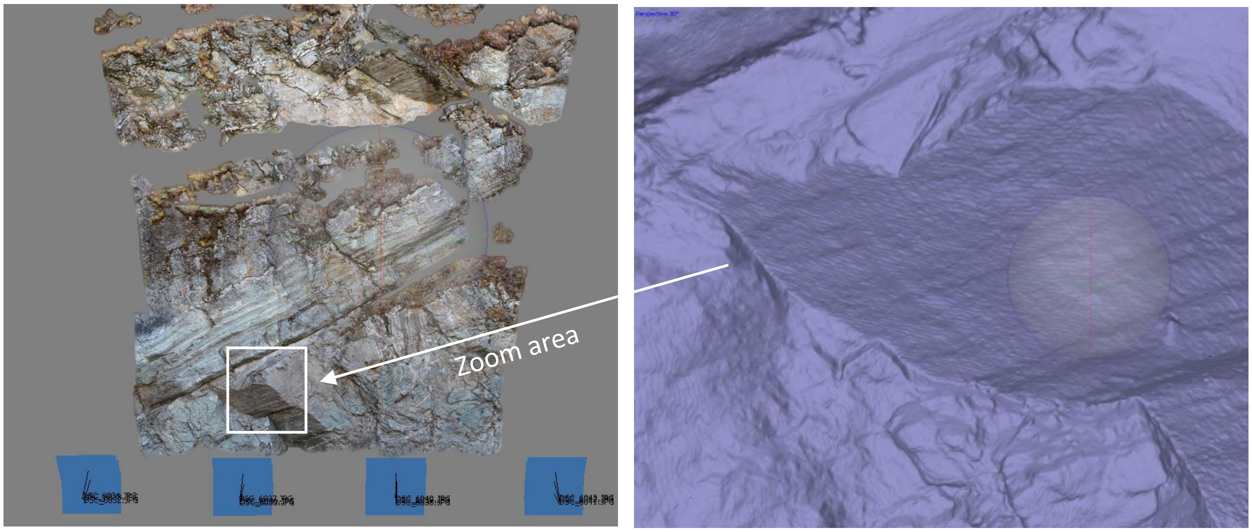

Figure 19: US 2 Badrock Canyon Model Detail. Photo model on the left and a detailed solid model on the right.

4.4 Data Collection Summary and Recommendations

The techniques and approaches summarized above illustrate recent methodology developments in field data collection and rockfall hazard assessment and management techniques. These methods were not available in 2005 and can now be utilized to better leverage available technologies. At this early stage, potential recommendations to better assess rockfall hazard include:

- Development of a mobile GIS-based data collection platform, potentially using ESRI's Collector Application.
- Collection of gigapixel photo mosaics at the top 50 sites and/or the top 5 corridors where topographic and vegetation conditions allow.
- Pilot program in a high-hazard corridor (I-90, MP 0 to 30, for example) for collection of two data sets in fall and spring for helicopter-based photographs for monitoring and change detection.
- Collection and processing of Sirovision photogrammetry at key discontinuity-controlled rockfall sites for kinematic and stability analyses, where appropriate.
- Use of existing base-earth ALS data for terrain mapping and map generation.
- TLS or MLS scanning by in-house survey crews for change detection for short hazardous slopes.

5 Transportation Asset Management

Transportation Asset Management (TAM) is a strategic and systematic process of maintaining and managing infrastructure assets throughout their life cycle, focusing on business and engineering practices for resource allocation and utilization. It uses data and analysis to improve decision making, with the objective of providing the required level of service in the most cost effective manner (Gordon et al 2011).

For certain major asset classes such as pavements and bridges, the techniques of TAM are codified in law (23 USC 119, FHWA 2015) and in various standards documents (Thompson and Hyman 1992, GASB 1999, Cambridge et al 2002, NAMS 2006, BSI 2008, Gordon et al 2011). Mature data collection processes are in place for these asset classes, with relatively advanced models and information systems (Cambridge 2003, Hawk 2003, Sobanjo and Thompson 2011 and 2013).

5.1 Relevance of the asset management concept

It is important at the outset to explain why the concept of “asset management” is relevant to rock slopes. Transportation assets such as pavements, bridges, and slopes are not usually bought and sold in a competitive market as may be the case for real estate, buildings, equipment, financial securities, and other common assets (Stanley 2011). Additionally, rock slopes usually do not directly carry traffic in the way that pavements and bridges do. On the other hand, rock slopes are constructed for a purpose, and are expensive to build:

- Roads often must be constructed on or near very large natural slopes whose stability is essential for the road’s continued function. Often slopes are modified or protected in order to reduce the likelihood of slope failures.
- Slopes are constructed and maintained in order to flatten and straighten the road geometry, allowing for the desired road grade, width, and speed. They provide value to the public, which justifies the cost of construction.
- Slopes can deteriorate because of rock or soil types, weather effects such as erosion and ice wedging, plant and animal activity, and for other reasons. Slope deterioration can lead to rockfall and other hazards such as landslides and debris flows which may impact or block the roadway and impede traffic.
- To maintain the function of the roadway, agencies incur maintenance costs to clear rockfall deposits, repair damage caused by rockfall, and protect the public from hazards.
- As slopes age, capital preservation work becomes necessary in order to offset deterioration, reduce maintenance costs and service disruptions, and ensure a long life.

In short, rock slopes are very much like any other constructed facility in that they require periodic maintenance and reinvestment in order to maintain the function for which they were originally built. It is in this sense that the same concepts and tools that are becoming universal for pavements and bridges are also important for rock slopes.

5.2 Basis for quantifying performance and project benefits

Agencies measure their performance in a variety of ways for a variety of purposes. These can include measures of resource **inputs** (e.g. hours of labor, cubic yards of material, hours of equipment usage, dollars of outside services); work **outputs** (e.g. lane-miles paved, tons of rock removed, linear feet of ditch cleaned); **productivity** (e.g. tons of rock per crew member, equipment availability in percent of hours, or haul miles per day); and customer **satisfaction** (e.g. percent of respondents who approve) (Poister 1997, OECD 2001, Transtech 2003, Hyman 2004).

For asset management, agencies define performance in terms of **outcomes** (Cambridge 2006, Anderson and Rivers 2013). The specific outcomes derive from statements of the agency mission, goals, and objectives, which are then reduced to measurable quantities for various analytical and communication purposes.

At the national level, a set of goals have been defined by the Congress in 23 USC 150(b):

> *(1) SAFETY.—To achieve a significant reduction in traffic fatalities and serious injuries on all public roads.*
>
> *(2) INFRASTRUCTURE CONDITION.—To maintain the highway infrastructure asset system in a state of good repair.*
>
> *(3) CONGESTION REDUCTION.—To achieve a significant reduction in congestion on the National Highway System.*
>
> *(4) SYSTEM RELIABILITY.—To improve the efficiency of the surface transportation system.*
>
> *(5) FREIGHT MOVEMENT AND ECONOMIC VITALITY.—To improve the national freight network, strengthen the ability of rural communities to access national and international trade markets, and support regional economic development.*
>
> *(6) ENVIRONMENTAL SUSTAINABILITY.—To enhance the performance of the transportation system while protecting and enhancing the natural environment.*
>
> *(7) REDUCED PROJECT DELIVERY DELAYS.—To reduce project costs, promote jobs and the economy, and expedite the movement of people and goods by accelerating project completion through eliminating delays in the project development and delivery process, including reducing regulatory burdens and improving agencies' work practices.*

Congestion reduction, system reliability, and freight movement are often considered together as "mobility."

In Montana, the MDT Strategic Business Plan (MDT 2004) summarizes the Department's major goals, which are resolved into policies and actions in Tranplan21, the Department's Long-Range Transportation Plan (Cambridge 2008). Among the major goals in the Strategic Business Plan are:

> *Ensure investment decisions consider policy directions, customer input, available resources, system performance, and funding levels.*
>
> *Enhance traveler mobility by providing a safe and efficient multimodal transportation system that supports Montana's economy and is sensitive to the environment.*
>
> *Reduce fatal and injury crash rates.*
>
> *Continuously strive to improve the effectiveness and efficiency of operations and processes.*
>
> *Consistently communicate standards, guidelines, policies, and expectations throughout MDT.*

A transportation asset management process structures a series of activities, data, and tools which provide a reasonable and consistent way to quantify these performance objectives, to assess how well the objectives are being met at a given time for a single asset or an entire network; to track performance over time; to estimate the ability of specific projects to improve performance, and to compare the relative merits and priorities of investments across all asset classes in the entire inventory (Gordon et al 2011).

5.3 The federal TAM process and its applicability to rock slopes

From the preceding section it can be seen that the federal and state goals and objectives are very much in alignment for asset management purposes. Under the Moving Ahead for Progress in the 21st Century (MAP-21) Act, state DOTs are required to describe and quantify their strategies, targets, and progress in pursuing these goals by means of performance measures and the Risk-Based Transportation Asset Management Plan (TAM Plan). Although only National Highway System (NHS) pavements and bridges are required to be covered by the TAM Plan, 23 USC 119(e)(3) encourages States to include all infrastructure assets within the right-of-way corridor. Coverage of non-NHS roads is also encouraged.

In response to MAP-21, the Federal Highway Administration has drafted a set of rules for performance measurement and for Risk-Based Transportation Asset Management Plans (FHWA 2015a and 2015b). This proposed rule clarifies that the analyses mandated within the TAM Plan should be risk-based, meaning that they should account for the strategies and costs of managing risks to the performance of the transportation system, including any aspects of performance listed in 23 USC 150(b).

Rock slopes are a class of assets that affect the safety, mobility, and efficiency of Department operations and processes by means of the risk and occurrence of rockfall. MDT routinely expends scarce resources to clear fallen rocks from roads, to recover from rock-vehicle collisions, to scale loose rock before it falls, and to install and maintain mitigation measures such as catchment ditches, barriers, drapes, and fences. The ultimate purpose of these activities is to satisfy Department goals for safety, mobility, and efficiency.

With the aid of a comprehensive inventory, condition assessment, and system-wide cost estimations of rock slopes, MDT will eventually be able to perform the same types of analysis for these assets as it already does for pavements and bridges, and as required for assets included within the TAM Plan:

- It will be able to use its condition and work history data to develop forecasting models for deterioration and costs;
- It will be able to compute reasonable estimates of life cycle cost taking into account near-term and long-term forecasts of maintenance and capital costs, and to promote efficiency by minimizing these costs.
- It will be able to quantify safety and mobility impacts of rockfall using research-based methods.
- It will be able to compute the return on investment of preservation work. In asset management for pavements and bridges it is not uncommon for preservation work to have a return on investment of 50%[3], which would mean that each investment of $1 will save $1.50 in life cycle costs, limited by the availability of feasible preservation projects. This return is increased to 100% or more when safety and mobility benefits are also included.
- It will be able to perform a fiscally-constrained investment analysis for the TAM Plan, satisfying all the federal requirements by incorporating funding uncertainty, and enabling the development of reasonable performance targets and expectations to fit any given funding level.

All of these are necessary conditions for the inclusion of rock slopes in the TAM Plan, according to the proposed federal rule. They all are also needed for inclusion in MDT's Performance Programming

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[3] This was documented by one of the authors in TAM Plan development projects now underway in Ohio, Nevada, and Texas.

Process (P3, MDT 2012). These capabilities are all dependent on a consistent, objective assessment of rock slope condition.

By tying the enhanced rock slope rating system to the federal TAM Plan process, MDT will satisfy the immediate goals of identifying current needs, and will position itself to achieve the longer-range goals of the TAM Plan and the P3 process. Since MAP-21 and subsequent regulations are consistent with, and strengthen, the existing Montana P3 process, applying the federal process to rock slopes will give these assets a “seat at the table” in resource allocation decisions.

5.4 General TAM guidance and examples

All of the basic components of asset management have been codified in various standards documents in recent years (Figure 1). In the United Kingdom, the authoritative source is Publicly Available Specification 55, volumes 1 and 2 (BSI 2008). In the United States, a basic framework is described in a financial management context in Government Accounting Standards Board Statement 34 (GASB 1999), and in a strategic planning context in Volume 1 of the AASHTO Guide for Asset Management (Cambridge et al 2002). A more detailed adaptation of the same principles is New Zealand’s International Infrastructure Management Manual (IIMM, NAMS 2006). For bridges specifically, AASHTO has published a guide for bridge management systems, which focuses on the requirements of databases, models, and information systems appropriate for long-lived assets (Thompson and Hyman 1992).

The IIMM introduces a concept of self-assessment and gap analysis, to help agencies plot a course toward implementation of improved asset management processes. In 2011, AASHTO built on this concept by publishing the AASHTO Transportation Asset Management Guide, Volume 2: A Focus on Implementation (Gordon et al 2011), a more detailed guide focused on transportation infrastructure, informed by experiences worldwide in developing and implementing transportation asset management processes and systems.

A key aspect of successful asset management implementation, brought out in the IIMM and the AASHTO Guide, is the notion of continuous improvement. A variety of human and automated ingredients need to be improved in tandem. The amount of progress that can be made in asset management tools is limited by the human and organizational readiness to use the technology, and vice versa. In a more tangible sense, the technology to produce quality asset management information depends on management willingness to accept asset management information in decision-making (and to see the value and pay the cost of producing this information); and management acceptance, in turn, depends on the quality of information that can be produced. A small improvement in the decision making process must be matched by an incremental improvement in technology, which then spurs the next small improvement in decision making.

Figure 20: International asset management standards

These same principles are widely used in the private sector, often taking the form of performance management frameworks such as the Balanced Scorecard and Six Sigma (Proctor et al 2010, Gordon et al 2011).

This way of improving the organization and technology in tandem was recognized in the software industry long ago, and resulted in the Capability Maturity Model (Paulk, 1994). The AASHTO Guide applied this to transportation asset management by defining a maturity scale and using it to group capabilities that typically are developed together and have strong interdependencies.

The Moving Ahead for Progress in the 21st Century Act, known as MAP-21, calls on state Departments of Transportation to prepare risk-based Transportation Asset Management Plans (TAM Plans) for the National Highway System to “improve or preserve the condition of the assets and the performance of the system”. The legislation mandates the establishment of condition and performance targets, and requires the TAM Plan “to include strategies leading to a program of projects that would make progress toward achievement of the targets.”

FHWA has published draft guidance on TAM Plan development (FHWA 2015a and 2015b). Examples, many of which include assets other than pavements and bridges, can be found online from many states[4]. Geotechnical assets are included in some of these efforts (ODOT 2011). Application of asset management concepts to geotechnical assets is relatively new (Hawkins and Smadi 2013). Some of the important considerations are:

- What is a geotechnical asset from the TAM perspective?
- How do geotechnical assets affect transportation system performance?
- How can this performance be measured?
- How can this performance be forecast, so it can be used in decision making to optimize performance?

The Central Federal Lands Division of FHWA gave these questions considerable thought in the preparation of its Implementation Concepts and Strategies document (Vessely 2013). The document describes numerous case studies where asset management thinking could help agencies make better long-term decisions about geotechnical assets. It visualizes GAM as a major driver of transportation system risk, with the corridor as the major unit of risk analysis. The report offers many practical ideas on establishing a GAM program.

Washington State DOT has published a brochure describing how it has implemented many of these ideas (WSDOT 2010). The Alaska Department of Transportation and Public Facilities has a Geotechnical Asset Management Plan under development for rock slopes, unstable soil slopes, retaining walls, and material sites. Colorado DOT is developing a plan for its retaining walls (unpublished work in progress).

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[4] See http://www.fhwa.dot.gov/asset/plans.cfm and http://www.tamptemplate.org/ for links.

6 Performance assessment and communication

Rock slopes affect transportation system performance primarily through the risk of rockfall to users and the possibility of service disruption, which may decrease network safety, mobility, and/or sustainability, and which may increase life cycle costs. Disruptions to service are typically uncommon and unexpected, but costly to the agency and to road users when they occur. As a result, asset management processes rely on the principles of risk management.

6.1 Risk assessment

There are many different kinds of risk in a transportation system (PIARC 2012b, FHWA 2012), so it is important to be clear on the types of risk that are significant to the management of rock slope assets. Specifically, the risk is the possibility that transportation service on a link of the network will be disrupted (blocked or severely impeded) by an unexpected failure, such as the fall of debris onto a roadway. By nature the hazardous event is unpredictable at any given site, and uncommon across the inventory. Yet road segments are disrupted one or more times every year by such events somewhere in the state, leading to substantial economic losses to the public, as well as injuries and property damage.

The nature of the hazards can vary, but all state DOTs have risk concerns and need risk management strategies. To support this need, AASHTO has published a Guide to Highway Vulnerability Assessment (SAIC 2002) and a series of technical guides to help implement a risk management plan (SAIC and PB 2009).

When a geotechnical asset fails, the consequence may be a local interruption of service at the failure site. Often it is more than this: failure of one link may mean failure of the entire corridor, with more widespread economic consequences. For precise analysis it is helpful to define some more specific concepts to increase understanding and provide a basis for risk-based asset management (Seville and Metcalfe 2005, Sobanjo and Thompson 2013):

- *Likelihood* of hazard. Slope failures are typically triggered by natural events, such as earthquakes, floods, ground saturation, groundwater movement, freeze/thaw, or general instability. These events are inherently uncontrollable. Another approach is to quantify the total number of failures for a given category of feature over a historical time period, then divide by the number of features in the category and number of years in the historical record (Sobanjo and Thompson 2013). Categories could be defined by geological character, water, or other characteristics for which data are available. Change in precipitation patterns may necessitate an analysis of changes in potential trigger processes over time (Mote et al 2012, Connor and Harper 2013).
- Direct *consequence* of hazard. A geotechnical hazard event is recognized if it causes damage requiring an agency response. This damage may be to the geotechnical asset itself, and may also encompass surrounding features, including a road or other transportation facility. It may also damage the property of others, or may cause personal injury. All of these consequences may be represented by costs in a risk computation. Alternatively, some risk assessment procedures use a scoring procedure (basically, a utility function) to represent the costs of a failure (Thompson et al 2012a). Agencies can often limit the consequences of a hazard event by making geotechnical assets and other nearby assets less vulnerable, or more resilient.
- *Impact* of hazard. If a hazard event occurs and causes damage to a road or other transportation facility, there may be social, environmental, and economic impacts that extend far beyond the geotechnical asset itself (Koorey and Mitchell 2000, HDR 2010, PIARC 2000, PIARC 2012a). Traffic may be forced to take a longer route, or use a different mode of travel, for an extended period of time while the facility is repaired. Road users then incur costs for travel time, vehicle

> operating costs, and fares. Added traffic on detour routes may cause congestion on those routes, with further inconvenience. Businesses may be disrupted; some may even fail due to changes in traffic patterns. In the longer term, businesses may not want to locate in areas they perceive to be vulnerable, thus depressing economic conditions and/or property values.

Some authors group the direct consequences and the impacts together and merely call them "consequences" (SAIC 2002). However, the further separation is useful in transportation risk management because the impacts are often very substantial, and because the methods of estimating them are different from the methods used for direct consequences. Also, the agency has some amount of long-term control of consequences by means of risk mitigation or replacement actions, while impacts are largely out of the agency's control.

A concern is sometimes expressed that gathering of risk-related data could potentially have liability consequences, in that it might increase the agency's responsibility with regard to risk management. Of course, the purpose of gathering the data is to improve risk management, so this observation only reinforces the need to follow through to put the data to work for its intended purpose (Hillier 2012).

The components of risk are often analyzed using probabilistic models (Taylor et al 2001). One of the key assessments to be made is the probability that a slope failure will damage or block a road. This is what then drives the large economic impacts of a geotechnical asset failure (Koorey and Mitchell 2000).

Risk is usually considered to be a quantity computed as likelihood × (direct consequences + impacts) (Seville and Metcalfe 2005). The process of estimating this risk is called *risk assessment*. The agency usually tries to minimize risk by hardening assets to make them more resilient. Often it is possible to reduce the likelihood of a hazard, for example by improving slope condition. Risk reduction actions may be costly, and they compete for funding with other project needs. It is necessary to prioritize and schedule these activities just like all other types of projects. This process is part of *risk management*.

6.2 Resilience as a measure of risk

Asset management procedures and tools are just as relevant to risk as to any other type of performance, so it is considered best practice to integrate risk management into asset management, using a measure of risk as a performance measure (Gordon et al 2011, Cambridge 2011). Since performance measures are usually quantities of desirable attributes under the agency's control, it is becoming common for agencies to focus on asset resilience as the performance measure (Thompson et al 2012a). Risk assessment activities record data related to asset resilience, and actions are taken to increase resilience.

Resilience then is any attribute, or combination of attributes, which help an asset resist damage in the face of an internal or external hazard (FHWA 2013b). In a field risk assessment process, trained personnel make note of the resilience attributes of each asset (NYSDOT 2013). This information is used in a risk computation, which then participates in asset management decision support capabilities. When communicating with the public, the term "resilience" (rather than its inverse, vulnerability) focuses attention on the positive outcomes of actions that the agency can control, and for which it can be accountable. In general, resilience is defined as follows:

> *The ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events* (Committees, 2012).

There are, in fact, a great many definitions of resilience in the literature, especially in areas associated with climate change adaptation (Hughes and Healy 2014, Levina and Tirpak 2006). One that is especially focused on engineering systems is:

> *… the capability of a system to maintain its functions and structure in the face of internal and external change and to degrade gracefully when it must* (Allenby and Fink 2005).

"Internal and external change" can be interpreted in the context of rock slopes as changes caused within the asset itself (i.e. normal deterioration) and change caused by external forces (natural extreme events). "Maintain its functions and structure" can be interpreted as the avoidance of transportation service disruptions. "Service disruptions," in turn, can be interpreted as unintended changes in the safety, mobility, or economic performance of the roadway. Based on this reasoning, a slope may be considered to have high resilience to the extent that it is sufficiently able to refrain from causing service disruptions due to normal deterioration or adverse events.

A risk management framework defines scenarios of undesirable service disruption events such as rocks on the roadway blocking traffic. An analysis attempts to predict the likelihood of each scenario as a probability, and the consequence of the scenario as a social cost. Resilience is the combination of asset characteristics which affect the likelihood of adverse events.

As an example, a rock slope that has good resilience has the following characteristics:

- Is in good condition (minimal damage, degradation, disintegration, or deformation relative to a newly cut, properly designed slope);
- Has appropriate catchment ditch and/or mitigation features;
- Lacks unmitigated characteristics of geology or geometry that are associated with catchment failure or slope collapse during foreseeable (but uncommon) seismic, weather, or other events;

A slope that would otherwise be in good condition may nonetheless have characteristics (such as high steep slope, adverse jointing, extreme freeze/thaw, or proximity to the traveled way) that make catchment of large blocks difficult to ensure, that make the slope vulnerable to rockslides, or that produce debris requiring constant maintenance. When addressed with appropriate rockfall reduction and/or catchment measures, the potentially adverse characteristics can be mitigated to improve both Condition and Resilience.

For most purposes in asset management, measures of condition focus purely on processes that damage, degrade, disintegrate, or deform the materials making up the facility (FHWA 2015a, AASHTO 2013). As agencies develop streamlined processes for rock slope management, they often expand the concept of "condition" to include resilience, facilitating a more direct linkage between asset deterioration and the probability of transportation service disruption. In Alaska, for example, the following properties of a rock slope are considered in the definition of condition index and condition state:

Material condition	Contributing properties
Raveling of rock or wall face	Ice and freeze/thaw
Disintegration of rock face or wall	Design criteria
Differential erosion	Geological character
Debris accumulation	Climate
Water infiltration and accumulation	Drainage and hydrology
Loss of vegetation tied to rockfall activity	Presence of mitigation features
Root wedging and wind jacking from trees	Geometry and size of slope face

The items in the left half of the above list are the same types of material damage, degradation, disintegration, and deformation that make up the concept of condition in pavement and bridge management. These describe processes that can deteriorate over time. The items on the right are typically corrected, if at all, only by adding, removing, or relocating significant assets. These properties in both columns make up much of the RHRS system, variations of which are in use by approximately half of the states (Pierson 1993, Turner and Schuster 2012).

There are only a few classic preservation treatments available to a transportation agency to reverse some of the condition defects: for example, scaling of a rock slope or correction of drainage. In most cases, the most cost-effective agency response is the addition of a mitigation measure(s) or protective system, which does not necessarily correct the material defects but merely slows further deterioration or ameliorates the effect on road users. Such treatments include:

Rock bolting
Addition of shotcrete, fences, drapes, and barriers
Construction of a retaining wall (where one did not previously exist)
Embankment reconstruction and realignment of the road

In order to develop a relatively simple yet actionable assessment process, the Alaska GAM research studies have adopted a relatively simple set of composite measures which depend on, and summarize, all of the causal factors listed above, and which can be considered to directly affect the likelihood of service disruption. The primary variables that make up the assessment are:

- Ditch (or catchment) effectiveness: assesses how often falling rocks reach the roadway, combining the effects of all design, mitigation, and geometry concerns.
- Rockfall activity: assesses how active the slope is in producing falling rocks, combining the effects of all condition characteristics, geological character, climate, and hydrology

This expanded definition is believed to be usable in all of the same contexts where a pure condition state measure is used for other asset classes: ability to forecast deterioration using relatively simple models; identification of appropriate treatment alternatives; estimation of reasonable costs and effects of treatments; quantifying the likelihood of service disruption; and communicating current network performance, past trends, and future targets in the form of maps, trendlines, and other graphics.

6.3 Communicating performance

Effective performance communication entails finding the right balance of content — not too much and not too little — to fit the needs of the audience. The art of effective communication of quantitative information is widely explored in the literature (Tufte 2001, Eckerson 2006, Zmud et al 2009). Some good examples of simple context and message in the communication of asset performance can readily be found online:

Michigan[5]
Minnesota[6]
Oregon[7] (Figure 21)
Utah[8]
Wisconsin[9]

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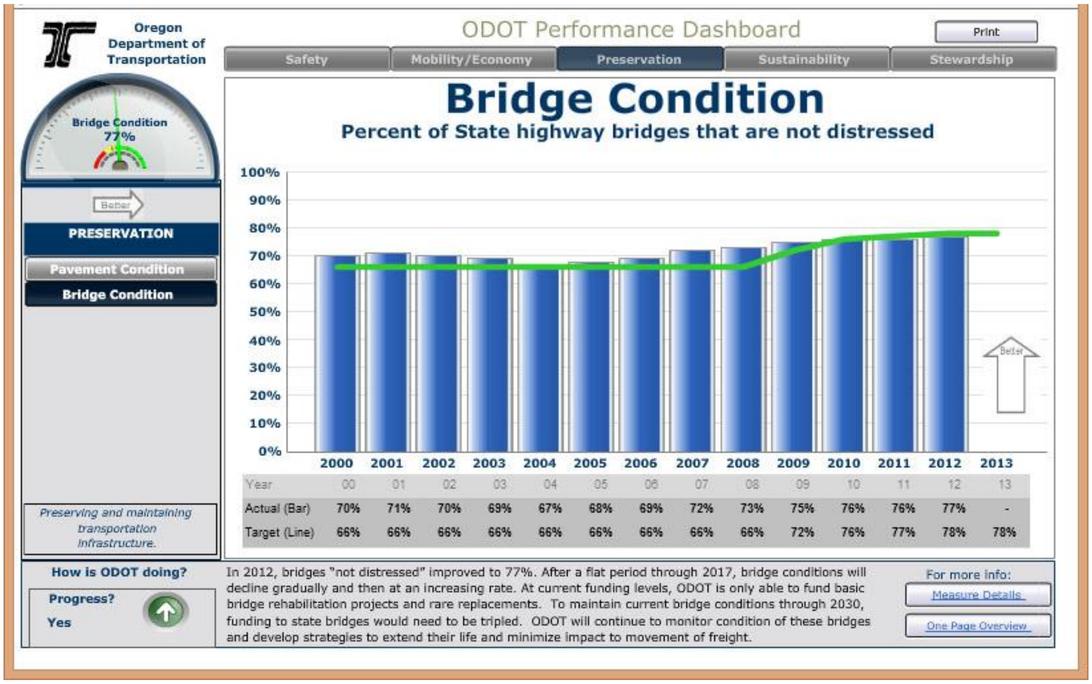
[5] http://www.michigan.gov/midashboard/0,4624,7-256-59297---,00.html
[6] http://www.dot.state.mn.us/measures/pdf/2011_Scorecard_10-19-12.pdf
[7] http://www.oregon.gov/ODOT/CS/PERFORMANCE/docs/2012dashboard.swf
[8] http://performance.utah.gov/agencies/udot.shtml
[9] http://www.dot.wisconsin.gov/about/performance/docs/scorecard.pdf



Bridge Condition

Percent of State highway bridges that are not distressed

Year	00	01	02	03	04	05	06	07	08	09	10	11	12	13
Actual (Bar)	70%	71%	70%	69%	67%	68%	69%	72%	73%	75%	76%	76%	77%	-
Target (Line)	66%	66%	66%	66%	66%	66%	66%	66%	66%	72%	76%	77%	78%	78%

Preserving and maintaining transportation infrastructure.

How is ODOT doing?

Progress?
Yes

In 2012, bridges "not distressed" improved to 77%. After a flat period through 2017, bridge conditions will decline gradually and then at an increasing rate. At current funding levels, ODOT is only able to fund basic bridge rehabilitation projects and rare replacements. To maintain current bridge conditions through 2030, funding to state bridges would need to be tripled. ODOT will continue to monitor condition of these bridges and develop strategies to extend their life and minimize impact to movement of freight.

Figure 21: Example performance dashboard from Oregon DOT

7 Decision support tools

A major goal of improved asset management is the ability to optimize decision making to maximize performance with limited funding. In order to optimize performance, decision makers need the ability to generate reasonable program alternatives, for a corridor or for the state as a whole, and evaluate their likely cost and performance outcomes. Effective asset management, like effective risk management, means taking cost-effective action before a problem becomes a crisis. It entails strategic, proactive policies and programs (Cambridge 2002). Information technology support, featuring predictive models, is necessary in order to adopt a reliable perspective about future outcomes (Keen and Scott Morton 1978).

Proactive asset management decision making addresses important questions on the minds of decision makers and stakeholders (Thompson 2013):

- If funding is cut, how much performance would be sacrificed?
- How much would it cost to keep performance from declining further?
- How much would it cost to improve performance to a desired level?
- Can we get more life out of our assets, and how best to do this?
- What policies would minimize life cycle costs?
- Is a given preventive maintenance program worth the expense, in terms of reducing life cycle costs?
- What is the best long-term preservation program for a given asset, in terms of the scope and timing of future interventions?

For geotechnical risk management it is impossible to know what geotechnical failures might happen in the future, yet it is possible and prudent to identify the weakest links in the network and find cost-effective ways to make them less vulnerable. Any reasonable, objective system for quantifying future risk is valuable for setting priorities and maximizing systemwide resilience. As the science of risk analysis advances, proactive decision making becomes more effective, and the frequency of catastrophic network failures should decline (Seville and Metcalfe 2005).

The same effect should be expected for any other aspect of transportation performance. Forecasting of performance allows resources to be focused on the assets whose performance can most efficiently be improved. The result should be a long-term improvement in systemwide performance. This approach has been clearly demonstrated in the traffic safety field, for example[10].

A Transportation Asset Management Plan (TAM Plan) is a forward-looking document that makes statements about expected future performance and describes how the Department intends to manage future performance (Lindquist and Wendt 2012). The decision support tools required for an ongoing transportation asset management process (Thompson 2013) are the same tools that are required for ongoing maintenance of the TAM Plan. Geotechnical Asset Management will ultimately be a part of TAM, so it will need to be able to feed into the Department's Enterprise Asset Management processes, tools, and plans. The key tools are:

An investment candidate file, which identifies each potential investment and summarizes its cost, resource requirements, and effects on transportation system performance (Gordon et al 2011, Figure 22). It is most often prepared as an Excel spreadsheet file, which is simple, flexible, and entails minimal

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[10] http://www.nhtsa.gov/About+NHTSA/Press+Releases/2012/New+NHTSA+Analysis+Shows+2011+Traffic+Fatalities+Declined+by+Nearly+Two+Percent.

system development costs. If the Department develops an enterprise investment candidate file covering all significant asset classes, the geotechnical version could use the same format, making it relatively simple to move geotechnical work candidates into the statewide programming process and STIP.

Forecasting models, especially deterioration models for rock slopes. Similar to the situation with bridges, precise deterministic forecasts are unlikely to be feasible, but probabilistic forecasts should be possible once a routine inspection process is in place (Thompson et al 2012b, Sobanjo and Thompson 2011, Flikweert et al 2009, PIARC 1997). In advance of data availability, an expert judgment elicitation process can generate models suitable for preliminary analysis (Cambridge 2003).

Risk analysis models. For the risk analysis, models of the likelihood of geotechnical hazards will be needed, as well as some parameters for estimating consequences and impacts (Sobanjo and Thompson 2013). In recent work underway in Alaska and Colorado, ranges of adverse event return periods have been estimated by panels of experts, with the intention of gathering data for later statistical analysis of actual event frequencies. In some agencies, typical return periods are built into the category definitions used in the rockfall hazard rating system (Turner and Schuster 2012).

It is common to employ user cost models to quantify the road user impacts of service disruptions. User cost models have been an important part of pavement and bridge management systems since the 1980s (Zaniewski et al 1985, Johnston et al 1994, Thompson et al 1999). They are also widely used in work zone design (Mallela and Sadasivam 2011, NJDOT 2001), comparison of project alternatives (Markow 2012, Mn/DOT 2013) and regulatory processes (Kragh, 1986), and are well supported by published economic data (FHWA 2013a). A standard methodology for this analysis can be found in the AASHTO Red Book (AASHTO 2010). A similar methodology has also been extended to address sustainability concerns (Litman 1996 and 2012, Matthews et al 2001).

A process to generate project alternatives. The Department already has capabilities to generate near-term geotechnical projects, but for proactive asset management it will need an additional capability to sketch possible future projects, based on performance forecasts, for an intermediate term, typically 10 years. The focus is on programmed preventive actions (to respond to deterioration) and risk mitigation projects (to increase asset resilience). This work entails making a list of action categories that respond to performance defects or risk mitigation opportunities. For each action, a decision rule then is needed in order to decide when the action is appropriate, using the data available (Loehr et al 2004). To a great extent this will be determined by the capabilities of Department forces and contractors. However, this may be an opportunity to start expanding local capabilities, including work order contracts for local contractors, and in the area of preventive activities (Fay et al 2012, WSDOT 2012b).

Forecasting of project outcomes. Models will be needed to forecast the costs and effectiveness of future geotechnical actions, in terms of the selected geotechnical performance measures. Initially these can be developed by summarizing current design practices. Eventually, inspection data and work accomplishment records should enable statistical models to be developed (Hearn et al 2010, Sobanjo and Thompson 2001). Landslide Technology has already performed this type of analysis on Montana projects in work performed for Alaska DOT (not yet published).

Life cycle cost models. Once the preceding tools are in place, even preliminary judgment-based models, the Department will be in a position to conduct a life cycle cost analysis (FHWA 2002, Hawk 2003, Walls and Smith 1998). This type of analysis helps to evaluate inter-temporal tradeoffs: sometimes it is better to make a small investment in prevention on a large number of assets now, rather than wait for a much larger disaster on one unpredictable site later on. Life cycle cost analysis helps to identify the most cost-effective candidates for preventive work. If performance measures and the risk analysis are converted to dollar terms, as discussed in the previous sections, then a net present value analysis can be used as the basis for comparing alternatives. If some aspects of performance are left in a non-economic format, then utility theory can be used to accomplish the same purpose (Patidar et al 2007).

Tradeoff analysis. A tradeoff analysis tool in its simplest form sorts a group of investment candidates according to benefit/cost ratio, and then selects the highest-priority candidates that fit within a budget constraint. It then uses the forecasting models to estimate performance measures for the following year, where it repeats the process for the remaining candidates valid for that year. It continues with these steps year-by-year to the end of a program horizon, usually about 10 years.

Where the tradeoff comes in, is that the analyst can vary the budget constraint to see how this affects the performance outcomes. Generally more money yields better performance. The analyst can also change the weight given to different types of performance or different parts of the network, to see how increasing performance in one area causes decreases in other areas, if total funding remains the same.

There is an extensive literature on more elaborate procedures to optimize performance. One slightly more sophisticated model, the incremental benefit/cost (IBC) technique, handles multiple investment alternatives for each asset and automatically downscopes some of the alternatives when funding is tight (Shahin et al 1985). More than 20 years after the IBC method was first used in asset management, a review and benchmarking analysis in 2007 found that it still offers a practical balance of responsiveness, reliability, and optimality (Patidar et al 2007).

Several suitable tradeoff analysis tools have been developed and could be adapted for routine asset management (Cambridge et al 2005, Patidar et al 2007, Sobanjo and Thompson 2007). The tradeoff mechanism itself is simple enough that many agencies will simply develop their own tools using an Excel spreadsheet.

Figure 22: Investment candidate file (Gordon et al 2011)

Type of information		Data items	Description	Purpose
Identification		Project or work order ID Responsibility (organization or unit) Means of execution (contract, in-house, etc.) Desired/planned year Planning/delivery/workflow status	Identifiers here would feed into project tracking or enterprise resource planning systems where applicable.	Uniquely identify projects. Interface with related information systems. Support project development workflow.
Assets	For each cost object:	Identification Geographic location Jurisdiction Value Utilization	List the assets and/or policy concerns that are affected by the action.	Support mapping and reporting by geography and jurisdiction. Provide planned work status to asset management systems. Provide asset weighting in the computation of benefits.
Activity Drivers	For each activity driver:	Performance measure or deficiency Threshold level Actual level	Includes action warrants, level of service standards, vulnerability conditions, damage, or defects. Existing or forecast.	Document the direct justification of projects.
Activities	For each activity:	Classification Quantity (of output) Cost	Includes any type of activity within the scope of asset management: capital, maintenance, preservation, functional improvement, expansion, etc. Also includes engineering, mobilization, traffic control.	Describe the work to be performed and build up the cost estimate.
Resources	For each resource:	Classification Quantity (of input) Cost	Includes labor, materials, equipment, or contract pay items.	Interface with resource management to forecast staffing, stockpiles, and other resource needs.
Forecast Outcomes	For each performance measure:	Forecast change in performance Scaled change in performance Effect of advancement or delay	Includes measures of condition, life cycle cost, user cost, mobility, safety, reliability, comfort/convenience, externalities, risk, etc.	Forecast the performance resulting from the work, and compare with performance targets. Support performance based management.
Project Inter-Relationships		Projects that must be completed first Projects that can't be programmed together Projects that must be programmed together Projects that are mutually exclusive	Constraints on the scheduling and funding of work.	Ensure that traffic control plans are valid, that projects are compatible, and costs are fully recognized.
Evaluation		Total and incremental cost Total and incremental benefit Total and incremental benefit/cost ratio	Priority setting and budgeting criteria.	Set priorities, manage funding limitations.

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Appendix B

TASK 2 REPORT – REVIEW OF MITIGATED SITES

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

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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.

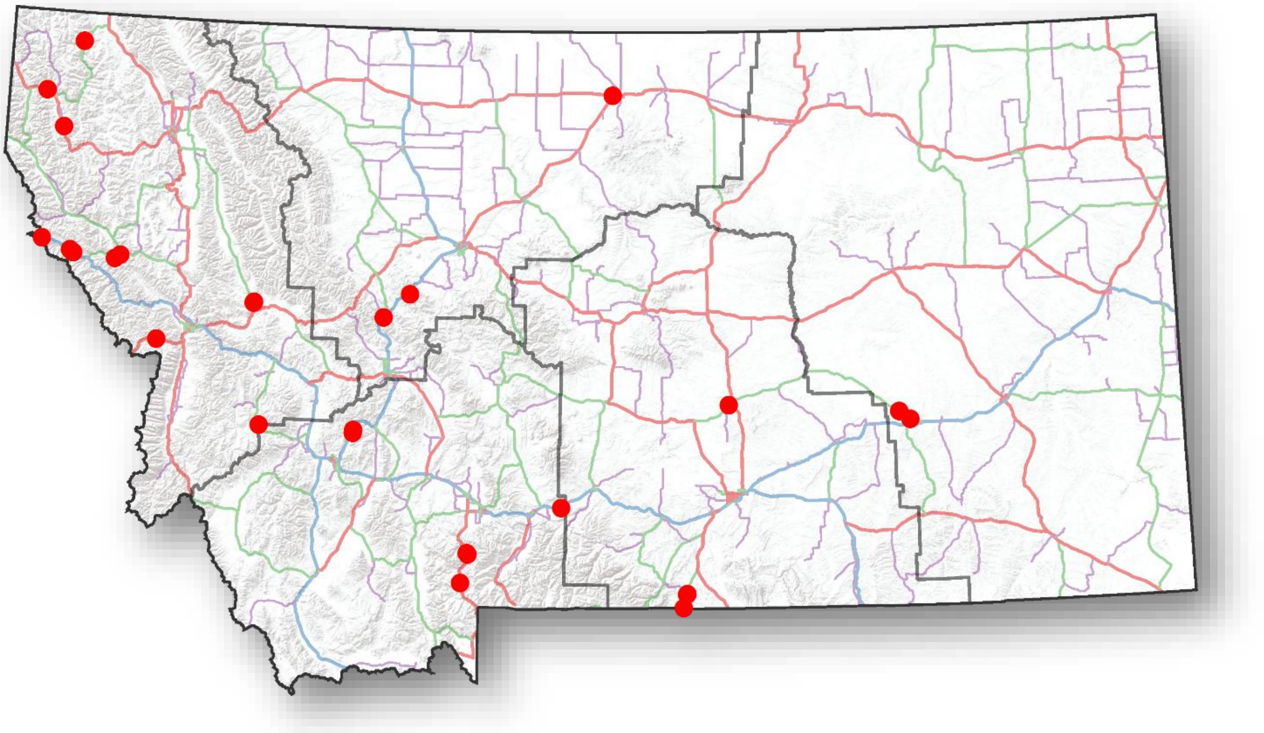

Figure 1: Sites visited as part of Task 2 indicated by red markers.

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

$$\begin{aligned} Method\ 2 = {} & Ditch\ Effectivness + Traffic\ Impacts + Immediate\ Hazard + Failure\ Potential \\ & + Block\ Size\ or\ Volume + Rockfall\ History \end{aligned}$$

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.

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[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.

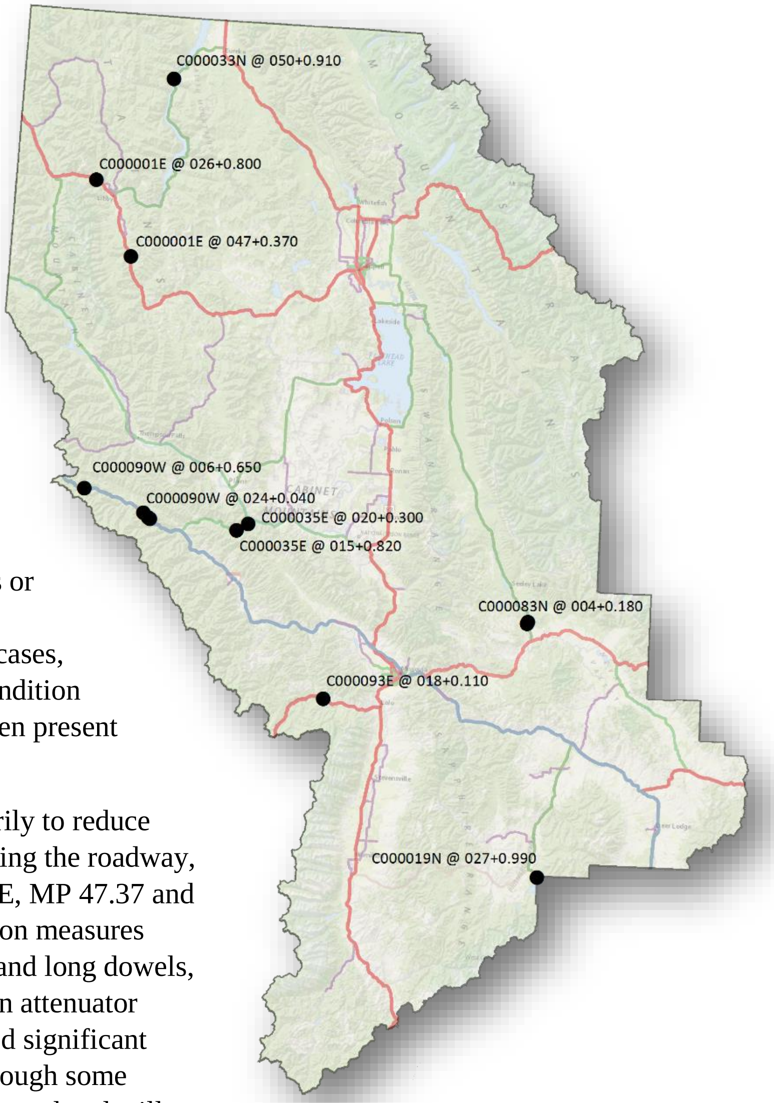

Figure 2: Sites Visited in D1 - Missoula

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.

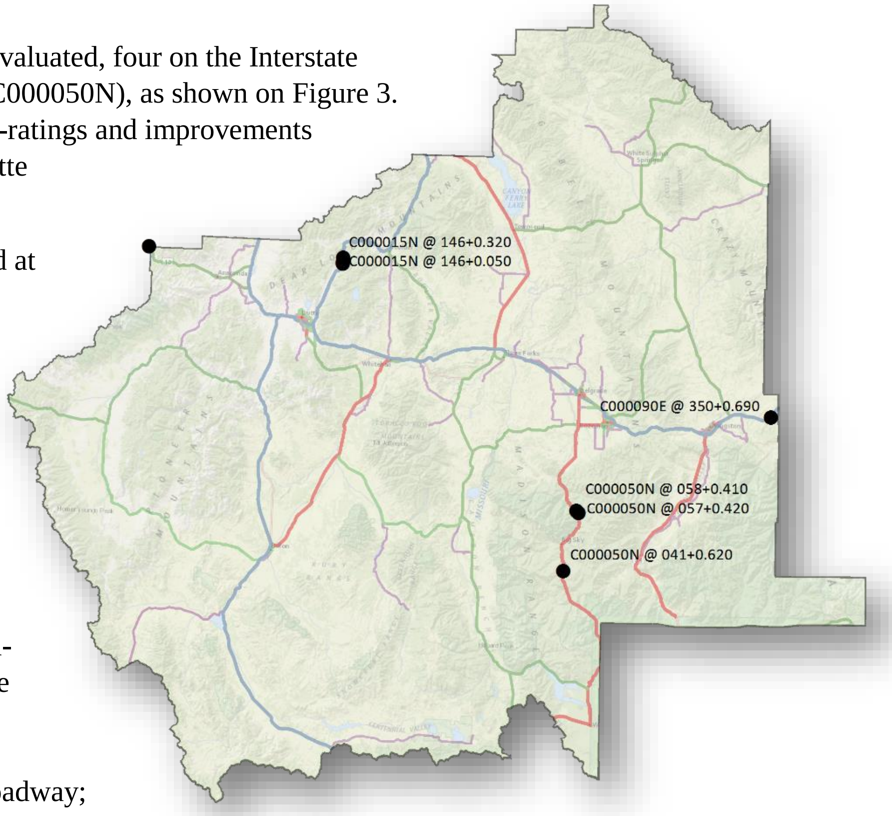

Figure 3: Sites Visited in D2 - Butte

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 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.

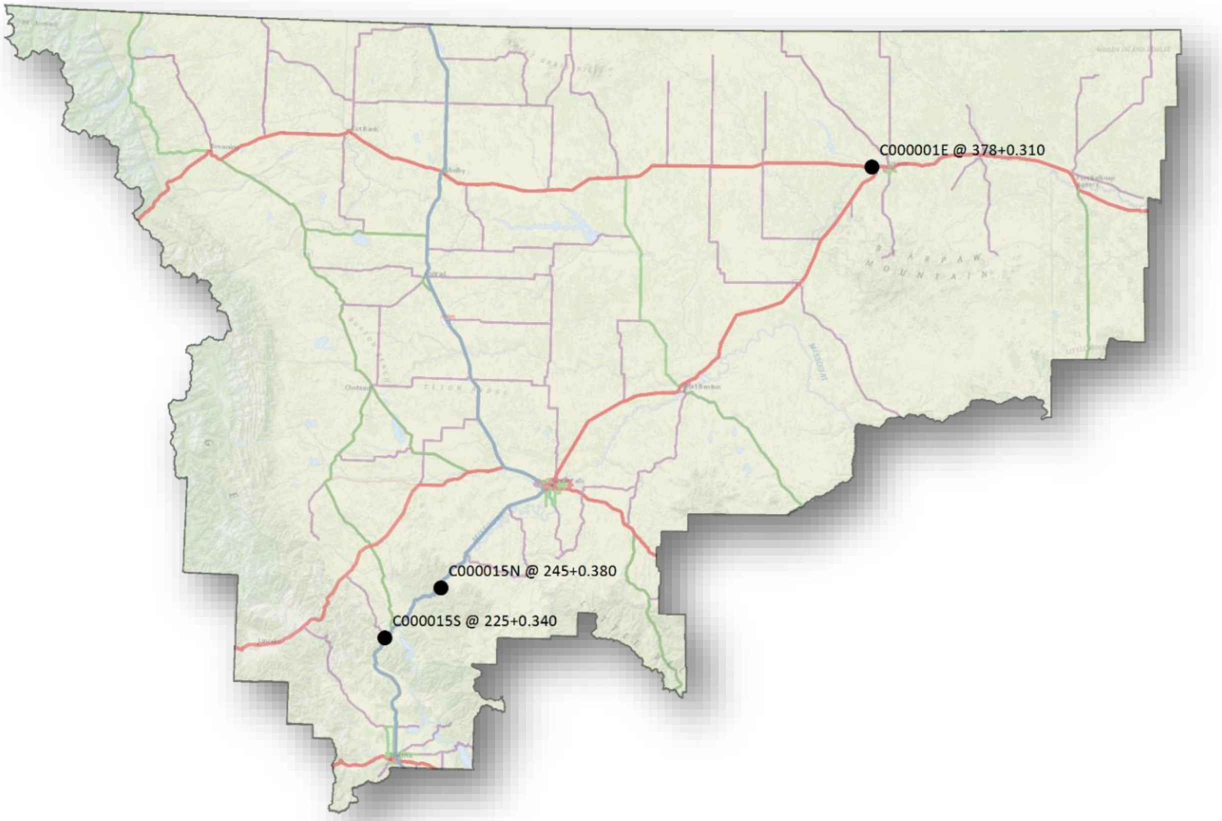

Figure 4: Sites Visited in D3 - Great Falls.

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 NA	-- / 13 NA	-- / 41 NA	-- / 11 NA	-- / 51 NA	-- / 2 NA	-- / $2 **--**	-- / 100 NA
US 12 C000012E MP 265.62-265.71	-- / 149 NA	-- / 13 NA	-- / 28 NA	-- / 11 NA	-- / 24 NA	-- / 2 NA	-- / $8 **--**	-- / 100 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.

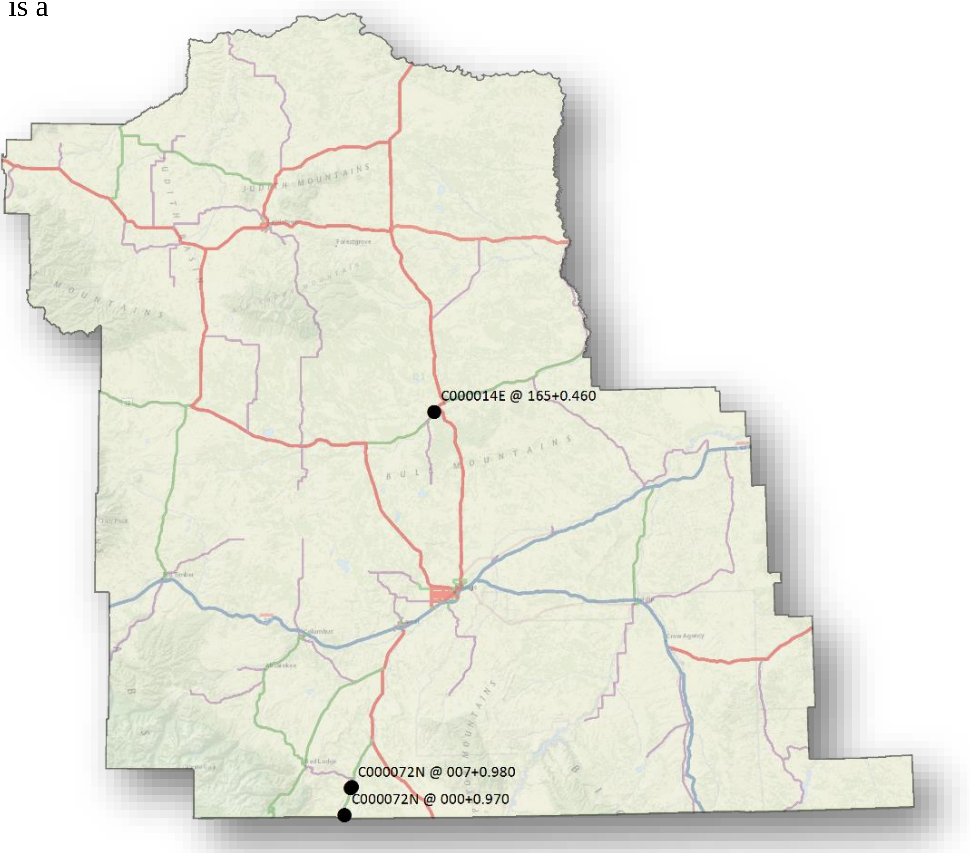

Figure 6: Sites Visited in D5 - Billings District.

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.

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[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

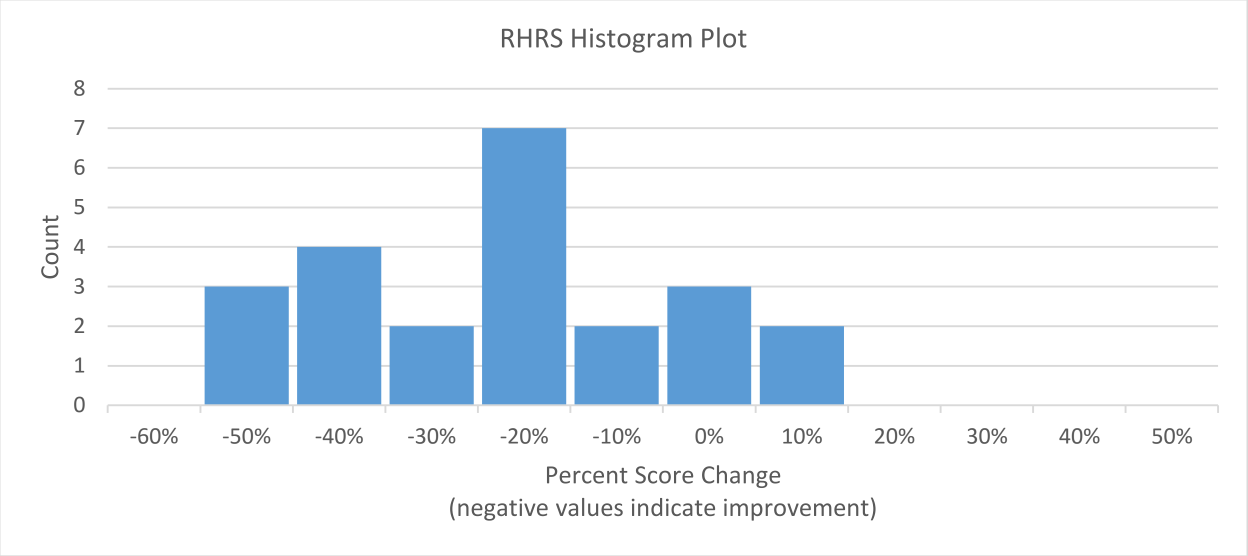

Figure 7: Histogram plot of RHRS percent change between 2004 and 2015 ratings.

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.

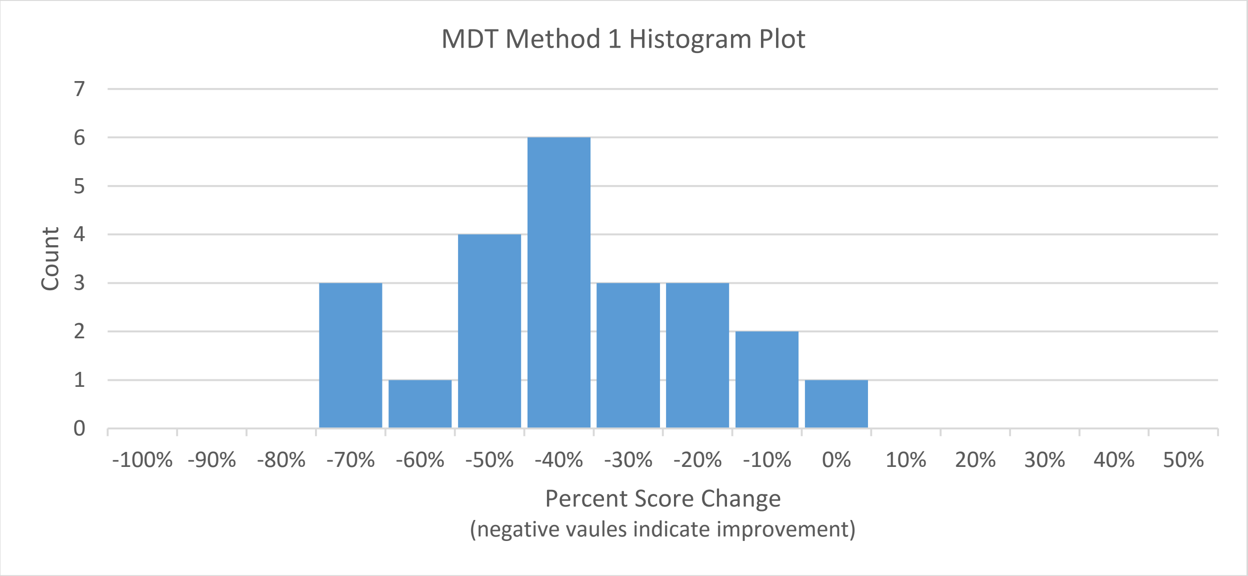

Figure 8: Histogram plot of MDT Method #1 percent change between 2004 and 2015 ratings.

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.

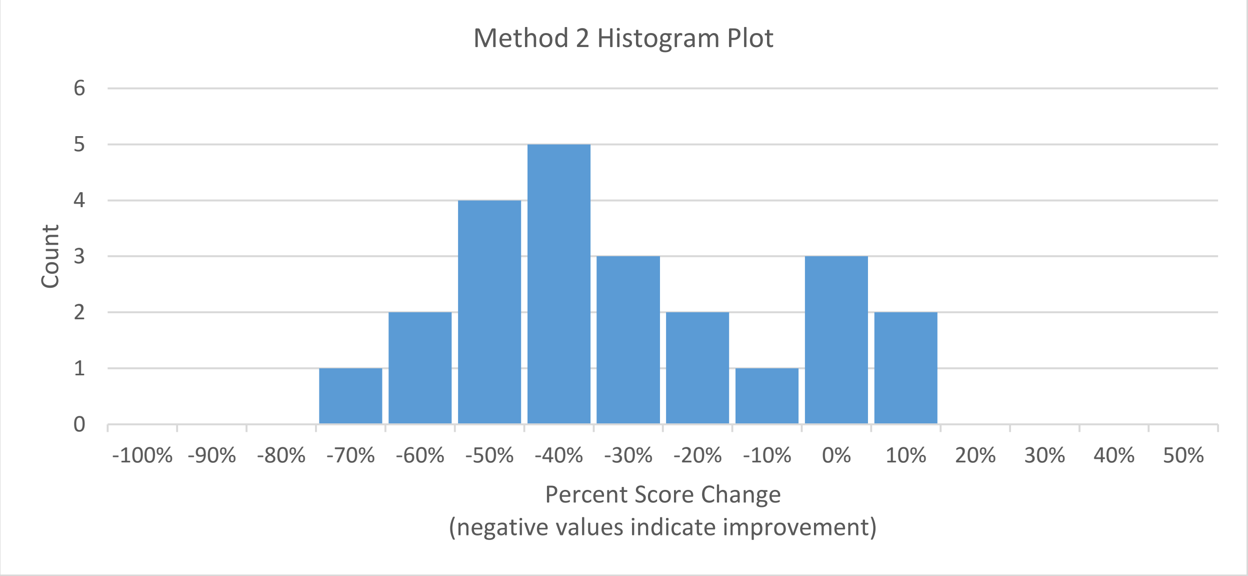

Figure 9: Histogram plot of MDT Method #2 percent change between 2004 and 2015 ratings.

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.

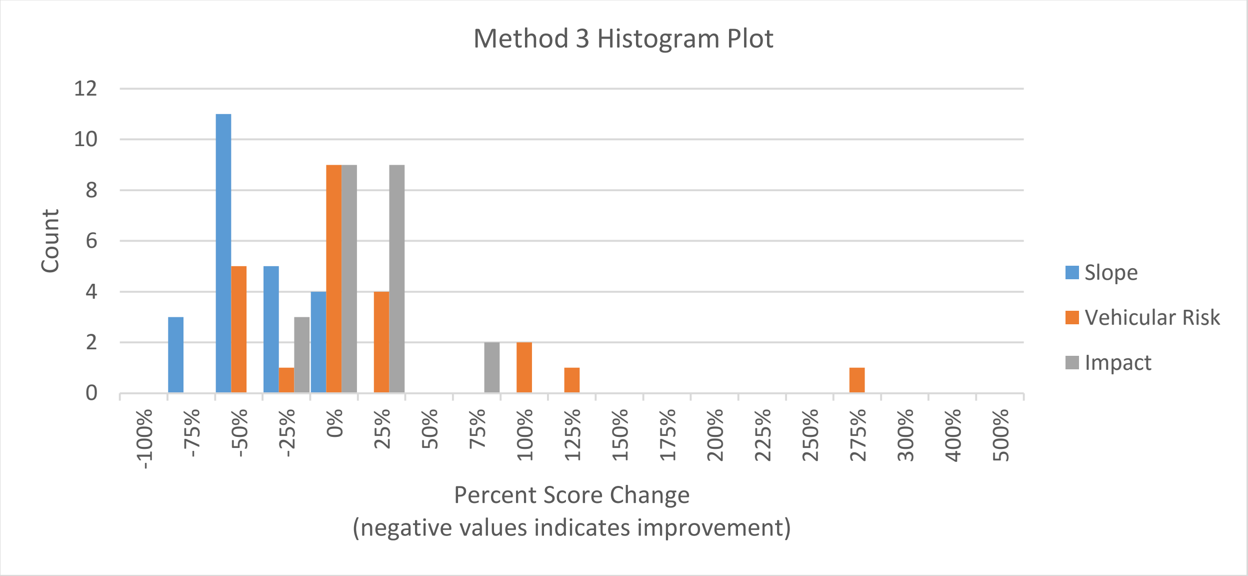

Figure 10: Histogram plot of the percent change of MDT Method 3 rating components between 2004 and 2015 ratings.

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.

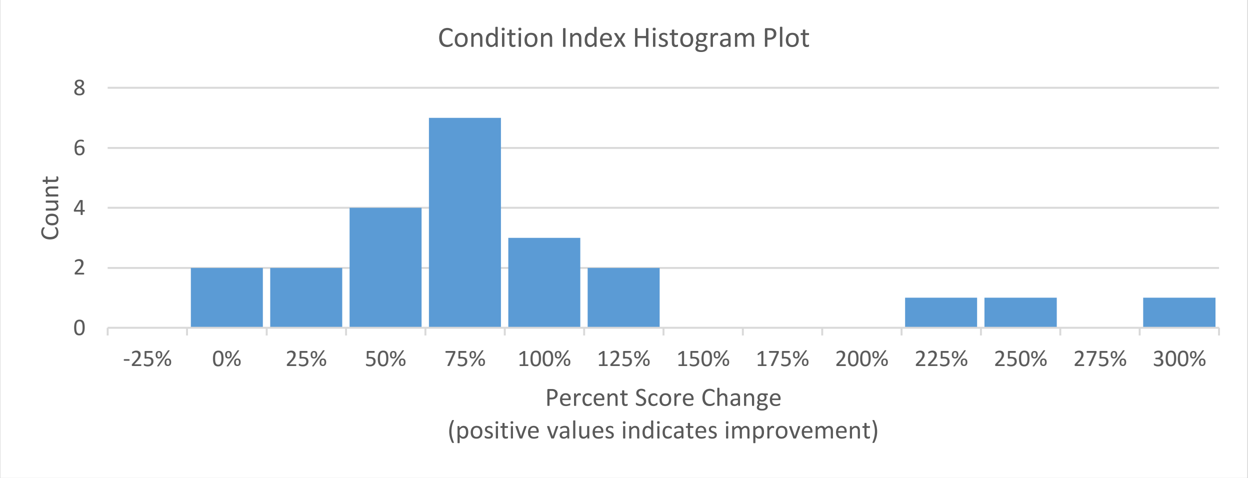

Figure 11: Histogram plot of Condition Index percent change between 2004 and 2015 ratings

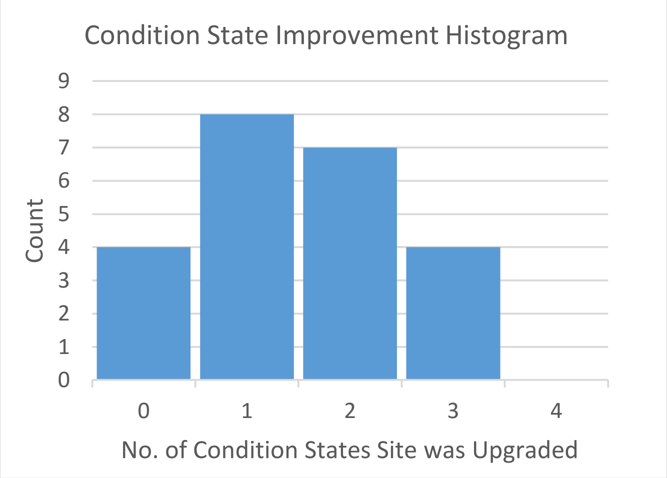

Figure 12: Histogram plot of condition state improvement between 2004 and 2015 ratings.

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.

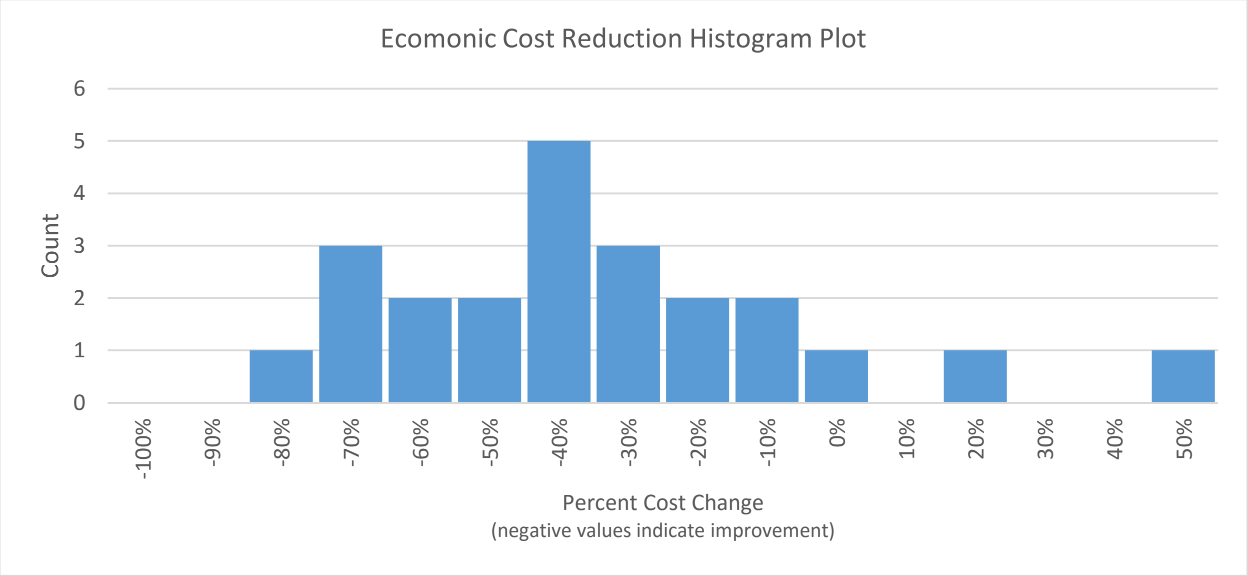

Figure 13: Histogram plot of economic cost reduction (as a percentage) between 2004 and 2015 ratings.

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

Appendix C

TASK 3 REPORT – ROCK SLOPE ASSET MANAGEMENT SYSTEM

Montana Department
or Transporation

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

Task 3 Report
Rock Slope Asset Management Program

LANDSLIDE
TECHNOLOGY
A DIVISION OF CORNFORTH CONSULTANTS

Prepared for:

Montana Department of Transportation
Helena, Montana

ROCKFALL HAZARD PROCESS ASSESSMENT

TASK 3 REPORT
ROCKFALL RATING CRITERIA

September 28, 2016

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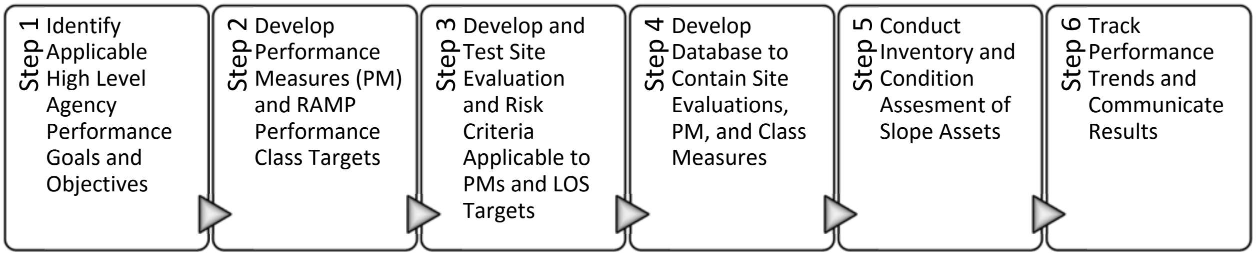
Executive Summary

This document is the deliverable for Task 3 of the Montana Department of Transportation (MDT) research project “Rockfall Hazard Rating Process Assessment” (Project No. 15-3059V). The objective of this task was to define, validate, and modify RHRS rating criteria to better fit MDT’s needs in assessment, prioritization, and risk analysis. The task consists of:

1) Developing RAMP Performance Classes, Performance Measures, and other criteria to assist MDT in managing their rockfall hazard risk;
2) Developing Condition States compatible with past RHRS scoring criteria;
3) Developing an approach for calculating risk measures for rock slope; and
4) Apply the criteria to the existing statewide dataset.

To accomplish these tasks, a roadmap for implementation of the Department’s newly christened Rock Slope Asset Management Program (RAMP) was developed and described in this Task report.



Aligning Rock Slope Performance Measures with MDT Goals

This report describes performance management and presents a roadmap for creating performance measures for the RAMP. This roadmap is in accord with MDT policies, goals, and objectives as set out in the key MDT guiding documents: TranPlan 21, the Performance Programming Process (P3) and the recently published MDT Transportation Asset Management Plan. It comprises a step-by-step process for MDT to follow as they move toward active asset management of their rock slopes by providing critical technical information and financial projections to decision-makers about the future condition of rock slopes. This information will help track how investment in mitigation options can affect the safety, physical condition, user mobility and fiscal health of the MDT highway system. Preliminary performance measures (PMs) and decision support tools are presented to jump-start MDT’s PM process.

The process begins with collecting and analyzing the MDT goals, objectives and policies for managing assets. RAMP Performance Classes are devised in support of agency goal- and objective-based performance targets. Using the this as a basis, the next step is forming the performance measures. The guiding documents lead to four distinct areas suitable for performance measures and decision support tools:

- **Condition** (RHRS rating plus lifecycle cost),
- **Mobility** (road closures delay/detour costs),
- **Safety/risk** (risk analysis and likelihood), and
- **Lifecycle cost effectiveness** (projected value and operational costs based on mitigation alternatives)

Assessment Procedures

The procedures proposed in the Task 2 report, including total RHRS scores, subsets of RHRS rating categories, and derivative condition measures, serve as the basis of the site-specific ratings and can be analyzed using a variety of methods to permit tracking with time, corridor prioritization, and correlation to mitigation costs and probabilistic risk factors. Spreadsheet and GIS database collection tools that facilitate Task 4 data collection are described.

Risk Assessment

Assessing the risk to the highway system and its function is a critical component of the RAMP. Risk posed by failing rock slopes is defined using the well-known equation:

Risk = Probability x Consequence

In many cases, risk is expressed in terms of dollar value following analysis that equates consequence events to cost. Risk is assumed to result in a consequence with an accompanying cost.

Risk assessment for RAMP equates to the standard dollar risk costs based on AASHTO standard user benefit analysis techniques. Using historical rockfall information collected by MDT, the likelihood of a road-closing rockfall event is calculated based on a slope’s condition and its size. These risk factors are compared to traffic volume, detour lengths and travel times, and recovery efforts to generate risk costs that permit risk-based assessment and prioritization. In upcoming tasks, the condition and risk factors will be applied to the Task 4 data and the remaining 2004 RHRS site rating data.

Tracking Trends and Communications

Successful implementation of a TAM-compatible RAMP includes the continued use of the existing dataset and tracking performance of rock slope assets over time. This is a common theme in other asset management programs, such as the pavement management example in MDT’s recent TAM Plan. Reporting and communicating with the public on the performance of rock slope assets should be integrated with reports on MDT’s pavement and bridge programs. MDT may be considering developing an interactive or digital performance communication portal that summarizes the contribution of these assets to mobility and commerce. In support of this, Section 7 provides examples of effective trend tracking and communication tools.

Using the PMs, decision support tools, assessment procedures, and risk analyses, MDT will be able to track performance of its rock slopes over time. The assessment of the results will lead MDT to better understand the efficiency and usefulness of the performance management system, and to more accurately quantify the condition of rock slopes statewide and guide investment strategies for sustained improvement. This understanding will form the basis of cost-effective decision-making and appropriate selection of and funding allocation for performance enhancing projects to improve rock slopes statewide.

1 Task 3 Introduction

The purpose of this task is to document the goals and objectives of the Montana Department of Transportation's (MDT) Rock Slope Asset Management Program (RAMP), define categories and site characteristics subject to field evaluation, document various rock slope evaluation criteria, describe and document the program's risk assessment process, and define performance measures used to evaluate asset and system management performance.

MDT's existing performance and asset management programs, including the Performance Programming Process (P3) Program and the Transportation Asset Management Plan (TAMP), create the link between agency goals, objectives and policies, and successful operation of the RAMP program. Performance management is a means for transportation agencies to measure progress towards agency goals and is an integral part of the RAMP's future compliance with the TAM programs required under federal law (23 U.S. Code § 119 n.d.). Note that only pavements and bridges are required under this code, but that inclusion of other assets, such as rock slopes, into their TAMP is encouraged. Performance management is the tool commonly used by transportation agencies to measure progress toward federal and state goals and objectives. Within this toolkit, performance measures are indicators of work performed and results achieved (NCHRP 2006).

In addition to technical management of MDT's numerous rock slopes, the RAMP provides support for management decision-making and allocating funding for the design, construction, maintenance, and eventual replacement/reconstruction of MDT's rock slopes. Combined with additional deterioration analysis and life cycle cost analysis, MDT would have all the information it needs in order to include the RAMP in MDT's TAMP.

The roadmap laid out below outlines the steps for creation of the RAMP and using its data to measure performance of MDT's rock slope assets. These steps are useful at the Executive, Planning, and Technical levels. Figure 1-1 contains a flow chart of the various steps in the process and are discussed in the following sections.

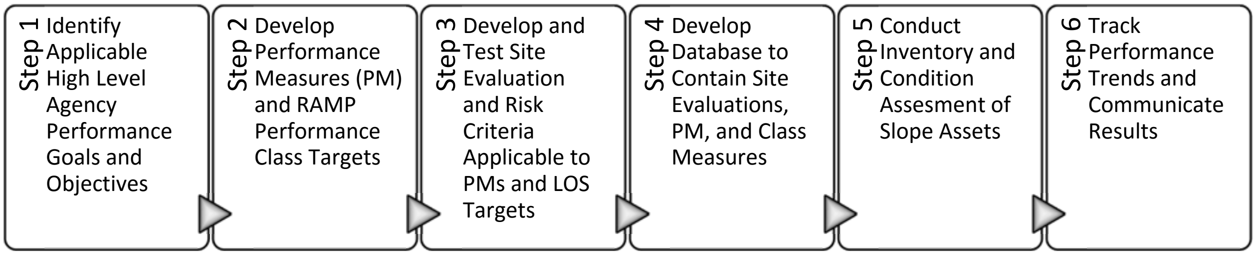


Figure 1-1: Flow Chart for RAMP Process.

RAMP Performance Management is largely based on slope performance, condition, and risk measures, with performance targets expressed as RAMP Performance Classes. The RAMP Performance Classes are similar to the winter condition Levels of Service currently in use in that they categorize performance targets and expectations. These specific targets are a necessary precursor for the performance measures and decision support tools developed for the RAMP. The performance metrics measure MDT's progress toward reaching the targets. The process also includes development of detailed decision support tools for condition and performance of rock slopes statewide and for individual assets (specific slopes) as set out below.

Section 3 describes Performance Classes created for the RAMP. Performance measures (PMs) are the quantitative indicators of how effectively MDT is progressing toward their targets. Performance measures range from high level, generalized, agency-wide “aspirational” goals to asset-specific “technical” goals.

In this application, performance measures will track how well the agency is managing and improving its rock slopes over time. Using data from slope rating and maintenance activities, an agency can track the condition of its slopes by periodically re-rating the slopes. MDT should also track the frequency of repairs, road closures, the cost of detouring and time delays for users due to reduced number of lanes for maintenance work, etc. with tools recently added to the work scope as part of RAMP implementation.

2 Step 1: Identify Applicable High-Level Agency Performance Goals and Objectives.

MDT has a number of high-level goals, objectives, and policies, which have not been applied to the former RHRS. Development of new PMs and key performance indicators will be needed to meet MDT needs for the RAMP. Agency staff should review, adapt, and adopt the preliminary PMs presented herein, which have been designed to reflect high-level agency goals, objectives and policies and the lower level needs of agency sections and subsections to effectively manage rock slopes. Those located so far are based on strategic information in the following documents:

- TranPlan Montana: MDTs long range transportation plan,
- TranPlan21 Roadway System Performance Policy Paper, and
- TranPlan21 Traveler Safety Policy Paper.
- Performance Programming Process ‘P3’ (2015) – MDT asset management program,
- Transportation Asset Management Plan (2015)

Transportation agencies have a variety of disciplines that operate within the organization, such as design sections, information technology, planning, preliminary engineering, safety or maintenance and operations. Each of the disciplines and functional groups typically has a set of guiding policies or mission directives that are coupled with specific goals and objectives of the agency. These form the basis for development of management programs that are in accord with the overall agency goals. At MDT, examples include specific agency goals for safety, congestion management, and winter maintenance levels of service (LOS). As part of Step 1, identified below are specific program guidance documents and directives applicable to the RAMP. MDT should identify the contributing disciplines and internal stakeholders that could use the RAMP, solicit feedback, notify them on its uses and key components, and leave the door open to future collaboration.

2.1 Goals and Objectives

Below are the key goals and objectives of select MDT documents that have informed the development of the RAMP’s PMs.

TranPlanMT Policies - Excerpts from the Roadway System Performance Policy Paper:
(Montana Department of Transportation 2007)

Policy Goal A – Establish Priorities for Roadway Improvements:

- First Priority - Preservation of Montana’s Existing Highway System to address:
  - Increases in repair costs
  - Increases in operating costs for users
  - Increases in accident rates
  - Increases in environmental damage
  - Increases in travel delays
- Second Priority – Capacity Expansion and Mobility Improvement to address:
  - Congestion management – maintaining levels of service
  - Mobility – capacity improvements
- Third Priority – Other Improvements – Includes:
  - Strengthening link between policy, planning goals and project selection.
  - Providing performance information.

Policy Goal B – Preserve Mobility

- Provide guidance to planning investments and operating systems. Recommended actions include:
    - Establish criteria for when capacity is added as part of projects.
    - Establish process for corridor strategies to determine reconstruction needs

Policy Goal C – Improve Productivity

- Promote efficient system management, emphasizing preservation through strategies enhancing mobility and extending the service life of the system.
- Use P3 Program to establish objectives and performance levels for preserving condition and addressing congestion.
- Use the Highway Economic Analysis Tool to support analysis of benefits and costs of alternative investments for the system.

Performance Programming Process (P3) Objectives and System Performance Measures
(Montana Department of Transportation 2015)

- Pavement
    - Objective: Preserve at existing or higher condition.
    - Performance Measure: Ride Index.
    - Target: Maintain average ride in the superior or desirable range.
- Bridges
    - Objective: improve the condition of bridges.
    - Performance Measure: Percent structurally deficient bridges by deck area.
    - Target: Maintain the percentage of structurally deficient bridges.
- Congestion
    - Objective: maintain and improve congestion levels in rural areas and improve interchanges and system operation in urban areas.
    - Performance Measure: Congestion Index measure of travel delay
    - Targets:
        - Interstate - Congestion Index – Level of Service B
        - NHS - Congestion Index – Level of Service C
        - Primary System – Congestion Index – Level of Service C
- Safety
    - Objective: Improve Safety
    - Performance Measure: Number of highway fatalities and incapacitating injuries
    - Target: Reduce the number of fatalities and incapacitating injuries by half from 2007 to 2030.
- Other Objectives - Maintenance
    - Replacing existing Maintenance Management System (MMS) with new system that provides information about what, when, and where work has been accomplished
    - New MMS system with “accountability module” to manage performance goals and targets.

Transportation Asset Management Plan

MDT's Transportation Asset Management Plan (TAM Plan or TAMP) was completed in 2015 (Montana Department of Transportation 2015), following the initiation of this RAMP Update project. The TAMP was pre-dated by the 1999 Performance Programming Process (P3), a performance management program. Together, MDT's TAMP, P3 program, and long range TranPlan21 provide the basis for a performance- and risk-based asset management system meeting state needs and federal requirements.

With the addition of the 2015 TAMP, MDT is aligning itself with the requirements of the federal MAP-21 legislation that requires a risk-based asset management plan. The TAMP provides a view of how MDT manages the two principal assets on which MAP-21 focuses; pavements and bridges. The TAMP also addresses other aspects of the MAP-21 requirements including managing risk, a financial plan and investment strategies, and MDT plans for future enhancement of TAM practices to fill gaps.

The TAMP emphasizes the following goals and objectives:

- Communicating asset management objectives (specifically for bridges and pavements);
- Documenting the management approach to align strategic goals from TranPlan21 with project selection and budgeting;
- Synthesizing information to tell a complete story of asset conditions statewide;
- Identifying potential investment strategies to achieve performance goals;
- Utilizing risk management concepts; and
- Documenting gaps in the asset management framework and what is needed to close the gaps.

These goals and objectives will apply to rock slopes as the RAMP is developed and as the TAMP is eventually updated to include assets other than bridges and pavements.

At present, the TAMP focuses on bridges and pavements and adopts commonly used condition rating systems that express condition within a Good/Fair/Poor format as do many transportation agencies. Pavement ratings are expressed in terms of Good/Fair/Poor (also known in the P3 program as superior/desirable/undesirable) based on the Ride Index. Bridge ratings are based on the National Bridge Inventory rating systems relating to Structure Condition, Deck Condition, and Structural Deficiency. Bridges are then grouped by overall condition. For both bridges and pavements, TranPlan 21 goals provide the priority for management under the TAMP:

- Preservation of the existing system,
- Capacity expansion and mobility improvements, and
- Safety and other improvements

In addition, for both asset types, MDT has projected future condition based on differing funding levels. However, MDT recognizes that additional work is required to fill gaps in the analytical capability and evaluation processes MDT is employing.

MDT's TAMP recognizes the importance of risk management (RM) and adheres to an accepted meaning and description of risk management. In addition to a typical framework of RM, MDT has identified a number of high-level risk concerns and consequences:

- Safety – risk of fatal or serious injury crashes
- Mobility – risk of failure to move people and freight
- Asset Damage – risk of physical damage and impact on functional condition
- Financial – risk of impact on the agency and costs related to asset management

MDT has summarized many of these high-level risks in a risk register which is included in the TAMP. MDT is in the early stages of incorporating risk management, but it has taken several important steps that provide guidance on how to develop the RAMP program in coordination with the TAM program. The funding discussion in TAM Plan Chapter 5 and investment strategy in Chapter 6 will help guide the process of obtaining funding for the RAMP and help guide MDT in the decision making process for creating an annual program with a dedicated funding source with prioritization through the P3.

3 Step 2: Develop RAMP Performance Classes and Measures

3.1 Introduction to Performance Measures

Performance measures are the quantitative indicators of the services provided by the agency's transportation system to the user and occur at several levels in a transportation agency. These levels vary from agency to agency, but for MDT, the levels may be subdivided as:

Agency Level – Policy Objectives and PMs: MDT manages its roadway system under the guidance of several high-level goals, objectives and policies at the agency-wide level, as noted above. These agency policy goals typically include areas such as safety, mobility, congestion reduction, preservation, environment, etc. High-level performance measures are typically developed for each of an agency's policy goal areas. As set out above, the P3 and the Transportation Asset Management Plan spell out these objectives and goals, many of which are applicable to RAMP.

Program Level – Program Objectives and PMs: Transportation programs at MDT such as the Congestion Management System and winter maintenance standards utilize goals and objectives that are more specific than the agency goals from which they are derived. The purpose of the RAMP is to operate a comprehensive rockfall management system for use on the Department's state-maintained roadways. The objectives of the program are to 1) reduce the overall rockfall hazard to the motoring public, 2) manage the cost of rockfall maintenance, and 3) limit MDT's potential exposure to rockfall litigation. It is uncertain at this time if the RAMP will operate at the program level or solely at the asset level.

Asset level: For single assets or asset groups, key performance indicators are developed. These are the most specific PM objectives in the agency. They are based on standards that describe the quality of service offered to the public against which service performance can be measured (Cambridge Systematics 2002).[1] These PMs may be formulated primarily to guide staff through the process of operating performance- and asset-management programs, rather than specifically for communication with the public and stakeholders.

The statutes and agency goals and objectives supporting the RAMP include broad agency goals of safety, infrastructure condition, congestion reduction, and system reliability resilience.

Using condition and risk assessments along with the event and maintenance tracking data that the RAMP should eventually incorporate, MDT will be able to track the expected decrease of cleanup and slope repair costs, number and duration of road closures, etc. over time as a means of measuring progress. Note that as with all such programs, agencies should generally expect several years to pass before well-defined trends are produced that show a marked decrease in maintenance and other operating costs and an obvious increase in system performance.

For the MDT RAMP, two general types of PMs are proposed:

Condition: Describes performance in terms of the physical state of rock slope assets. In the RAMP, this rating encompasses individual assets (a single rock slope), but this information can readily be combined and applied to a variety of mileage segments, corridors or groups of segments that share cross-functional classifications. These PMs are based on evaluation criteria derived from the ratings and, as such, they can be reported in a "Good/Fair/Poor" nomenclature. These are largely *Asset Level PMs*.

Management: Describes performance in terms of how well the agency is operating, preserving, and improving these specific program assets. Examples include tracking the changing condition of rock slopes, the number of rockfall-related road-closing events, and reducing the risks associated with rock

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[1] AASHTO TAM Guide I, Section 5.2.3.

slopes over time. MDT can also track cost efficiency and investment effectiveness by collecting data on the frequency of repairs, road closures, the cost of detouring and time delays for users due to reduced number of lanes for maintenance work, etc. These *Management Level PMs* incorporate the overarching Agency and Program Level PMs.

Consistent with MDT's TAM Plan, the proposed PMs provide the desired decision-support tools and address the high-level risk concerns and consequences related to:

- Safety – risk of fatal or serious injury crashes
- Mobility – risk of failure to move people and freight
- Asset Damage – risk of physical damage and impact on functional condition
- Financial – risk of impact on the agency and costs related to this asset class

3.2 RAMP Performance Classes

While MDT does not have a generalized agency-wide performance classification scheme to guide the RAMP, there are examples in other MDT agency programs. These include:

- Statewide: Winter Maintenance Standards – Six classifications of Levels of Service (LOS) based on AADT and proximity to urban areas.
- Statewide: Congestion Management System (CoMS) provides a "congestion index" with key performance indicators for Interstate, NHS and Primary highways. CoMS also includes a five-level A - E LOS classification scale. Level A means vehicles are unimpeded in their ability to maneuver in the traffic stream. For Level E, the roadway operates at full capacity with few usable gaps in the traffic stream.
- There are also local/regional classification examples, such as the 2007 "MDT TRED (Transportation Regional Economic Development) – Theodore Roosevelt Expressway Working Paper #5 on Level of Service and Safety" which has a six-level classification scheme.

For the above examples, the performance classes are effectively based on goals related to the mobility of the road user. Some classes are indicative of little to no mobility, such as winter pass road closures (Level 5). Others indicate the public's ability to drive at their desired speed and limited time waiting to pass slow moving vehicles (LOS A in TRED Working Paper #5).

The five-tier classification scale is typical of many transportation agencies and sets the targets for the quality of road service to users. As with the winter LOSs above, MDT can vary its goals for rock slope performance rather than using a standardized approach that treats each rock slope and corridor identically. A five-tier performance classification scheme for the RAMP that focuses on slope condition and likelihood of road closing events is proposed in Table 3-1 and should guide MDT on how and where to implement decision support tools discussed in Section 3.5.

Table 3-2 contains proposed route/segment LOS goals and the associated PMs based on the roadway's Functional Classification. Figure 3-1 illustrates a map of the proposed RAMP LOS targets. The LOS goals and percentage targets would be applied to these routes and where no rock slopes exist, the default RAMP LOS would be 'A', as shown in Table 3-1.

The table recognizes that some routes and highway systems are higher priority than others. Follow-up inventory and condition surveys can be prioritized based on functional classification or other metrics, such as the AADT.

Table 3-1: Proposed RAMP Performance Classification Scheme (Addresses Mobility and Safety)

RAMP Perf. Class	Road Segment Performance Classification, Likelihood, and Associated Condition Targets*
A	Very high level. Rock slopes pose a very low likelihood (<0.25% annual likelihood per centerline mile) of user delays. Condition target: >80% of rock slope area (square-foot basis) in GOOD condition and <2% in POOR.
B	High level. Rock slopes pose a low likelihood of user delays (<0.5% annual likelihood). Condition target: >70% of rock slopes in GOOD condition and <5% in POOR.
C	Minimum acceptable level. Rock slopes pose a moderate likelihood of user delays (<1% annual likelihood). Condition target: >50% of rock slopes in GOOD condition and <10% in POOR.
D	Unacceptable level. Rock slopes pose a high likelihood of user delays (<3% annual likelihood). Condition target: <50% of rock slopes in GOOD condition and <10% in POOR.
F	Failing level. Rock slopes pose an unacceptably high likelihood of user delays (>3% likelihood). Condition target: >50% of rock slopes in FAIR condition and >10% in POOR.

* Rock slope condition discussed in Section 3.6.1, likelihood discussed in Section 5.

Table 3-2: Functional Classification and LOS Targets

Roadway Functional Classification	Example	Target RAMP Class	Minimum RAMP Class
Principal Arterial – Interstate	I-90, I-15	A	B
Principal Arterial – Non-Interstate	US 191 Belgrade to W. Yellowstone, US 2	B	B
Minor Arterial	MT 56 Troy to Noxon, Beartooth Pass	B	C
Major Collector	Rt 421 Joliet to Columbus, Rt 279 Helena to MT 200	B	C
Minor Collector (all Off System, not part of original RHRS)	Stampede Pass Road Dillion to Rt 357	C	C

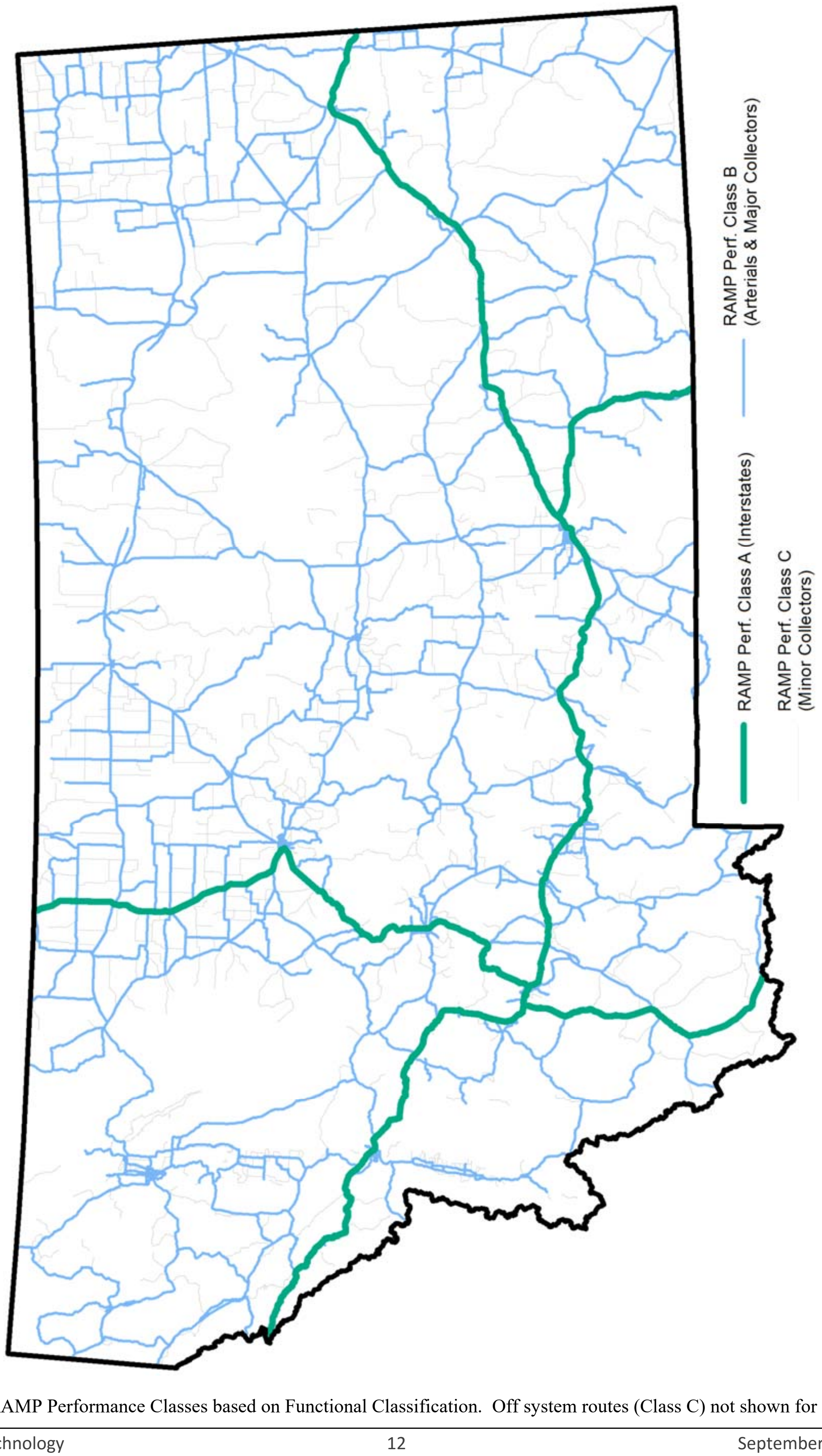


Figure 3-1: RAMP Performance Classes based on Functional Classification. Off system routes (Class C) not shown for clarity.

3.3 Performance Measurement for Condition

Performance measurement based on condition follows and expands upon examples outlined in an FHWA Office of Transportation Performance Management factsheet describing a Notice of Proposed Rulemaking (NPRM) for pavements and bridges (Federal Highway Administration 2015). FHWA is proposing measures to assess the conditions of pavement and bridge assets with performance targets set by the States or Metropolitan Planning Organizations receiving federal funding. This NPRM also proposes a minimum condition level as required by MAP-21. For pavements, the minimum condition level is no more than 5% of Interstate System lane miles in a Poor condition. For NHS bridges, the percentage of deck area on Structurally Deficient bridges cannot exceed 10% of overall deck area. For non-Interstate pavements, no minimum condition level was proposed with this rule.

For unstable slopes, the performance measures approach is based on condition rating and periodic re-rating of unstable slopes. The basis of much of the RAMP system is understanding the condition of the inventoried slopes. This is a concept common to both geotechnical engineering of rock slopes and to asset and performance management systems.

The Condition State of slopes is readily determined under the RAMP, as described in the Task 2 report and in Section 3.6.1 of this report. Application of categories to groupings of slopes is created in the form of numerical condition indices and by the “Good/Fair/Poor” (G/F/P) system favored by FHWA and described in Section 4.6.

Network-level performance measurement systems allow for adjustments to targets and minimum conditions based on the RAMP Performance Class scheme, described in Section 3.2. Typically, at this early stage of program development, the targets can be directly applied only to those roads that have had inventory and condition assessments performed. MDT will be able, however, to make projections based on surveys of representative corridors or segments to estimate the statewide picture for all rock slopes since the developed evaluation rubrics utilize rating categories and methods from the initial MDT RHRS implementation. These Condition Performance Measures can be recast on a statewide or District basis for the five MDT regions. As the RAMP is operated over the course of some years, revisions will likely be needed as conditions change and the state of practice for asset and performance management matures, both nationally and within MDT.

3.4 Performance Measurement for Management of Rock Slopes

Performance measures to track the long-term improvements gained by proactive rock slope management are intended to track how well the Agency is improving their rock slope assets over time using data obtained during the slope ratings, tracking maintenance investments, and documenting any mitigation or repair projects. When managed effectively and timely, the occurrence of failures, patching, and road closures that are directly the result of geotechnical deficiencies should decrease over time. Although trends at individual sites will vary due to the sporadic nature of slope failures and a close relationship between failures and unpredictable climatic events, several years will be required before a marked decrease in reactional responses can be confirmed and a system-wide performance improvement noted.

Results of effective rock slope management can be assessed using several different scales: a road-mile linear scale (0.25, 1-mile, 5-mile, etc.), a route or corridor scale (I-90, I-15 Shelby to Canada Border, US 2, MT 56 Beartooth Pass, etc.), or the scale may be regional by Districts, or ultimately, statewide. As an example, pavement condition indices are typically reported on a per mile basis, but recent federal guidelines recommend condition being reported on a 0.10-mile basis while minimum condition levels are being proposed on the State level. MDT can monitor its performance by using the decision support tools below to guide how well it is adhering to fiscal objectives while also using the tools to populate and process a candidate project file. Trends of improvement at various scales can be tracked to illustrate where performance and conditions with the assistance of the Decision Support Tools described in Section 3.6.

3.5 Event and Maintenance Tracking

In addition to rating slopes at scheduled intervals, it is important to capture costs and data for all maintenance activities related to unstable rock slopes, including periodic ditch cleaning and rockfall debris clean-up work. Performance monitoring is only productive if the agency is able to capture the data needed to support its calculations. The scope of rockfall events would need to be tracked along with the size, repair cost, time of closures or restrictions on travel and other characteristics. Generalized record keeping, such as "one-week of rockfall ditch cleaning on I-90 from MP 0 to 10, using 5 crew, a loader, two trucks and a flagging crew" is not suitable for performing follow up evaluations or to support performance management. Recording maintenance activities with specificity provides the data resolution needed to identify deteriorating conditions and, eventually, more informed life-cycle cost analysis. Detail such as that in the example below is needed, and preferably reported through the use of a simple form that can be submitted to program managers electronically.

- Cleaned 25 CY of rock from the right side of westbound I-90 between MP 26.05 to MP 26.12 for slope Site ID 1320 at a cost of $19,500 for state crew.
- Flagging contract for three days work at $2,000/day.
- Closed both westbound lanes for four hours on April 6, 2017 for initial removal of rock.
- Closed outside lane April 6-8, 2017 for cleanup and slope repair for 32 hours.
- Geotechnical Section notified by email with photos attached.

Tracking road closing events and maintenance activities by individual site ID is strongly recommended.

3.6 Decision Support Tools

Although rock slopes often appear to be a permanent road feature, they do in fact have a finite service life. The difficulty is determining where a slope is in its life cycle and when it is most appropriate to invest to prolong the service life and/or reduce operating costs. When a slope is near the end of its service life and approaching a failed state, it will no longer provide an acceptable Level of Service. The occurrence of rockfall-related accidents; travel times and interruptions; and maintenance requirements may all become unreasonable and unacceptable. At this point, the slope has failed and the decision to make a capital investment becomes obvious. Although it is easy to render a decision based on this eventuality, waiting until a slope failure occurs, as with pavement assets, will typically not yield the lowest life cycle cost.

Rock cuts have a finite life that is highly variable and is, in fact, highly indeterminate in nature. This is an understandable reality. Highways and highway corridors, on the other hand, are perceived differently. They are considered to have an infinite duration operational role to play. This infinite service requirement needs to be maintained while the performance of supporting slope assets with a finite life is preserved at an efficient operating cost. The current condition of a slope can be evaluated based on performance criteria and to a certain degree simply on age, but slope performance is not unchangeable and further degradation can be curtailed or reversed by timely investments. Given the competing priorities MDT faces with budgets that are understandably also finite, investment in slopes needs to be tied to an agency policy with some degree of flexibility, but with a determined commitment to long-term, system wide performance improvement. Based on such a policy, MDT can use the tools outlined in the following sections to help guide its decision process.

3.6.1 Decision Support Tool – Risk Reduction

All rock slopes pose some level of threat to smooth functioning of the transportation corridor. Rockfall events can cause road closures or require traffic slowdowns while material is removed, and more rarely, rocks on the road can cause property damage, injury accidents, or even fatalities. The likelihood of an adverse event is the combination of the rock slope condition (including its proximity to the roadway) and its surface area. As discussed in Section 5.5, data from a rockfall event survey provided by MDT geotechnical personnel was used to relate annual risk of an adverse event with rock slope size and condition.

The decision support tool (DST) in Table 3-3 below shows one example of how risk reduction can be incorporated into long-term planning. In this example, different levels of risk are acceptable based on the significance of the route. For instance, sites that pose an unacceptable risk along interstate routes may be acceptable on minor collectors. Since rock slopes of similar condition are frequently found in groups, mobility and safety risks can also be expanded from the individual site level to a specific segment of the transportation corridor. Geotechnical personnel familiar with site history and geology can define similar route segments. Using this metric, multiple sites posing an unacceptable risk on an individual level could be candidates for mitigation as a group.

Projected long-term costs of adverse events could also be incorporated into this decision support tool. The annual risk of an event can be multiplied by projected costs based on AADT at the site, detour length, likely closure duration, additional travel time, etc. Because a higher AADT results in increased impact costs, this decision tool would tend to pull funding towards sites along the interstate, potentially at the expense of sites in poorer condition on less travelled roads.

Table 3-3: Decision support tool for Mobility Risk Reduction

DST Objective – Reduce Mobility Risk and Track Management Performance				
Decision support tool: Mobility Risk (MR). Maintain slope condition to applicable low, medium, high mobility risk levels, as measured by service-disrupting events. Service-disrupting events include both road closures and traffic slowdowns. Where no rock slopes exist, the annual risk approaches zero. Apply Performance Measure using "Good/Fair/Poor" ratings based on the Proposed Condition- and Risk-Based RAMP Performance Classes, and the Functional Classification and Targets contained in Tables 3-2 and 3-3.	Prev. Period Closure Frequency & Density	Current Period Closure Frequency & Density	RAMP Class Target	Trend
Low Mobility Risk: Roads critical to interstate travel and commerce. Individual sites pose an annual risk of service disruption that adhere to event frequency in Class 'A' (Table 3-1).			Class A	
Medium Mobility Risk: Roads important to interstate travel and commerce, or of intra-state significance. Individual sites pose an annual risk of service disruption that adhere to event frequency in Class 'B' (Table 3-1).			Class B	
High Mobility Risk: Route of local significance, but which has low AADT or easily accessible detours, which result in lower mobility costs. Individual sites pose an annual risk of service disruption that adhere to event frequency in Class 'C' (Table 3-1).			Class C	
Reevaluate this DST every three to five years.				

3.6.2 Decision Support Tool – Cost Effective Performance Improvement and Risk Reduction

The level of effort required to mitigate a rock slope, thus improving performance and reducing risk can vary widely based on a variety of site specific and geotechnical factors. However, in general, mitigation costs increase as slopes deteriorate, and larger slopes cost more to address than smaller slopes in the same condition.

Mitigation costs and long-term risk costs are estimated for each site using rock slope condition data and mitigation costs from the 2004 study (Beckstrand, et al. 2016) combined with risk estimates from the 2015 rock slope activity survey and the AASHTO-recommended (AASHTO 2010) TAM mobility and safety cost constants provide industry-standard user costs.

The DST in Table 3-4 provides an example of how these costs can be used to demonstrate judicious allocation of department funds. Instead of addressing rock slopes in a purely worst first or reactionary method, the Department could target slopes where the return on reduced risk outweighs the projected mitigation cost by a given percentage. This would help justify timely intervention in slopes that are degraded, but which have not yet reached a failed state. Because risk costs incorporate both event likelihood and AADT, this decision support tool is biased towards sites along highly travelled routes.

Table 3-4: Decision support tool for Cost Effective Investment in Performance Enhancements and Risk Reduction

DST Objective – Demonstrate Prudent Fiscal Decision Making	
Allocate funding based on a comparison of mobility/safety risk costs calculated for a site over a 30-year period to the estimated mitigation cost for the site. Risk costs are a combination of event likelihood, closure times, AADT, and detour length. Mitigation costs are high-level estimates based on slope condition and conceptual mitigation designs developed for RHRS sites rated in MDT's 2004 project.	Corresponding action
Highly cost effective: Where $1 dollar of mitigation work returns an estimated $1.50 to the department and public in reduced mobility and safety risks, mitigation work should be pursued as a wise investment.	Pursue and prioritize highly cost effective mitigation at all sites statewide
Moderately cost effective: Consider mitigation for sites/corridors where $1 of mitigation returns an estimated $1 to $1.50 in reduced mobility and safety risks. To increase cost effectiveness, the department may choose to scale down mitigation efforts to improve costs. For example, a Poor condition site may be improved to Fair condition, as opposed to Good condition.	Pursue and prioritize moderately cost effective mitigation on routes at the arterial level
Cost effective: Consider mitigation for sites/corridors where mitigation costs are essentially equal ($1 to $1) to reduced mobility and safety risks under unique circumstances. Investments should be considered for incorporation in large projects along a transportation corridor. Intentionally targeting mitigation efforts for Poor to Fair improvements as opposed to Poor to Good may be enough to shift investments into the "moderately cost effective" category.	Pursue and prioritize cost effective sites for mitigation as part of a larger corridor project
Not cost effective: Sites where mitigation costs return less than $0.90 to the department in reduced mobility and safety risks should not be prioritized for mitigation work based on cost effectiveness alone. However, in certain cases, larger corridor projects addressing multiple sites may result in reduced overhead costs, making mitigation of these sites cost effective as part of the larger project. Alternatively, changing traffic patterns or continued slope degradation could result in increased mobility and safety risks, making slope mitigation cost effective in the future.	Pursue cost ineffective mitigation only as part of corridor-wide improvement project
Reevaluate this DST, risk calculations, and mitigation cost estimates every three to five years.	

3.6.3 Decision Support Tool – Mitigate Rock Slopes in Unacceptable Condition

The public has certain expectations for roadway performance, such as paved roads will generally be open for travel (with seasonal exceptions); road-closing events are cleared as quickly as possible; and traffic-slowing events are addressed daily (i.e., a rock on the road requiring evasive maneuvering to avoid will be moved off the roadway and into the ditch as needed).

The DST in the following table is an example of how the Department can allocate funds to improve the overall condition of its rock slope assets, similar to how failing pavements are repaired to meet minimum public expectations. Slope prioritization is based on a variety of metrics or combinations thereof. For example, cutoffs could be applied based on total RHRS score, or on a combination of slope condition and AADT, or could be based purely on slope condition. The various rating metrics evaluated in the RAMP are discussed in detail in Section 4.

In the following table, the proposed scores used to determine unacceptable conditions for the various RAMP Classes are based on an Excel percentile function analysis of RHRS sites scored in 2004. These scores could be adjusted to reflect different percentiles or raw scores, or to ensure that rock slopes meet a certain minimum criteria (i.e., Poor condition slopes are not tolerated). Sites could also be chosen within a corridor to improve overall corridor performance. As presented below and as described in the Task 2 Report, the Condition Index represents a linear continuum from 100 (ideal condition) to 0 (a failed condition) and it is based on a combination of the RHRS history score and the ability of the roadside ditch to contain the rockfall event and prevent it from reaching the roadway.

Table 3-5: Decision support tool - Minimum Acceptable Conditions

DST Objective – Improve system-wide rock slope conditions
Maintain slope condition to applicable service levels statewide, as measured by service disrupting events (road closure or slowdown). The goals in this table correspond to the RAMP Class Targets in Table 3-2.
RAMP Class Target A (Interstates): Roads will require only application of routine maintenance to remain open. Sites are selected for mitigation based on slope condition. Consider sites scoring in the worst 15th percentile in the various rating schemes for mitigation. These scoring cutoffs are: • Condition Index/Condition State: <35/Poor (4/5) • Total RHRS Score: >450 • Method 1: >175 • Method 2: > 280 • Method 3 Slope Rating: >160
RAMP Class Target B (Arterials and Major Collectors): Road closing events occur on an annual or biannual basis. Consider sites scoring in the worst 10th percentile on the various rating schemes for mitigation. These cutoffs are: • Condition Index/Condition State: <30/Poor (4/5) • Total RHRS Score: >485 • Method 1: >190 • Method 2: > 305 • Method 3 Slope Rating: >175
RAMP Class Target C (Minor Collectors and off-system routes): Road closing events may occur multiple times yearly, seasonally concentrated. Consider sites scoring in the worst 5th percentile in the various rating schemes for mitigation. • Condition Index/Condition State: <25/Poor (5) • Total RHRS Score: >550 • Method 1: >215 • Method 2: > 345 • Method 3 Slope Rating: >200
Reevaluate this DST every three to five years.

3.6.4 Decision Support Tool – Rock Slope Improvement Investment

MDT has invested millions of dollars over many decades to construct and maintain its rock slope assets. In the absence of periodic improvement, the performance of these assets will decline to the point where safe and efficient movement is unacceptably degraded. Using RAMP metrics, MDT will be able to track statewide slope performance and formulate a reasonable investment strategy to reach its performance goals while reducing the demands placed on maintenance personnel and state dollars. The rate of investment would need to be large enough to counter on-going slope deterioration while also addressing older slopes that were originally designed or constructed improperly or that were built using antiquated construction techniques and have never met reasonable performance expectations.

The decision support tool shown in Table 3-4 represents one example of how an investment policy/strategy could be monitored. In this simplified example, MDT opts to obligate $10,000,000 per biennium for all rock slope maintenance actions and design improvements, and sets a maximum divergence target of ±7%. If the Department begins to diverge from its biennial expenditures, it can either reassess its fiscal goals or adjust fiscal allocations during the following period to get back on track. For illustrative purposes, if $11.5 million is expended in the first performance period, placing MDT above their investment target, then expenditures are adjusted and reduced to $9.5 million in the following period, bringing the Department back into alignment with stated investment goals. The adherence to the goal should be reevaluated every budget cycle. This simple tool will help MDT adhere to its fiscal policy and report policy results. The actual level of investment could be determined by a collaborative agreement between MDT stakeholders and supported by modelling slope deterioration and applying life cycle cost analysis. Other methods to set-aside funding would be incorporate the RAMP data into the early stages of planning to take advantage of other corridor improvement projects to address rock slope condition improvements as a project component.

Table 3-6: Decision Support Tool for Rock Slope Investment Plan Adherence

MDT Goal: Make systematic improvements to rock slopes while adhering to MDT's investment plan by diverging no more than ±7% from investment goals.		
Prev. Period Performance	Current Period Performance	Trend
+15%, not meeting target	-5%, meeting target	Improved, meeting targets.

4 Step 3a: Rock Slope Evaluation

4.1 Applying Task 2 Evaluation Criteria to Existing RHRS Data

MDT internally developed three modified rating methods and requested that Landslide Technology (LT) test them using the existing 2004 data. The MDT scoring conditions were described and summarized in the Task 2 report and applied to the rating information collected at mitigated sites in November 2015. The 2004 RHRS ratings were detailed in MDT report FHWA/MT-05-011/8176 (Pierson, Beckstrand and Black, Rockfall Hazard Classification and Mitigation System 2005) and generally adhered to the standard RHRS categories and processes (Pierson and Van Vickle, Rockfall Hazard Rating Program - Participants' Manual 1993).

Concurrently, LT applied condition assessment criteria developed during other research programs to the 2015 data to illustrate their ability to demonstrate condition improvement following mitigation activities. The Task 2 report summarized the condition assessment approaches used. Brief summaries and distribution histograms as applied to the full 869 rated sites in the 2004 RHRS are contained in this Task 3 report.

For the Task 3 report, LT processed and mapped the various rating and condition criteria to all 869 sites that received a detailed rating evaluation in 2004, as summarized in the following sections. Histograms of data distributions are shown for each scoring criterion; Appendix A contains large format statewide maps for each criterion; and Figure 4-7: illustrates maps applying the various rating criteria for a rockfall corridor on Highway 2 east of West Glacier.

4.2 Total RHRS Score

Scores from both the 2004 and 2015 rating reconnaissance work were compiled and compared. The RHRS 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. A spreadsheet of the 2004 detailed ratings was provided to MDT Geotechnical personnel for their analysis and included data that were inaccessible in MDT's Oracle application.

Figure 4-1 contains a histogram distribution of 2004 scores and includes the rated sites which scored below the 350 point 'B' site cutoff score established in 2005.

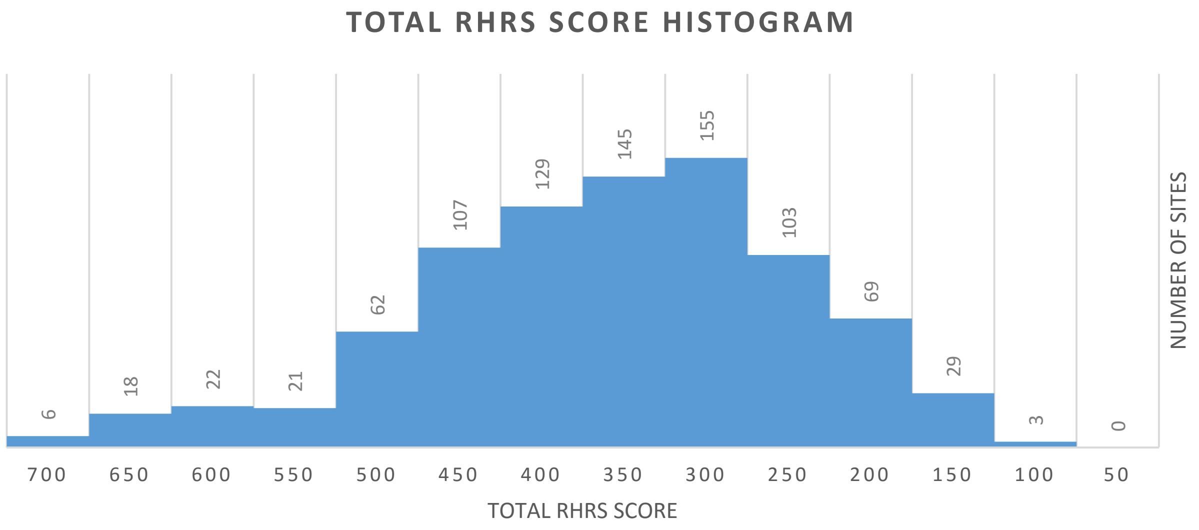


Figure 4-1: Histogram distribution of total RHRS scores for the 869 sites evaluated in 2004.

4.3 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

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

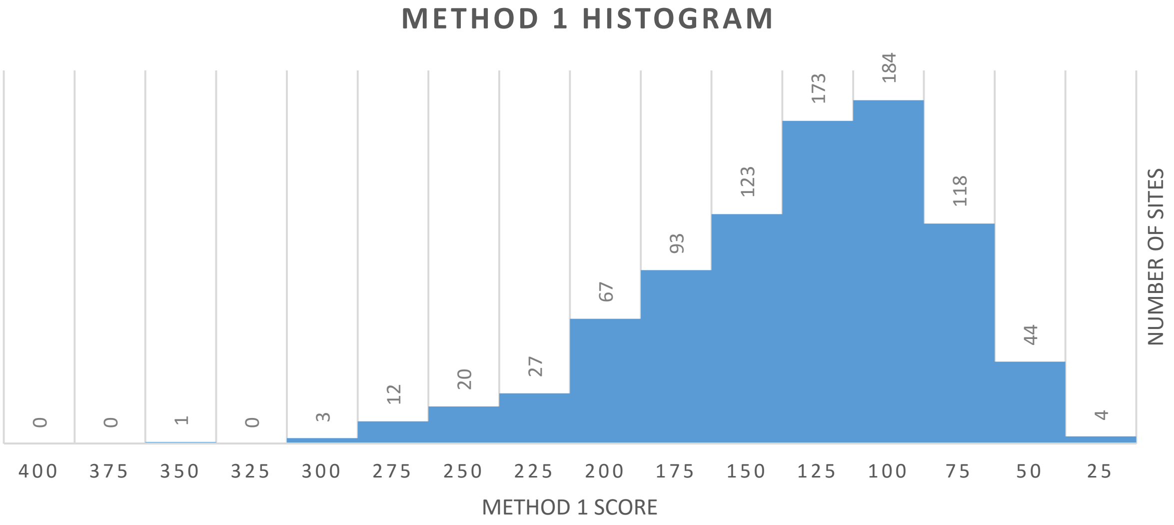


Figure 4-2: Histogram distribution of Method 1 scores for the 869 sites evaluated in 2004.

4.4 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 2. 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 2: Rating Method 2

$$\begin{aligned} Method\ 2 = {} & Ditch\ Effectivness + Traffic\ Impacts + Immediate\ Hazard + Failure\ Potential \\ & + Block\ Size\ or\ Volume + Rockfall\ History \end{aligned}$$

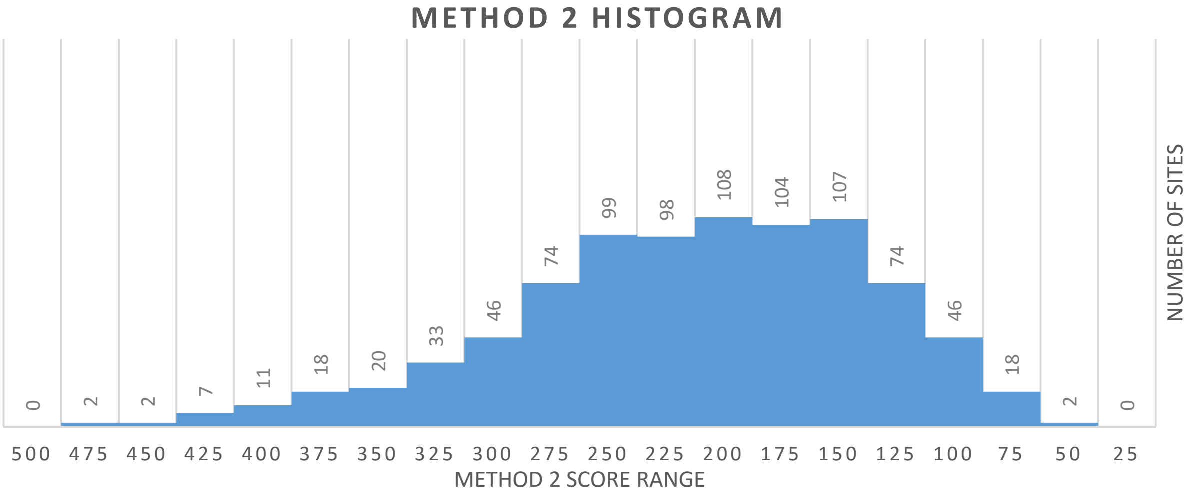


Figure 4-3: Histogram distribution of Method 2 scores for the 869 sites evaluated in 2004.

4.5 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 3. 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 maximum possible Slope Rating Score in Method #3 is 300 points.

Equation 3: Rating Method 3 – Slope Rating Score

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

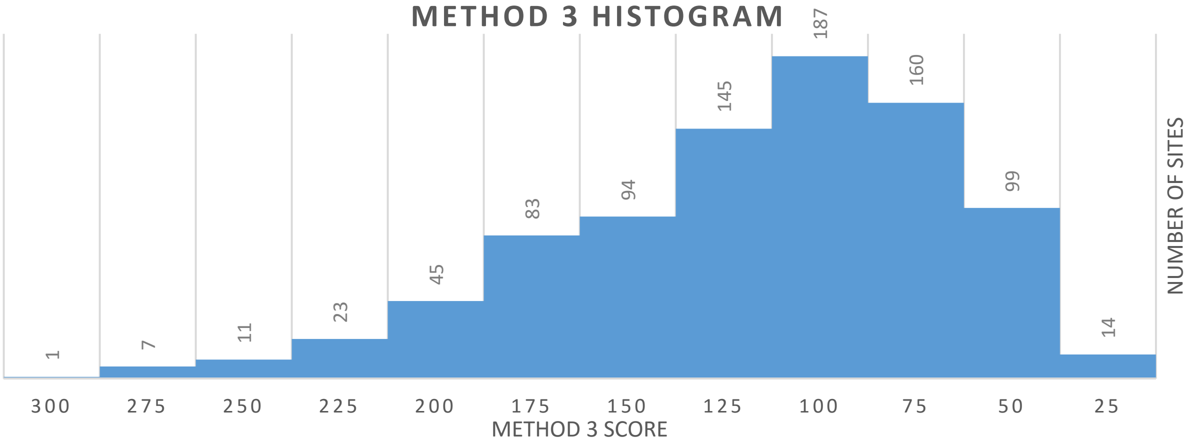


Figure 4-4: Histogram distribution of Method 3 Slope Rating scores for the 869 sites evaluated in 2004.

4.6 FHWA Good/Fair/Poor Classification

Recent research (Guerre, et al. 2012) and proposed federal regulations recommend categorizing condition assessments into Good/Fair/Poor divisions, as opposed to the purely numerical rankings like those generated by the above scoring and rating methods. In their current form, Good/Fair/Poor divisions are intended to improve FHWA's ability to assess the health of the nation's highway infrastructure and serve two primary objectives:

- Define a consistent and reliable method of assessing infrastructure health with a focus on bridges and pavements on the Interstate Highway System; and
- To develop tools to provide FHWA and State Department of Transportation (DOT) personnel ready access to key information that will allow for a better and more complete view of infrastructure health nationally.

To meet these objectives, the research focused on the development of an approach for categorizing assets, mainly bridges and pavements at this point, as Good, Fair, or Poor, which can be used consistently across the country. Asset performance in this context is based on condition information. This research has recommended the following parameters for Good/Fair/Poor for bridges and pavements:

> ***Good condition*** *– Bridge and pavement infrastructure that is free of significant defects, and has a condition that does not adversely affect its performance. This level of condition typically only requires preventive maintenance activities.*
>
> ***Fair condition*** *– Bridge and pavement infrastructure that has minor deterioration of bridge elements; or isolated surface defects or functional deficiencies on pavements. This level of condition typically could be addressed through minor rehabilitation, such as crack sealing, patching of spalls, and corrosion mitigation on bridges; and overlays and patching of pavements that do not require full depth structural improvements.*
>
> ***Poor condition*** *– Bridge and pavement infrastructure that is exhibiting advanced deterioration and conditions that impact structural capacity. This level of condition typically requires structural repair, rehabilitation, reconstruction or replacement*

Adapting these descriptive condition states to rock slopes yields the following Good/Fair/Poor classification:

Table 4-1: Rock Slope Good/Fair/Poor Classification

Classification	Description
Good	Rock slopes and appurtenant rockfall mitigation elements are free of significant defects and are of a condition that does not adversely affect good performance. Preventive maintenance such as regular ditch cleaning keeps the slopes and mitigation elements in good condition. There is a low likelihood of adverse effect on users.
Fair	Rock slopes exhibit minor deterioration with occasional rockfall that does not frequently interfere with operation of the roadway or create significant delays to users. Rock slope maintenance may include some scaling, or more frequent ditch cleanout. Rockfall mitigation elements exhibit some deterioration or damage, but continue to function adequately without significant maintenance effort. Rockfall fences and drapes may require replacement of small amounts of damaged fence panels, braking elements and cables. Roadside barriers may require repair or replacement of a small percentage of barrier.
Poor	Rock slopes and mitigation elements exhibit advanced deterioration and damage. Individual slopes in a District, or groups of slopes along a corridor (e.g., I-90) may have deteriorated to a level that requires an unacceptable amount of maintenance and repair costs for slopes and rockfall mitigation. Some slopes may have failed catastrophically, requiring major cleanup efforts and reconstruction projects with attendant impacts on users, including detours and delays.

4.7 Rock Slope Condition

LT has been working with the Alaska Department of Transportation (AKDOT) to develop the nation's first Geotechnical Asset Management (GAM) program. This program incorporates its previously existing

Unstable Slope Management Program (USMP), which was developed to assess soil and rock slopes. Like MDT's original RHRS, this component of AKDOT's program uses rating categories with exponential scoring systems. Both states' rating systems are based on the RHRS, though the Alaska rating system includes a few additional categories to capture the extreme climate challenges in that state.

The Condition Index is a linear continuum from 100 (ideal condition) to 0 (a failed condition) that is evenly divided into five Condition States. It is a combination of the potential for a rockfall event and the ability of the roadside ditch to contain the rockfall event and prevent it from reaching the roadway. The RHRS "Ditch Effectiveness" and "Rockfall History" categories provide these components. The Condition State category descriptions are presented in Table 4-2 below. The means and methods used to derive these Condition States were applied to MDT's 2004 RHRS ratings, 2015 mitigated site ratings, and will be applied to the 2016 re-ratings in the Task 4 Report.

The Condition Index is useful to illustrate nuances within Condition State. For instance, an Index score of 100 indicates a totally effective ditch and low rockfall activity, while an Index score of 87 can indicate a less effective ditch but an equally low rockfall activity and no history or rockfall reaching the road. The two hypothetical sites used in this example are both Condition State 1, 'Good' slopes, but one could be less capable of keeping the very infrequent rockfall from reaching the road. It is likely that neither site would warrant mitigation and therefore it is reasonable to be within the same Condition State 1 classification. Figure 4-5 and Figure 4-6 plot the distribution of Condition Index and Condition State across the 869 rated sites.

Table 4-2: Rock Slope Condition Category Descriptions

Condition State	Good Fair Poor Descriptor	Cond. Index Range	Description
1	**Good**	**100 - 80**	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**	**80 - 60**	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**	**60 - 40**	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**	**40 – 20**	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**	**20 – 0**	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.

Like the calculation methods above, these condition calculations were applied to the original 869 RHRS sites. The histograms included as Figure 4-5 and Figure 4-6 illustrate the distribution of the Condition evaluations and the condition of the rated slope network along with the number of sites within each category. Note that 1,000 of the 1,869 sites evaluated during the original RHRS implementation were classified as 'B' sites. They were not rated with regard to ditch effectiveness or rockfall activity. It could be assumed that most of these remaining slopes are considered 'Good' for the purposes of the RAMP program; however, there will likely be a subset, possibly a significant portion, of historic B sites that would not be classified as Condition State 1, Good slopes. The upcoming Task 4 Report will review the Interstate B sites that were rated as part of 2016 fieldwork.

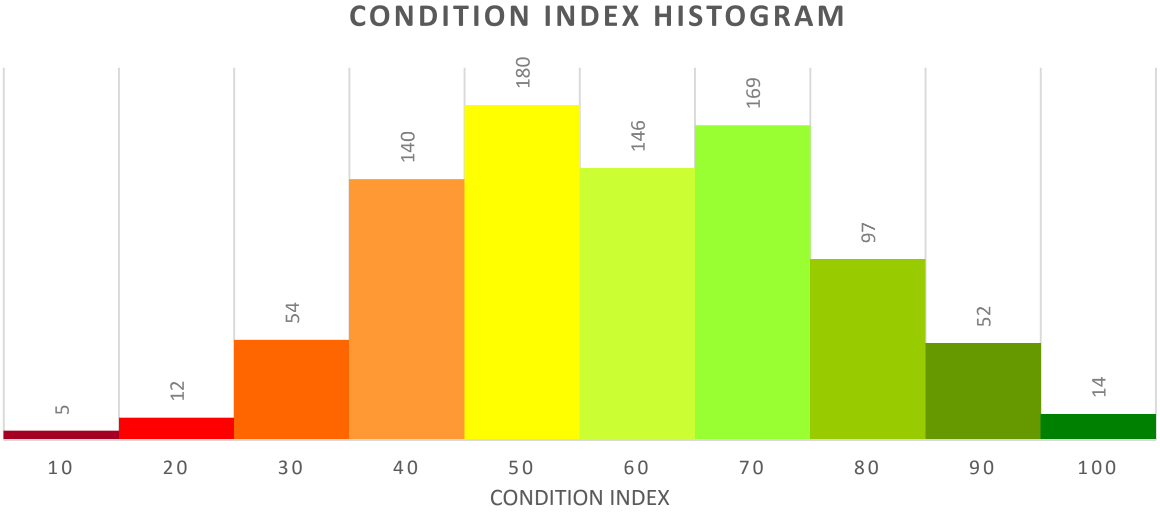


Figure 4-5: Histogram distribution of Condition Indexes for the 869 sites evaluated in 2004. Color gradient signifies the transition through Good/Fair/Poor conditions.

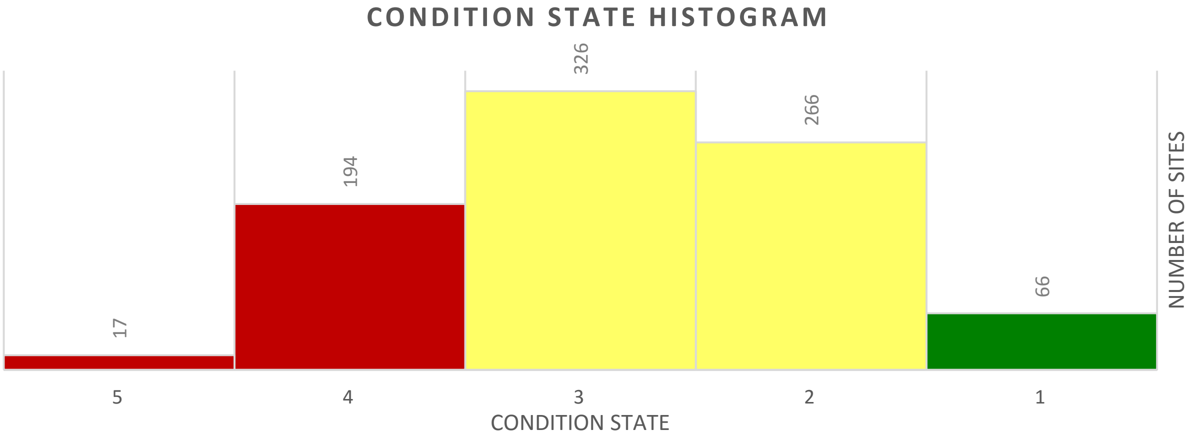


Figure 4-6: Histogram distribution of Condition States for the 869 sites evaluated in 2004. Green/yellow/red color scheme indicates Good/Fair/Poor condition.

Figure 4-7 compares how the RHRS scores, the three proposed MDT Methods, and the Condition Indices and States of the rockfall sites along a portion of Highway 2 can be presented for enhanced communications within the department and to the public. This type of visual analysis can also help the Department distinguish nuance between the multiple alternatives currently available.

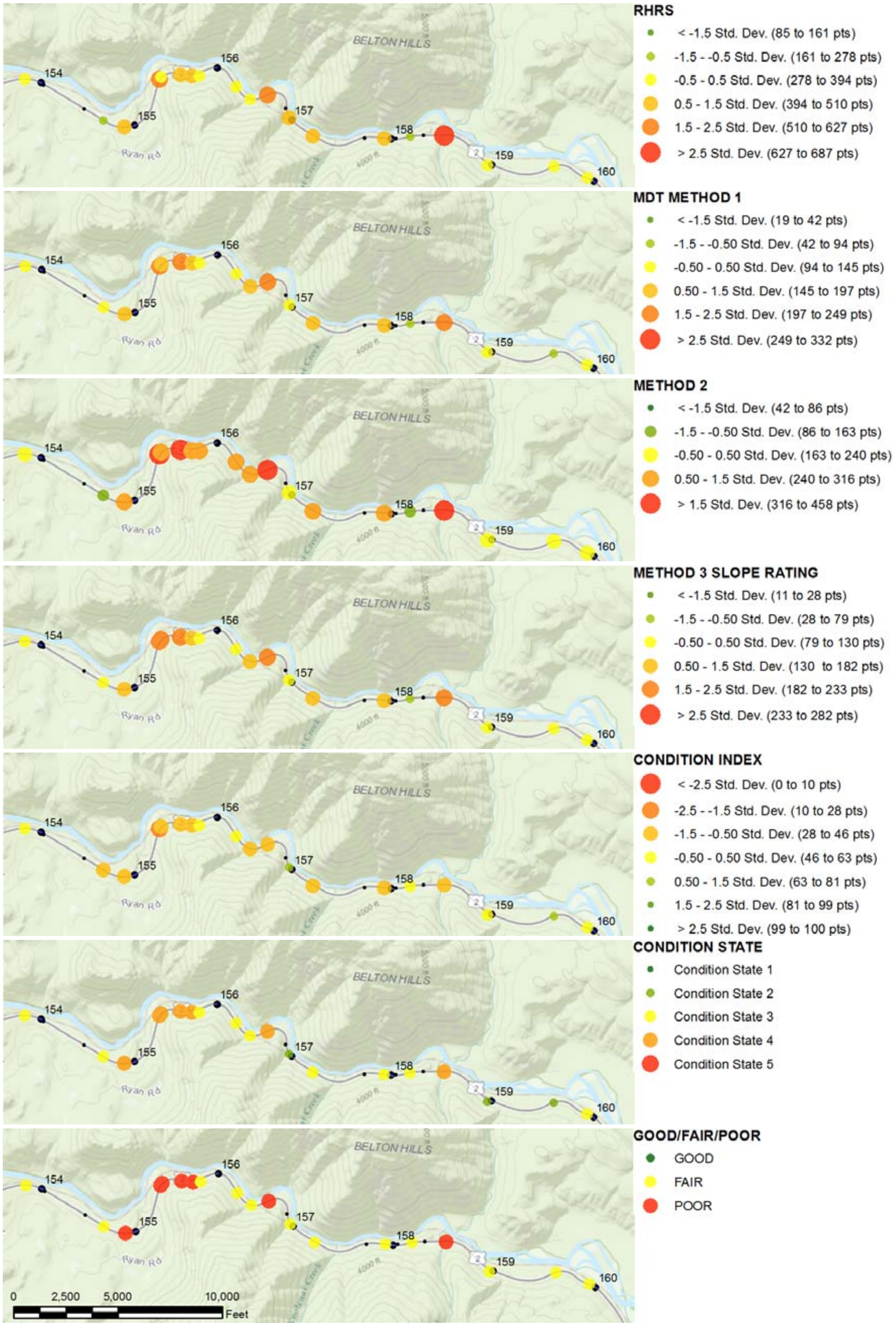


Figure 4-7: Comparison of rating methods for a six mile corridor immediately east of West Glacier on Highway 2, MP 154 to 160.

Regardless of the rating methods ultimately utilized by MDT for various purposes, the RAMP system is founded on quantifying the condition of inventoried rock slopes. Slope condition and Good/Fair/Poor descriptions are readily derived from the RHRS as demonstrated in the previous sections and detailed in the Task 2 Report. This is a common concept for both evaluation of rock slopes and asset/performance management systems.

If the event and maintenance data is tracked using means and methods similar to those discussed in Section 3.5, this information can also be used to help prioritize rerating work. During fieldwork, the event tracker data is used during the rerating process to refine category scores. In the office, data on event cost and frequency can be correlated with RAMP data to forecast future maintenance and/or mitigation costs based on asset Condition State. These potential applications underscore the need to track road closure events by individual RHRS section to the extent possible, so that event data can be readily integrated into the RAMP.

4.8 Relating Condition to Improvement Costs and Event Likelihood

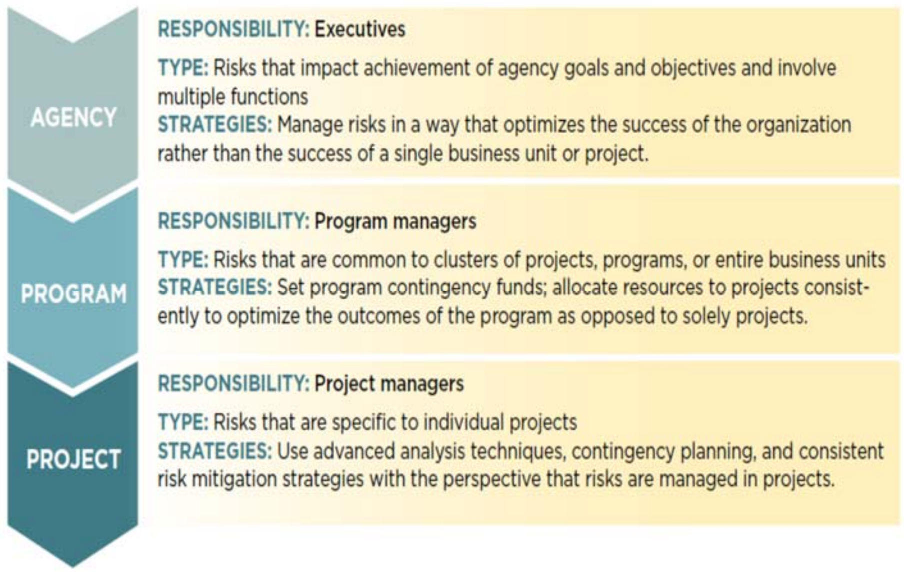
A critical aspect of TAM-compatible assessment systems is the ability to demonstrate the economic benefit of implementing mitigation measures that reduce the likelihood of mobility interruptions, vehicle accidents, maintenance activity, and other associated costs. Consider the hypothetical situation that rockfall mitigation measures may reduce the likelihood of mobility interruptions and rockfall-related accidents on a high AADT Interstate slope with only a long detour available or traffic slowdowns of a long duration required. The reduction in likelihood from a pre-mitigation likelihood of one adverse event per 10 year period to one every 20 years after mitigation measures are constructed is considered. In this hypothetical situation, the total 30-year economic loss without mitigation could be on the order of $19.6 million dollars; but, if the mitigation measures costing $2 million dollars are constructed, the loss would have been $9.3 million. In this example, if the mitigation measures reduced the likelihood of economic loss by 50%, the public would realize an approximately 515% [(19.6-9.3)/2 x 100%] return on the mitigation investment.

Determining the likelihoods and mitigation costs estimates for the entire network on a site specific basis would not only be cost prohibitive, but also unnecessary for TAM compatibility and corridor selection and identification. Site specific mitigation and risk analyses could be performed on a corridor basis once a select few candidate corridors are identified. For RAMP, programmatic correlations between the slope's size and Condition State have been determined for the likelihood of a road-blocking event (Section 5.5) and the mitigation costs based on improving slope condition (Task 6). Correlations between Condition State and mitigation cost have been carried out on the original 2004 MDT data for the AKDOT GAM study as published in the Transportation Research Record (Beckstrand, et al. 2016). This information will be incorporated into this study as part of Task 6.

By integrating historical events and costs, high-level estimates of future costs are estimated for MDT's rock slopes based on slope Condition State. These projected costs provide additional support of the economics underlying a TAM-compatible system. Conversely, failure to develop a methodology to extract slope condition information from MDT's RHRS program complicates integration of MDT's geotechnical assets into the state's TAM program and makes it harder to properly compete for funding.

5 Step 3b: Risk Assessment

Risk is about uncertainty. In the context of asset management, risk is defined as "the positive or negative effects of uncertainty or variability upon agency objectives" (Federal Highway Administration 2012). Risk has a well-known defining equation where Risk = Probability x Consequence. In many cases risk is expressed in terms of dollar value following analysis that equates consequence events to cost. An example where a risk may be considered positive is when a slope performs with unexpectedly small life-cycle cost well beyond its design life, resulting in a Maintenance budget surplus. More often, risk is assumed to result in a negative consequence.



RESPONSIBILITY: Executives

TYPE: Risks that impact achievement of agency goals and objectives and involve multiple functions
STRATEGIES: Manage risks in a way that optimizes the success of the organization rather than the success of a single business unit or project.

RESPONSIBILITY: Program managers

TYPE: Risks that are common to clusters of projects, programs, or entire business units
STRATEGIES: Set program contingency funds; allocate resources to projects consistently to optimize the outcomes of the program as opposed to solely projects.

RESPONSIBILITY: Project managers

TYPE: Risks that are specific to individual projects
STRATEGIES: Use advanced analysis techniques, contingency planning, and consistent risk mitigation strategies with the perspective that risks are managed in projects.

Figure 5-1: Transportation Agency Levels of Risk. (Federal Highway Administration 2012)

For a transportation agency, risk occurs at different levels: Agency (Executive or Administrative level), Program, and Project, as outlined above in Figure 5-2. In the context of transportation asset management, risk is often assessed as vulnerability to a variety of hazards, both man-made and natural. However, there is a spectrum of threats to agency objectives. The focus of risk management for the RAMP should be at the program and project level, so long as the agency level goals and objectives are incorporated into it.

An assessment of RHRS risks and the focus of risk management may include the following threats at various times during the service life of a slope (AASHTO 2011):

- **External Impacts** such as premature asset failures due to faulty construction or materials.
- **Natural Events and Failures** caused by unpredicted or abrupt events such as rockfall, landslides, earthquakes or flooding.
- **Physical Asset Failures** including gradual degradation of slope conditions caused by weather, deterioration of rockfall mitigation devices and abrupt failures such as rockfall overloading mitigation elements
- **Operational Risk** events including: a) programmatic threats such as unacceptable wear due to inadequate maintenance, decision failures resulting from inaccurate data or modeling, loss of funding, failures caused by increased demand and inadequate response; and b) policy or strategic threats, including failure to manage slopes for the long term, legislative mandates that conflict with agency objectives regarding safety and condition, reductions in funding for unstable slope management programs, and general resistance to asset management.

Agencies that recognize these and other threats incorporate risk management as a core value and take steps to mitigate slope risks in order to meet agency goals and objectives.

5.1 Risk Management

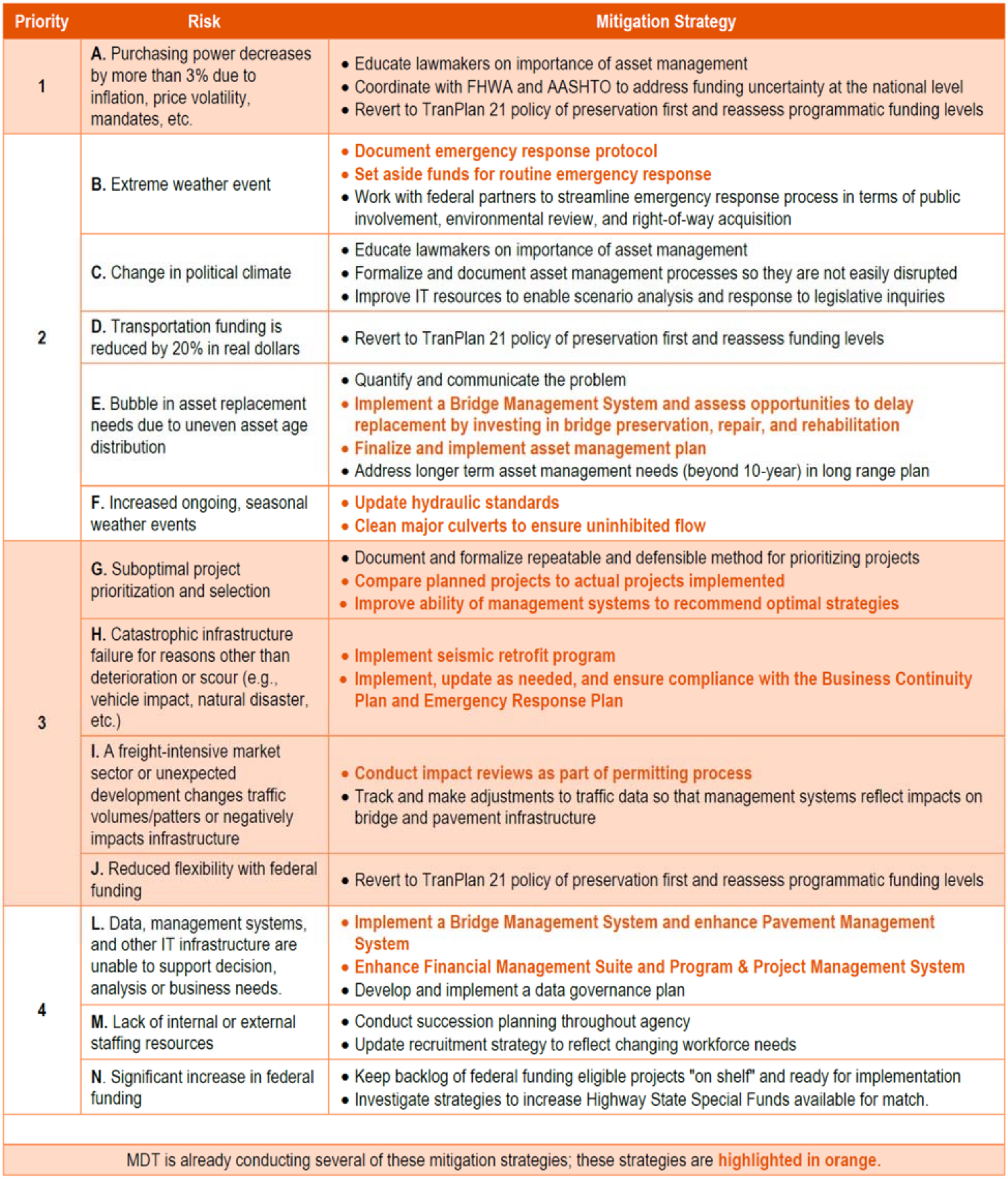
Risk influences all actions of the agency and risk management must therefore be viewed as a core business activity, not as an add-on process. Risk management is "the consistent application of techniques to manage the uncertainties in achieving…strategic objectives." It is also "a process of identifying sources of risk, evaluating them, and integrating mitigation actions" into the routine of the agency. The basic steps of risk management are:

- **Establishing the Context.** For RAMP, the context includes understanding the program's role (present and future) in MDT's asset management program and identifying the agency's existing goals, objectives and policies that apply to the RAMP, including the TranPlan21 state-wide long range transportation plan, the Performance Programming Process (P3 program) and the STIP. An important part of establishing context is creating a communication process with executive management, geotechnical staff statewide, and other stakeholders, as needed.
- **Identifying the Risks.** These should include any significant threat to the functioning and success of the RHRS: condition of slopes around the state, expected but unpredictable natural events, inadequate maintenance funding to maintain slopes, inability to collect, store and retrieve and manage critical slope data, etc. The identified risks can be portrayed in a risk register (Figure 5-3). Economic risk is also an integral part of the risk assessment. Economic risk factors addressing mobility and safety can be factored into benefit/cost calculations to help support decision-making.
- **Risk Analysis.** The risk calculation can be qualitative or quantitative. Risk analysis may consist of complex quantitative mathematical modeling but may be based upon a qualitative elicitation of expert opinion and judgment. The results may be expressed in probability terms but expressing risks in dollars is common. Recent research has resulted in methodologies to calculate risk cost and the economic effects of alternative courses of action to address risk.
- **Risk Evaluation.** This decision-support step allows comparison of the magnitude of the identified risks with the agency tolerance for risks. Use of the risk register in a spreadsheet eases the comparison of alternative courses of action that are determined in the step below.
- **Risk Treatment.** This step is known as the "Five Ts": Treat (maintain or mitigate slope problems), Tolerate (do nothing beyond routine maintenance), Terminate (rebuild the slope or construct new slope), Transfer the risk to somewhere else, or Take advantage of the (positive) risk. These are the principal alternatives available to an agency in addressing risks

5.2 Risk Management for MDT's RAMP

The Department's Performance Programming Process (P3) is a method to develop an optimal investment plan and measure progress in moving toward strategic transportation system goals (MDT 2015). It ensures that the best system-wide investment decisions are made given overall direction from customers, available resources, and system performance monitored over time. By implementing the RAMP, MDT will satisfy the immediate goals of identifying current needs, and position itself to achieve the longer-range goals of the Transportation Asset Management (TAM) Plan and the P3 process.

MDT's TAM Plan makes use of the risk register concept to summarize the Department's high level risks and mitigation strategies (Figure 5-2). MDT populates the risk register using risk likelihood and consequence scores using an overall risk level for each identified risk. MDT uses these scores to assign a priority level to each risk that is included in an overall risk register.



Priority	Risk	Mitigation Strategy
1	**A.** Purchasing power decreases by more than 3% due to inflation, price volatility, mandates, etc.	• Educate lawmakers on importance of asset management • Coordinate with FHWA and AASHTO to address funding uncertainty at the national level • Revert to TranPlan 21 policy of preservation first and reassess programmatic funding levels
2	**B.** Extreme weather event	• **Document emergency response protocol** • **Set aside funds for routine emergency response** • Work with federal partners to streamline emergency response process in terms of public involvement, environmental review, and right-of-way acquisition
	C. Change in political climate	• Educate lawmakers on importance of asset management • Formalize and document asset management processes so they are not easily disrupted • Improve IT resources to enable scenario analysis and response to legislative inquiries
	D. Transportation funding is reduced by 20% in real dollars	• Revert to TranPlan 21 policy of preservation first and reassess funding levels
	E. Bubble in asset replacement needs due to uneven asset age distribution	• Quantify and communicate the problem • **Implement a Bridge Management System and assess opportunities to delay replacement by investing in bridge preservation, repair, and rehabilitation** • **Finalize and implement asset management plan** • Address longer term asset management needs (beyond 10-year) in long range plan
	F. Increased ongoing, seasonal weather events	• **Update hydraulic standards** • **Clean major culverts to ensure uninhibited flow**
3	**G.** Suboptimal project prioritization and selection	• Document and formalize repeatable and defensible method for prioritizing projects • **Compare planned projects to actual projects implemented** • **Improve ability of management systems to recommend optimal strategies**
	H. Catastrophic infrastructure failure for reasons other than deterioration or scour (e.g., vehicle impact, natural disaster, etc.)	• **Implement seismic retrofit program** • **Implement, update as needed, and ensure compliance with the Business Continuity Plan and Emergency Response Plan**
	I. A freight-intensive market sector or unexpected development changes traffic volumes/patters or negatively impacts infrastructure	• **Conduct impact reviews as part of permitting process** • Track and make adjustments to traffic data so that management systems reflect impacts on bridge and pavement infrastructure
	J. Reduced flexibility with federal funding	• Revert to TranPlan 21 policy of preservation first and reassess programmatic funding levels
4	**L.** Data, management systems, and other IT infrastructure are unable to support decision, analysis or business needs.	• **Implement a Bridge Management System and enhance Pavement Management System** • **Enhance Financial Management Suite and Program & Project Management System** • Develop and implement a data governance plan
	M. Lack of internal or external staffing resources	• Conduct succession planning throughout agency • Update recruitment strategy to reflect changing workforce needs
	N. Significant increase in federal funding	• Keep backlog of federal funding eligible projects "on shelf" and ready for implementation • Investigate strategies to increase Highway State Special Funds available for match.

MDT is already conducting several of these mitigation strategies; these strategies are **highlighted in orange.**

Figure 5-3: MDT's Departmental Risk Management Register, MDT Transportation Asset Management Plan, 2016.

The product of the risk likelihood score and risk consequence score is plotted on a likelihood and consequence plot (Figure 5-4). For RAMP, each rock slope can be plotted on a similar graph, with likelihood correlated to Condition Index and likelihood times consequence to the 30-year economic impact. Tentatively, the consequence levels could follow a five step logarithmic scale starting at <$1,000, increasing to >1,000,000, using techniques described in the following sections.

Consequence Level Likelihood Level	1 Negligible	2 Minor	3 Major	4 Critical	5 Catastrophic
1 Low	1	2	3	4	5
2 Medium Low	2	4	6	8	10
3 Medium	3	6	9	12	15
4 Medium High	4	8	12	16	20
5 High	5	10	15	20	25

Figure 5-4: Likelihood and consequence plot and heat map. MDT Transportation Asset Management Plan, 2016

5.3 Strategic goals

The MDT Strategic Business Plan (MDT 2004) summarizes the Department's major goals, which are resolved into policies and actions in Tranplan21, the Department's Long-Range Transportation Plan (Cambridge 2008). Among the major goals in the Strategic Business Plan are:

> *Ensure investment decisions consider policy directions, customer input, available resources, system performance, and funding levels.*
>
> *Enhance traveler mobility by providing a safe and efficient multimodal transportation system that supports Montana's economy and is sensitive to the environment.*
>
> *Reduce fatal and injury crash rates.*
>
> *Continuously strive to improve the effectiveness and efficiency of operations and processes.*
>
> *Consistently communicate standards, guidelines, policies, and expectations throughout MDT.*

At the federal level, the same goals are expressed in the Moving Ahead for Progress in the 21st Century (MAP-21) act in 23 USC 150(b) as amended. State Departments of Transportation are required to describe and quantify their strategies, targets, and progress in pursuing these goals by means of performance measures and the Risk-Based Transportation Asset Management Plan (TAM Plan). Although only National Highway System (NHS) pavements and bridges are required to be covered by the TAM Plan, 23 USC 119(e)(3) encourages States to include all infrastructure assets within the right-of-way corridor. Coverage of non-NHS roads is also encouraged.

In response to MAP-21, the Federal Highway Administration has drafted a set of rules for Risk-Based Transportation Asset Management Plans (FHWA 2015). This proposed rule clarifies that the life cycle cost analysis and investment analysis mandated within the TAM Plan should be risk-based, meaning that it accounts for the strategies and costs of managing risks to the performance of the transportation system, including any aspects of performance listed in 23 USC 150(b).

Rock slopes are a class of assets that affect the safety, mobility, and efficiency of Department operations and processes by means of the risk of rockfall. DOTs routinely expend scarce resources to clear fallen rocks from roads; recover from rock-vehicle collisions; scale loose rock before it falls; and install and maintain mitigation measures such as catchment ditches, barriers, and fences. The ultimate purpose of these activities is to satisfy Department goals for safety, mobility, and efficiency.

With the aid of a comprehensive inventory and condition assessment of rock slopes, MDT will be able to perform the same types of analysis for these assets as it already does for pavements and bridges, and as required for assets included within the TAM Plan:

- It will be able to use its condition and work history data to develop forecasting models for deterioration and costs, using methods such as those documented in NCHRP Report 713 (Thompson et al 2012);
- It will be able to compute reasonable estimates of life cycle cost taking into account near-term and long-term forecasts of maintenance and capital costs, to promote efficiency by minimizing these costs, using methods such as those documented in NCHRP Report 483 (Hawk 2003).
- It will be able to quantify safety and mobility impacts of rockfall in economic terms using research-based methods, based on the standard AASHTO Red Book (AASHTO 2010).
- It will be able to compute the return on investment of preservation work. In asset management for pavements and bridges it is not uncommon for preservation work to have a return on investment of 50% or more, which would mean that each investment of $1 will save $1.50 in life cycle costs, limited by the availability of feasible preservation projects. This return is increased to 100% or more when safety and mobility benefits are also included.
- It will be able to perform a fiscally-constrained investment analysis for the TAM Plan, satisfying all the federal requirements by incorporating funding uncertainty, and enabling the development of reasonable performance targets and expectations to fit any given funding level.

All of these are mandatory for inclusion of rock slopes in the TAM Plan, according to the proposed federal rule. They all are also needed for inclusion in MDT's P3 Process. These capabilities are dependent on a consistent, objective assessment of rock slope condition as described in this report.

5.4 Resilience and risk

In its efforts to manage risk and achieve Department performance goals, while minimizing long-term costs, MDT manages the characteristics of its rock slopes. The risk of service disruption caused by rock slope activity has two dimensions:

- Likelihood of service disruption, influenced by slope height, ditch effectiveness, precipitation, block size/event volume, erosion rate, and rockfall history.
- Consequence of service disruption, influenced by affected road length, speed, traffic volume, decision site distance, roadway width, detour length, and the duration of event repairs.

The likelihood factors are primarily attributes of the slope, while the consequence factors are primarily attributes of the road network. Since the Department's geotechnical activities primarily affect the likelihood factors, these factors may be grouped together for convenience and summarized in a concept known as resilience. Resilience is defined as:

> *… the capability of a system to maintain its functions and structure in the face of internal and external change and to degrade gracefully when it must* (Allenby and Fink 2005).

> *'Vulnerability' seems largely to imply an inability to cope while 'resilience' seems to broadly imply an ability to cope. They may be viewed as two ends of a spectrum (Levina and Tirpak 2006).*

In the context of geotechnical assets, "internal and external change" can be interpreted as changes caused within the asset itself (i.e. normal deterioration) and change caused by external forces (natural extreme events, such as floods and earthquakes). "Maintain its functions and structure" can be interpreted as the avoidance of transportation service disruptions. "Service disruptions," in turn, can be interpreted as unintended changes in the safety, mobility, or economic performance of the roadway. Based on this reasoning, a geotechnical asset may be considered to have high resilience to the extent that it is sufficiently able to refrain from service disruptions caused by normal deterioration or by adverse events.

5.5 Likelihood Analysis of MDT's Significant Rockfall Events

In early 2016, MDT submitted an Excel spreadsheet-based questionnaire to district geotechs, requesting information on adverse rockfall events that had affected the transportation system. These impacts included road closures, traffic slowdowns, property damage, and injury. The final summary table of adverse events included the highway and milepost where the event occurred, the RHRS section number (where available), the event data, and a breakdown of event impacts. Respondents also provided specific event dates and information where available. For those sections of the highway where events occur on a near-annual basis, the range of RHRS sections and average impacts were provided instead. Event dates ranged from 1995 to 2015. Districts 1 and 2 completed the survey, with most data provided by District 1.

The 2005 rating information for RHRS sections was pulled from the RHRS database and appended to the data provided by MDT. The same TAM-compatible equations used in AKDOT's GAM Program were used to calculate RHRS section Condition State. These Condition State equations and definitions have already been discussed in detail in the Task 2 Report, and briefly summarized in Section 4 of this report.

For use in risk probability analyses, several edits were made to the final data set. Events that took place at rock slopes not in the RHRS were eliminated. This affected two sites in District 1: the Bearmouth Frontage Road, which is the site of regular failures but is not part of the highway system, and the 1995 failure on US 93, which was resloped prior to RHRS survey work. The final dataset contained events occurring between 2001 and 2015, and is included in Appendix B.

Events with a specific date and RHRS section were left unchanged. However, other survey entries identified corridors that experience regular failures, providing a range of RHRS sections and the general adverse event type. For example, one to two failures occur annually between Milepost 5 and 10 on MT 83, resulting in road closures and property damages. To capture risk in these sections, LT split out the individual RHRS sections, estimated the total number of events between 2001 and 2015, and divided those events evenly between the RHRS sections along the roadway segment.

Several assumptions were necessary to capture the likelihood of adverse events. Respondents were asked to provide information on the following adverse event types: road closure, work zone slowdown, vehicle/property damage, and injury accident. For road closures, respondents also provided an estimated duration of any closures or work slowdowns. Unfortunately, the sample size was too small to integrate disruption length as part of the rock slope Condition State. Instead, the category was replaced with a yes/no input. If the respondent entered "???" then a closure or slowdown was assumed to follow 50% of adverse events at that site. The Vehicle/Property damage was answered on a yes/no basis. For those sites where respondents wrote "possibly" or "???" it was assumed that some vehicle or property damage occurred following 50% of slope failures. Only one injury accident, a fatality, was reported in the event survey. For those sites where respondents answered "???" to the injury accident question, an injury was assumed to occur following only 10% of slope failures. The lower 10% value was selected because injury accidents are generally better remembered than accidents that damage a bumper or transmission and would tend to be reported. The edited event summary is available as Appendix B.

Incorporating the 2001-2015 date range, the recorded individual events, and the estimated events and event consequences, an annualized rate for the different adverse events was calculated for each RHRS section in the survey. Significant adverse events have not occurred at many of the sites in MDT's RHRS database over the surveyed time period. To more accurately estimate adverse event likelihoods, all of the 869 sites in the RHRS were also incorporated into the final Statewide Likelihoods table. For those sites where no adverse events were reported, the annualized rate of adverse events was zero.

Within this final dataset, Condition States for each RHRS section were calculated with the equations used in AKDOT's GAM Program. For each Condition State group – 1, 2, 3, 4, and 5 – the average annual likelihood of an event somewhere in the state was calculated by summing all the annual event likelihoods for individual sites. This statewide likelihood was then divided by the estimated total square footage in that Condition State to develop an annual likelihood/square foot of rock slope face. Plots of average Condition State and average annual likelihood of an adverse event were developed for each adverse event type. Trendlines were added to each scatter plot using Excel's linear best-fit equations.

5.6 Likelihood of service disruption

To increase the sample size and improve correlation, the annual closure rates and average slowdown rates obtained from the survey were combined into a generalized "service disruption rate," this service disruption consisted of a road closure of approximately 6 hours (the average closure length in the survey data) and a slowdown to approximately one week. As expected, slopes in worse condition generally had a higher likelihood of generating a rockfall event that disrupted service, as shown in Figure 5-5 below. The notable exception was the Condition State 5 sites, which had a significantly lower annual event likelihood than Condition State 4 sites. There are a couple reasons this might be the case. First, the total square footage in Condition State 5 is much lower than that in any other Condition State, so any unreported events would have a larger impact on this data point. Second, many of the survey responses provided event likelihood within a corridor segment, and these segments had rock slopes in multiple condition states. Rockfall events probably occur at some slopes in a given section more frequently than at others. With better data over time, it will be possible to refine annual likelihoods for individual slopes, and Condition State 4 sites in these corridors may prove to be slightly less active than the neighboring Condition State 5 sites.

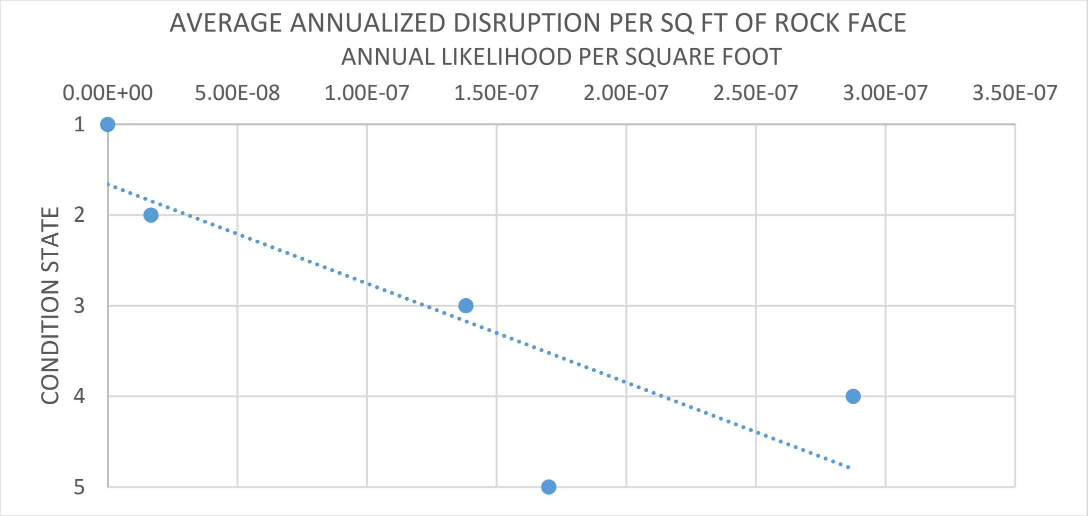


Figure 5-5: Average annual likelihood of service disruption per square foot of rock slope face, based on 2016 MDT survey responses.

The sample size for injury accidents was very small with only one fatality recorded in the survey. Since this fatality occurred at a Fair Condition site, it skewed the correlation between Condition State and injury accidents. The risk of an injury accident appeared to decease as rock slope condition worsened. This is not realistic but is rather the result of small sample size and the unpredictable nature of individual rockfalls. In discussions of the survey data, MDT personnel estimated that an injury accident occurred in about one in ten service disrupting rockfall events. Based on this information, the injury accident rate calculated from the survey responses was discarded, and the annual risk of an injury accident was instead linked to the annual risk of traffic disruption. The annualized risk of an injury accident was estimated to be 10% of the annualized risk of a traffic disruption.

There were no recorded events from Condition State 1 (Good) sites, but it is unlikely that nothing has ever or will ever happen at these rock slopes. To capture risk at these sites, LT assumed a 5% annual chance (or once every 20 years) of an adverse event occurring somewhere in Montana from a Good site. All other event likelihoods were calculated from the line of best fit drawn using the survey data.

Final annualized risks for traffic disruption and injury accidents are presented in Table 5-1 below, and have been incorporated into the risk calculations. The dataset used in these likelihood analyses was relatively small, and multiple assumptions were applied to determine event types and to allocate events to various sites with a transportation corridor for those situations where no specific event location was provided. The likelihoods presented in this section can be improved with additional data collection and follow-up statistical research in coming years.

Table 5-1: Condition States and Rates of Adverse Events for MDT rock slopes, derived from 2004 rating data and adverse event data provided by MDT.

Condition State (CS)	**Annualized Risk of Service Disruption per sq ft of rock face (AR_{mob})**	**Annualized Risk of Injury Accident per sq ft of rock face (AR_{inj})**
1	9.51E-09	9.51E-10
2	6.45E-08	6.45E-09
3	1.34E-07	1.34E-08
4	2.04E-07	2.04E-08
5	2.73E-07	2.73E-08

The annualized risks in Table 5-1 replaced the initial Resilience Index used in Task 2. In future site ratings, probability of service disruption is estimated using the following general equation:

$$LD = AR\ (Estimated\ Square\ Footage\ of\ Rock\ Slope\ Face)$$

Where

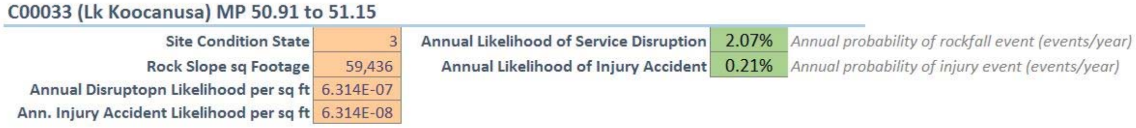
LD = Annual likelihood of disruption caused by slope, a probability (events/year). Subscript ‘mob’ for mobility likelihood and ‘inj’ for injury accident likelihood.

AR = Annualized likelihood of adverse event per square foot of rock face, based on rock slope Condition State. Subscript ‘mob’ for mobility likelihood and ‘inj’ for injury accident likelihood.

All possible values of AR_{cs} are shown in Table 5-1. The same basic equation is also used to estimate annual probabilities of injury accidents, applying the AR_{cs} values for injury accidents.

Figure 5-6 shows an example of these calculations for a site on Highway 37 in the Missoula district. This example uses the calculated Condition State of the slope (3) to pull the correlated likelihood values from Table 5-1, above (6.31E-07 and 6.31E-08). The likelihood is multiplied by the approximate square foot surface area of the slope (59,436 sf) to calculate the annual likelihood of a service disruption of 2.07% per year for a service disruption and 0.21% likelihood of an injury accident.

Figure 5-6: Example calculation of likelihood of service disruption



C00033 (Lk Koocanusa) MP 50.91 to 51.15

Site Condition State	3	**Annual Likelihood of Service Disruption**	2.07%	*Annual probability of rockfall event (events/year)*
Rock Slope sq Footage	59,436	**Annual Likelihood of Injury Accident**	0.21%	*Annual probability of injury event (events/year)*
Annual Disruptopn Likelihood per sq ft	6.314E-07			
Ann. Injury Accident Likelihood per sq ft	6.314E-08			

5.7 Consequences of adverse events

The GAM priority-setting process is intended to minimize life cycle agency cost at the same time that it maximizes safety and mobility. However, these are competing objectives: when the funding level is fixed because adding money to safety-related improvements means taking money away from preservation, and vice versa. The framework requires a fair way to balance these important objectives through a consistent summarization of project benefits that consider performance changes resulting from a project. One common way to do this is to monetize safety and mobility in the form of social cost. The likelihood and consequence analysis we are describing here gives us a means of computing a consistent measure of project benefits across all performance concerns, that can then be used in benefit/cost priority-setting. The models for this kind of analysis are well established (AASHTO 2010). Bridge and pavement management systems use these models for the same purpose. A good description with example application to risk analysis is found in a recent Florida DOT research report (Sobanjo and Thompson 2013).

Social cost models can convert estimates of accident count and road closure duration in hours per year into consistent estimates of social cost as long as traffic volume and detour route or alternative mode information is available. For the present application, AASHTO's Red Book (AASHTO 2011) has a very detailed presentation of alternative methods, including quantitative parameters derived from dozens of studies. Given the relative scarcity of data available for this analysis, a reasonably simple adaptation of the Red Book Models provides the computations. Since social costs are additive, the total consequence of service disruption is the sum of safety, mobility, and recovery costs.

5.7.1 Safety consequences

Estimated annual monetary safety consequences are calculated from site Condition State and the annual likelihoods derived in Section 5.6. For this analysis, all safety incidents are single-vehicle crashes. The average cost per crash is from the AASHTO Red Book, page 5-24. This figure is an average over all vehicle classes and accident types, and takes into account that a small fraction of crashes involve injuries or fatalities. It excludes insurance reimbursement to avoid double counting of costs. It is updated to 2015 dollars using the Consumer Price Index.

The current monetary safety consequences are a yearly cost based on the likelihood of an adverse event at a given site. The present analyses assume a linear relationship, computed as follows:

$$AS\$_s = LD_{inj} \times ACC\$$$

Where

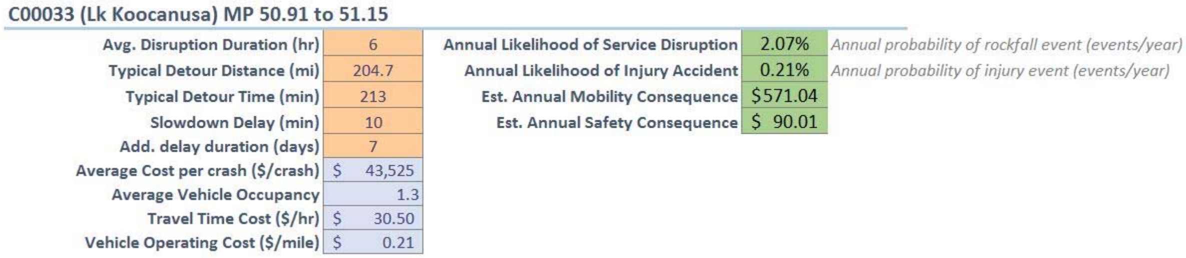
$AS\$_s$ = Safety cost of an individual disruption caused by slope s, (\$/year)

LD_{inj} = Annual likelihood of injury accident caused by slope s, a probability (events/year) at the slope

as computed in Section 5.6
$ACC\$$ = Average cost per crash ($43,525 in 2015$; AASHTO Red Book)

Figure 5-7 shows an example of these calculations for a site on Highway 37 in the Missoula district using the same likelihood examples from Figure 5-6 above with the addition of variables for safety in order to calculate annual safety consequence costs. In this case, the AADT is quite low, resulting in a safety consequence of $90 per year

Figure 5-7: Example calculation of annual monetary safety consequence



C00033 (Lk Koocanusa) MP 50.91 to 51.15

Avg. Disruption Duration (hr)	6	**Annual Likelihood of Service Disruption**	2.07%	*Annual probability of rockfall event (events/year)*
Typical Detour Distance (mi)	204.7	**Annual Likelihood of Injury Accident**	0.21%	*Annual probability of injury event (events/year)*
Typical Detour Time (min)	213	**Est. Annual Mobility Consequence**	$571.04	
Slowdown Delay (min)	10	**Est. Annual Safety Consequence**	$ 90.01	
Add. delay duration (days)	7			
Average Cost per crash ($/crash)	$ 43,525			
Average Vehicle Occupancy	1.3			
Travel Time Cost ($/hr)	$ 30.50			
Vehicle Operating Cost ($/mile)	$ 0.21			

Unless the probability of an adverse event is greater than one, the annual safety cost is a fraction of the hypothetical accident cost. Thus, it is unlikely that the safety consequence computed for a given site for a single year will accurately describe the safety costs incurred by the department for that slope. Instead, the costs should be evaluated over a multi-year period closely tied to the benefit period of the actions under consideration.

Currently, the assumed likelihood of an injury or property damage only accident is 10% of the likelihood of a service disruption. An additional period of data collection and follow-up statistical analysis will improve the relationship between the site condition and the actual number of accidents.

5.7.2 Mobility consequences

If a rockfall event occurs, traffic is often forced to wait while the debris is cleared; experiences congestion if the road is partially blocked; or is forced to detour around the closure. Road users may experience economic losses related to the travel delay time and may experience additional vehicle operating costs related to detour distance.

To enable the computation of mobility consequences, revision and refinement of the RAMP system can include an estimate of the duration of the disruption, should a disruption take place. Disruption duration is typically expressed in ranges, such as:

- Negligible: No closure or interference with traffic (0 hours);
- Minor: Less than one hour of closure (0.5 hours);
- Major: 1-24 hours of closure (12 hours);
- Critical: One to four days of closure (60 hours);
- Catastrophic: More than four days of closure (120 hours).

For the Task 4 field work and based on the average closure times reported by MDT, six hours of closure time is used to uniformly assign closure times for each slope.

The numbers in parentheses are representative values for each range, for use in calculations. If the duration is less than one hour, it can be assumed that travellers will wait for the road to be cleared, unless the detour route is shorter. In this case, the impact of a service disruption will be a closure of up to an hour, for which the mean closure would be 30 minutes. The mobility disruption cost is:

$$M\$_s = \frac{ADT_s \times DD_s}{24} \times \frac{DD_s}{2} \times TT\$ \times VO$$

Where
$M\$_s$ = Mobility cost of an individual disruption caused by slope s, (\$/event)
ADT_s = Average daily traffic on the road at slope s
DD_s = Duration of the delay in hours, if an event occurs on slope s
$(ADT_s \times DD_s)/24$ is the number of vehicles delayed
$DD_s/2$ is the average delay per vehicle
$TT\$$ = Travel time cost, the value per hour of a vehicle occupant's time ($30.50 in 2015$)
VO = Average vehicle occupancy rate (1.3)

The travel time cost is obtained from the AASHTO Red Book, page 5-4. This figure uses the average value per hour over all occupations, computed as an opportunity cost. It is updated to 2015 dollars using the Consumer Price Index. The average vehicle occupancy rate was also suggested in the Red Book, but the Department Planning Office might have a different estimate specific to Montana.

If the duration is greater than one hour, the traveller will likely use an alternate route if one is available. In this case the mobility disruption cost is:

$$M\$_s = \frac{ADT_s \times DD_s}{24} \times (DL_s \times VOC\$ + DL_s/DS_s \times TT\$ \times VO)$$

Where
$M\$_s$ = Mobility cost of an individual disruption caused by slope s, (\$/event)
ADT_s = Average daily traffic on the road at slope s
DD_s = Duration of the delay in hours, if an event occurs on slope s
DL_s = Detour length in miles if the road is blocked at slope s
DS_s = Detour speed in miles per hour if the road is blocked at slope s
$VOC\$$ = Average vehicle operating cost per mile ($0.207 in 2015$)
$TT\$$ = Travel time cost, the value per hour of a vehicle occupant's time ($30.50 in 2015$)
VO = Average vehicle occupancy rate (1.3)

The vehicle operating cost is obtained from the AASHTO Red Book, page 5-10. This is based on the "large car" column and includes fuel, oil, maintenance, and tires. It is updated to 2015 dollars using the Consumer Price Index. If the speed on the detour route is not available, the speed at the slope may be used instead as an estimate. During 2016 fieldwork, detour length and time is calculated using online mapping applications. A typical route was selected based on the estimated trip start and end points for the majority of travellers in that particular corridor section.

In cases where the duration is greater than one hour and no detour route is available, the computation can assume a shift to a different mode, if one is available. In this case mobility disruption cost is:

$$M\$_s = ADT_s \times DD_s \times AM\$ \times VO$$

Where
$M\$_s$ = Mobility cost of an individual disruption caused by slope s, (\$/event)
ADT_s = Average daily traffic on the road at slope s
DD_s = Duration of the delay in hours, if an event occurs on slope s
$AM\$$ = Alternate mode cost per one-way trip
VO = Average vehicle occupancy rate (1.3)

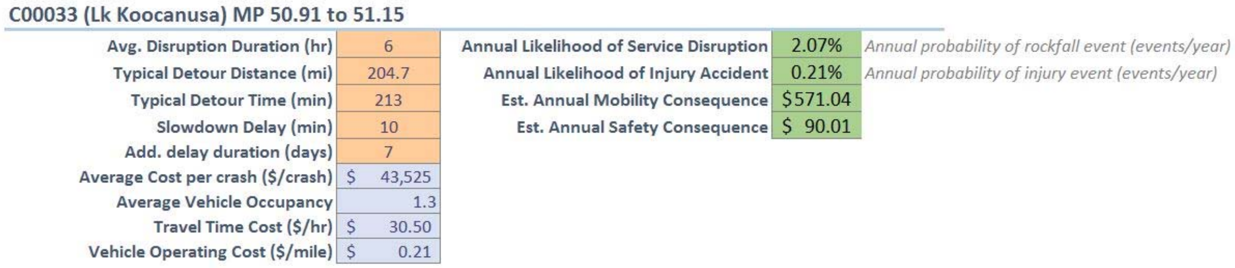
The alternate mode cost can be assessed in the office using published air fares, and is only needed for sites that lack a detour route. It is likely that many of the trips that would otherwise use the obstructed route may end up being cancelled, or completed at a later date, rather than using an alternate mode. This possibility should be taken into account when deciding whether to use the alternate mode cost, and may result in an adjustment to this cost. This alternate mode cost was not applied to any sites visited during 2016 fieldwork.

Once the mobility consequence for an event at a given site is obtained, the projected annual mobility consequence for a given site based on Condition State can be calculated from the following equation:

$$AM\$_s = AR_{mob} \times M\$_s$$

Where
$AM\$_s$ = Projected annual mobility consequence of slope s
AR_{mob} = Annual likelihood of a service disruption at slope s as computed in Section 5.6
$M\$_s$ = Mobility cost of an individual disruption caused by slope s, (\$/event)

Figure 5-8 shows an example of this calculation. As the figure suggests, it is possible for a disruption event to incur multiple types of mobility costs. An initial road closure may be followed by a traffic slowdown as additional clean-up work is completed. In this case, the mobility cost is the sum of the detour cost and any additional delay cost from the traffic slowdown.



C00033 (Lk Koocanusa) MP 50.91 to 51.15

Avg. Disruption Duration (hr)	6	**Annual Likelihood of Service Disruption**	2.07%	*Annual probability of rockfall event (events/year)*
Typical Detour Distance (mi)	204.7	**Annual Likelihood of Injury Accident**	0.21%	*Annual probability of injury event (events/year)*
Typical Detour Time (min)	213	**Est. Annual Mobility Consequence**	$571.04	
Slowdown Delay (min)	10	**Est. Annual Safety Consequence**	$ 90.01	
Add. delay duration (days)	7			
Average Cost per crash ($/crash)	$ 43,525			
Average Vehicle Occupancy	1.3			
Travel Time Cost ($/hr)	$ 30.50			
Vehicle Operating Cost ($/mile)	$ 0.21			

Figure 5-8: Example calculation of annual mobility consequences

As for safety consequences, unless the probability of an adverse event is greater than one, the annual cost is a fraction of the cost of a hypothetical service disruption. Thus, evaluating the mobility consequence at a site over a multi-year period provides a more accurate cost estimate to the Department of events at that rock slope.

Currently the data set correlating rock slope Condition State with likelihood of service disruption is small. An additional period of data collection and some follow-up statistical analysis will improve the relationship between the site condition and the actual number of disruptive events. Likewise, the detours, vehicle occupancies, and other costs are Red Book estimates, which may be replaced by Montana-specific values in MDT's final TAM plan.

5.7.3 Recovery costs

If a rockfall event occurs, the Department will incur costs for its own forces or for a contractor to clear the road, repair damage, and restore service. This potential cost may be assessed in ranges such as:

- Acceptable: Less than $10,000 per event ($5,000);
- Low: $10,000-$50,000 ($30,000);
- Minimal: $50,000-$100,000 ($75,000);
- Major: $100,000-$250,000 ($175,000);
- Catastrophic: More than $250,000 ($350,000).

The numbers in parentheses are representative values for each range, used in the calculations.

$$AR\$_s = AR_{mob} \times midpoint\ of\ applicable\ cost\ range$$

Where
$AR\$_s$ = Recovery cost of an individual disruption caused by slope s, ($/event)

These costs are not currently tracked by MDT. An upcoming overhaul of their Maintenance Management System may incorporate tracking rock fall events and recovery costs. An online GIS tool for the adding rockfall event and maintenance actions and costs will also facilitate tracking of critical cost and risk data.

In the current absence of this actual event data, the correlation of Condition- and size-based likelihoods multiplied by the categorical midrange costs assigned to each Condition State is used, such that Condition State 1 is assigned the ‘Acceptable’ costs of $5,000, Condition State 2 is assigned the ‘Low’ cost of $30,000, and so on.

5.8 Total risk cost

The total economic value of the geotechnical risk of a slope is the product of likelihood and consequence of service disruption:

$$RC_s = AS\$_s + AM\$_s + AR\$_s$$

This result is an annual cost. If the slope is improved so that resilience is increased and the likelihood of service disruption is reduced, then this annual cost applies only up to the year in which the improvement is implemented. After that, a lower annual risk cost would apply. The difference in annual risk costs between the improved and unimproved cases may be termed the benefit of the improvement. In any given year, if there is a funding constraint, candidate improvements may be prioritized by the ratio of benefit divided by improvement cost. This will have the effect of maximizing the possible network-wide total benefit for any given input of improvement funding.

In some decision contexts, it may be desirable to compare two or more strategies at a given time, for example, to decide whether a specific mitigation treatment is justifiable at a given site regardless of funding constraints, or to compare the cost-effectiveness of two alternative approaches. In this case, the annual risk cost can be converted to a life cycle cost, using an annuity formula:

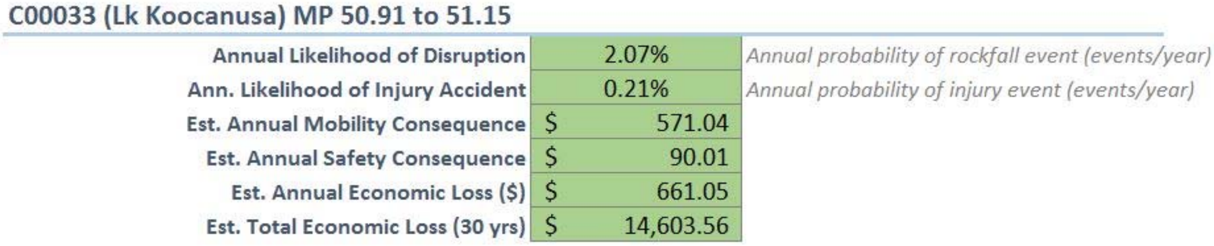
$$LRC_s = RC_s \times \frac{1-(1+r)^{-T}}{r}$$

Where
LRC_s = Lifetime risk cost of slope s ($)
RC_s = Annual risk cost of slope s ($/year)
r = Discount rate (percent per year)
T = Amortization period or estimated lifespan of improvement (years)

For significant transportation capital improvements, 30 years is a common amortization period. The discount rate is determined by agency policy, which should be consistent across all types of assets and all investments of similar lifespan. A common source of guidance is The White House Office of Management and Budget (OMB) Circular A-94 (OMB 2016). Typically, life cycle cost analyses omit inflation because this practice simplifies the computations. A riskless and inflationless cost of capital for long-lived investments may use 30-year US Treasury bonds for guidance, with a 2015 real interest rate of 1.5%. Transportation agencies usually specify higher discount rates than this, because of uncertainties in long-term future travel demand and infrastructure requirements. In recent (as of March 2016) Transportation Asset Management Plans, the authors have observed discount rates most commonly in the

1.9% to 2.4% range. The discount rate used in the following example is 2.1%. If MDT has selected a discount rate for its TAM Plan, it should use the same rate in its geotechnical economic analyses.

Table 5. Example annual and lifetime risk cost calculation, excluding restoration costs



C00033 (Lk Koocanusa) MP 50.91 to 51.15

Annual Likelihood of Disruption	2.07%	*Annual probability of rockfall event (events/year)*
Ann. Likelihood of Injury Accident	0.21%	*Annual probability of injury event (events/year)*
Est. Annual Mobility Consequence	$ 571.04	
Est. Annual Safety Consequence	$ 90.01	
Est. Annual Economic Loss ($)	$ 661.05	
Est. Total Economic Loss (30 yrs)	$ 14,603.56	

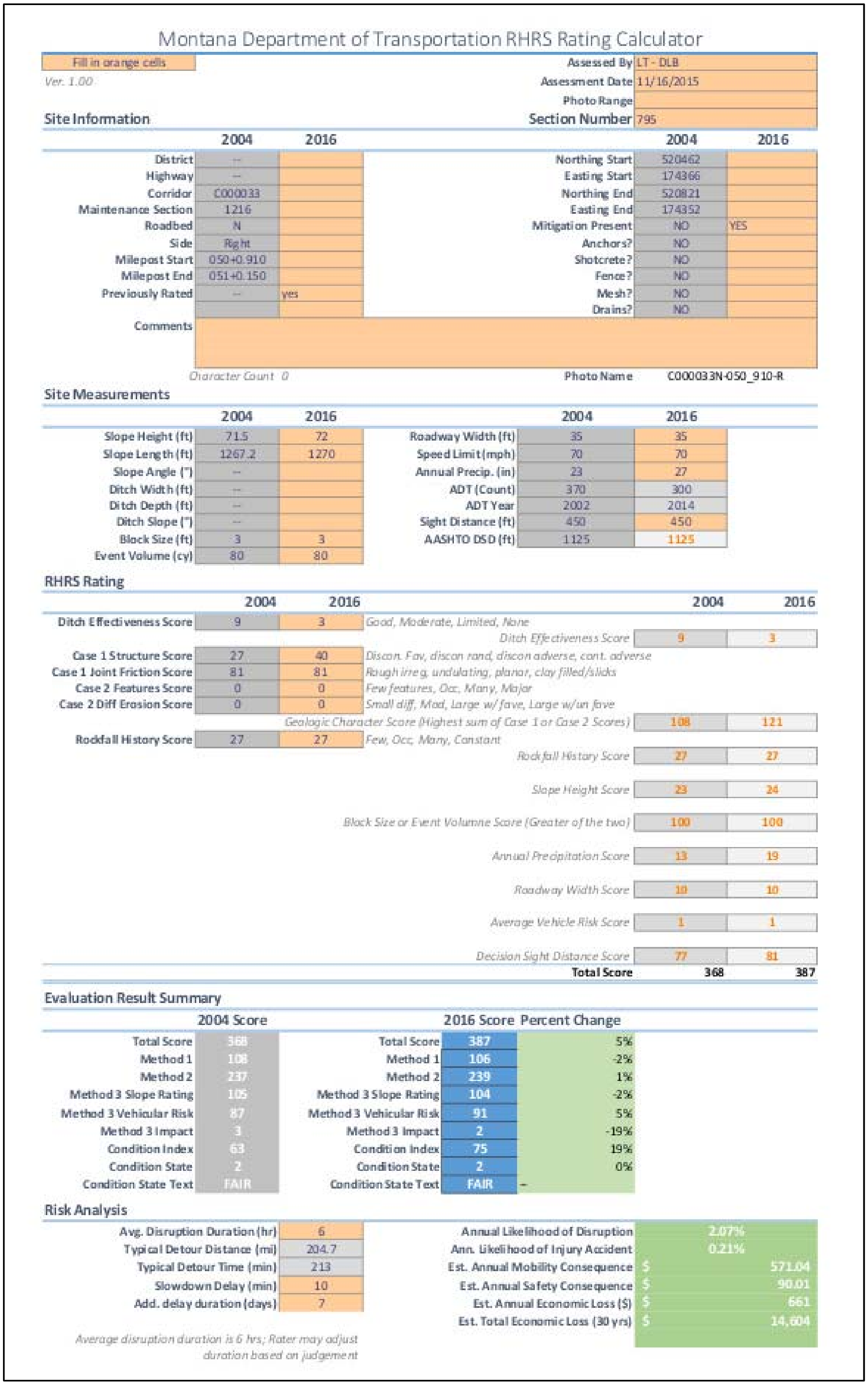
6 Steps 4 and 5: Database and Conducting Assessments

6.1 Excel-based Field Rating Form

An Excel-based data collection workbook was developed for the 2016 RAMP fieldwork (Task 4 of this project). The workbook consists of multiple sheets. The first sheet, the “Site Rating Calculator” was the main user interface, designed to work on a handheld tablet. It is shown in Figure 6-1. Raters filled in only the orange cells. Grey, green, and blue cells were either filled in from the linked reference tables or calculated from measurements or rating values entered into the orange cells. All links were based on RHRS section number. Once the site rating was completed, a data summary was copied into the “2016 RHRS Data” sheet. No calculations were performed in this sheet, which was a data depository designed for eventual import into the RAMP GIS and Excel Database.

The various reference sheets supported the Site Rating Calculator, and were locked so that data could not be accidentally deleted. Because the new ratings incorporate potential event costs, projected average detour lengths and travel times were obtained for the 376 sections selected for re-rating. This data was compiled in the “Detour Lengths” sheet. Various average costs and the condition state-based event likelihoods discussed in Section 5 were compiled in the “Reference Tables” sheet for use in calculations. “2004 RHRS Data” contained all rating data for RHRS sections in the 2004 study, for both A and B sites. It was exported from a GIS geodatabase. Prior to this export, the section locations were spatially joined to 2014 ADT data obtained through MDT’s AGOL platform. This join allowed easy referencing of updated ADT during the ratings. The sheet “2004 Maintenance Survey” contained survey responses collected in 2004 from maintenance station supervisors. Prior to the start of 2004 fieldwork, LT reviewed this data and determined which milepost ranges corresponded to which section(s). By referencing the section number, this 2004 data could automatically be pulled into a table in the “Site Rating Calculator” where field personnel could quickly view it during ratings. It also simplified conversations with maintenance personnel in 2016, since the rater could reference the 2004 data and ask if those survey responses still rang true, or if conditions had changed in the intervening decade.

At this time, the programmatic costs and likelihood estimates applied in the rating worksheet are identical to those discussed in previous sections of this report. As new information is incorporated and edits are made, the references in this sheet should also be updated.



Montana Department of Transportation RHRS Rating Calculator

Fill in orange cells

Ver. 1.00

Assessed By	LT - DLB
Assessment Date	11/16/2015
Photo Range	
Section Number	795

Site Information

	2004	2016
District	--	
Highway	--	
Corridor	C000033	
Maintenance Section	1216	
Roadbed	N	
Side	Right	
Milepost Start	050+0.910	
Milepost End	051+0.150	
Previously Rated	--	yes

	2004	2016
Northing Start	520462	
Easting Start	174366	
Northing End	520821	
Easting End	174352	
Mitigation Present	NO	YES
Anchors?	NO	
Shotcrete?	NO	
Fence?	NO	
Mesh?	NO	
Drains?	NO	

Comments

Character Count 0

Photo Name C000033N-050_910-R

Site Measurements

	2004	2016
Slope Height (ft)	71.5	72
Slope Length (ft)	1267.2	1270
Slope Angle (°)	--	
Ditch Width (ft)	--	
Ditch Depth (ft)	--	
Ditch Slope (°)	--	
Block Size (ft)	3	3
Event Volume (cy)	80	80

	2004	2016
Roadway Width (ft)	35	35
Speed Limit (mph)	70	70
Annual Precip. (in)	23	27
ADT (Count)	370	300
ADT Year	2002	2014
Sight Distance (ft)	450	450
AASHTO DSD (ft)	1125	1125

RHRS Rating

	2004	2016	
Ditch Effectiveness Score	9	3	*Good, Moderate, Limited, None*
Case 1 Structure Score	27	40	*Discon. Fav, discon rand, discon adverse, cont. adverse*
Case 1 Joint Friction Score	81	81	*Rough irreg, undulating, planar, clay filled/slicks*
Case 2 Features Score	0	0	*Few features, Occ, Many, Major*
Case 2 Diff Erosion Score	0	0	*Small diff, Mod, Large w/ fave, Large w/un fave*
Rockfall History Score	27	27	*Few, Occ, Many, Constant*

	2004	2016
Ditch Effectiveness Score	9	3
Geologic Character Score (Highest sum of Case 1 or Case 2 Scores)	108	121
Rockfall History Score	27	27
Slope Height Score	23	24
Block Size or Event Volumne Score (Greater of the two)	100	100
Annual Precipitation Score	13	19
Roadway Width Score	10	10
Average Vehicle Risk Score	1	1
Decision Sight Distance Score	77	81
Total Score	368	387

Evaluation Result Summary

	2004 Score		2016 Score	Percent Change
Total Score	368	Total Score	387	5%
Method 1	108	Method 1	106	-2%
Method 2	237	Method 2	239	1%
Method 3 Slope Rating	105	Method 3 Slope Rating	104	-2%
Method 3 Vehicular Risk	87	Method 3 Vehicular Risk	91	5%
Method 3 Impact	3	Method 3 Impact	2	-19%
Condition Index	63	Condition Index	75	19%
Condition State	2	Condition State	2	0%
Condition State Text	FAIR	Condition State Text	FAIR	-

Risk Analysis

Avg. Disruption Duration (hr)	6
Typical Detour Distance (mi)	204.7
Typical Detour Time (min)	213
Slowdown Delay (min)	10
Add. delay duration (days)	7

Average disruption duration is 6 hrs; Rater may adjust duration based on judgement

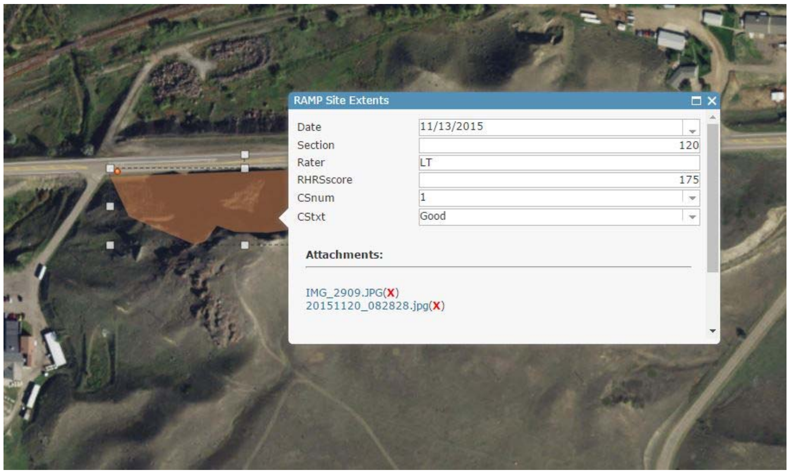
Annual Likelihood of Disruption	2.07%
Ann. Likelihood of Injury Accident	0.21%
Est. Annual Mobility Consequence	$ 571.04
Est. Annual Safety Consequence	$ 90.01
Est. Annual Economic Loss ($)	$ 661
Est. Total Economic Loss (30 yrs)	$ 14,604

Figure 6-1: Excel worksheet for RHRS section rating, calculations, risk estimate, and change over time, with values for a section on MT 35 in the Missoula District entered as an example.

6.2 Use of Online Mapping Software in Field Assessments

Online GIS mapping programs, such as the ArcGIS Online (AGOL) platform hosted by ESRI, are increasingly accessible. MDT has a subscription to AGOL, and already publishes geospatial information, such as AADT and road classifications, through this online platform. These online platforms are an excellent way to share and present asset data to Department personnel and to the general public. With this in mind, AGOL tools are recommended for integration into the RAMP Task 4 and as one of the Department's methods to interact with the data.

During 2016 fieldwork, raters used the AGOL Collector App on GPS-enabled tablets to check site coordinates and collect site extent polygons. Basic rating data (RHRS Score, Condition State, and Good/Fair/Poor descriptors), shown in Figure 6-2, was added to the polygon table. Site photos were also obtained with the tablet at each rock slope and uploaded in the field via the Collector App.



Date	11/13/2015
Section	120
Rater	LT
RHRSscore	175
CSnum	1
CStxt	Good

Attachments:

IMG_2909.JPG(X)
20151120_082828.jpg(X)

Figure 6-2: Data entry for RHRS section 120 (MT 2 near Havre) using the AGOL Collector Application. Note uploaded photos and dropdown entry options.

Eventually, the polygon data layer will be exported to ArcMap for desktop, and centroids calculated for each shape. These centroids were joined to the more extensive detailed ratings contained in the Excel database for analysis and presentation on MDT's ArcGIS Online platform.

7 Step 6: Tracking Performance and Communicating Results

Successful implementation of a TAM-compatible RAMP program includes the continued use of the dataset and tracking the performance of the assets over time. This is a common theme in nearly all asset management programs, such as the pavement management example in MDT's recent TAM Plan (Figure 7-1:).

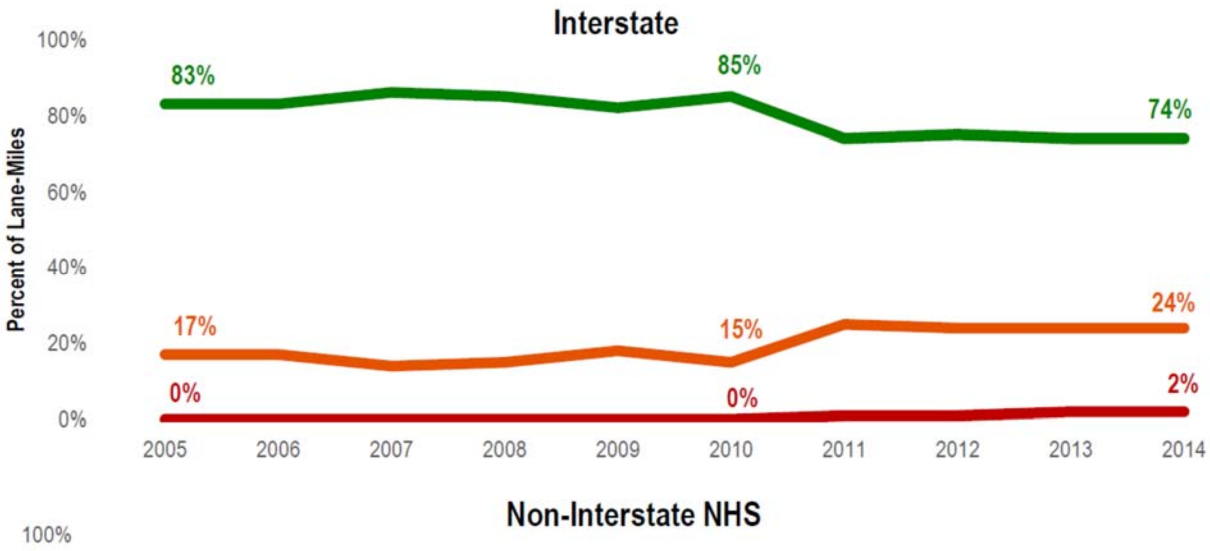


Figure 7-1: Example of Pavement Performance over the time.

Tracking and communicating annual percentages of rock slopes in Fair or Poor condition could be labor and cost intensive, so focusing rerating intervals on certain subsets (such as RAMP Class A at 3 year intervals and RAMP Class B at 7 year intervals) of corridors would be justified. Annual communications could be focused on the frequency of road-closing events tracked in the maintenance or GIS system to be developed.

Reporting on the performance of MDT's rock slopes should be integrated with their pavement and bridge programs. MDT may be considering developing an interactive or digital performance communication portal that summarizes their contribution to mobility and commerce. An excellent example of this 'Performance Journalism' is the City of Seattle's Dashboard[2] where basic metrics and how they are doing on meeting goals and objectives is communicated effectively and succinctly (Figure 7-2).

7.1 Communication Plan

At the conclusion of this initial RAMP process, MDT should consider developing a Communication Plan that adheres to the National Cooperative Highway Research Program's (NCHRP) Report 610: Communication Matters - Communicating the Value of Transportation Research (NCHRP 2009).

MDT would tailor the plan to for various criteria, including:

- Target Audiences (Federal, State, and Local agencies and professional societies)
- Primary and Secondary Key Messages
- Implementation Strategies and Tactics (reporting, publications, presentations, Task and Final Reports, online and desktop GIS)

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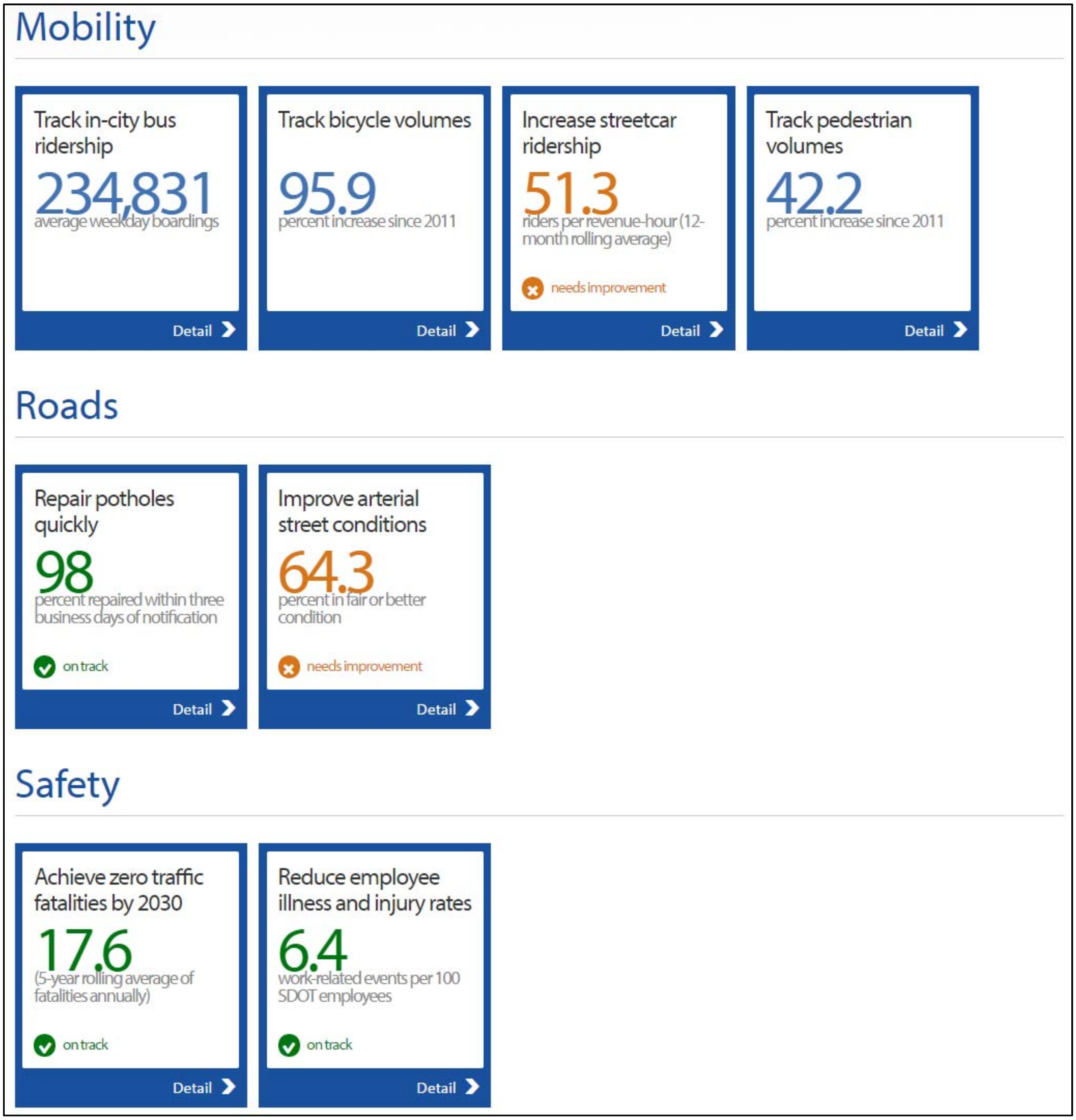
[2] https://performance.seattle.gov/stat/goals/r7sc-af3t

- Training and Implementation, both internal and external.

Effectively communicating the results of the research and the existence of the rock slope geodatabases will facilitate use of the data and provide greater return on the research efforts.



Mobility

Track in-city bus ridership
234,831
average weekday boardings
Detail ❯

Track bicycle volumes
95.9
percent increase since 2011
Detail ❯

Increase streetcar ridership
51.3
riders per revenue-hour (12-month rolling average)
✗ needs improvement
Detail ❯

Track pedestrian volumes
42.2
percent increase since 2011
Detail ❯

Roads

Repair potholes quickly
98
percent repaired within three business days of notification
✓ on track
Detail ❯

Improve arterial street conditions
64.3
percent in fair or better condition
✗ needs improvement
Detail ❯

Safety

Achieve zero traffic fatalities by 2030
17.6
(5-year rolling average of fatalities annually)
✓ on track
Detail ❯

Reduce employee illness and injury rates
6.4
work-related events per 100 SDOT employees
✓ on track
Detail ❯

Figure 7-2: City of Seattle's Performance Dashboard.

8 Task 3 Recommendations

This task consisted of describing the recommended plan for implementing MDT's Rock Slope Asset Management Program (RAMP). The next task (Task 4) is to implement these slope ratings at approximately 350 sites, a subsection of sites within MDT's highway network. The sites to be revisited and rated are those on the Interstate Highway System and any rated slopes with daily traffic above 2,000 vehicles per day.

We recommend implementing the condition and risk rating rubrics described in this report on the approximately 350 Task 4 sites. The results of the Task 4 visits and the further analyses for the remaining Tasks will help refine scoring cutoffs, prioritization schemes, degradation models, and other condition modelling approaches.

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Appendix D

TASK 4 REPORT – ROCK SLOPE ASSESSMENTS

Montana Department
or Transporation

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

Task 4 Report
Rock Slope Assessments

LANDSLIDE
TECHNOLOGY
A DIVISION OF CORNFORTH CONSULTANTS

Prepared for:

Montana Department of Transportation
Helena, Montana

ROCKFALL HAZARD PROCESS ASSESSMENT

TASK 4 REPORT
ASSESS ROCKFALL SITES IN MONTANA

December 19, 2016

Prepared by:

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

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Appendix A: Table of RAMP Sections Evaluated in 2016 Ranked by Total RHRS Score

Executive Summary

This document is the deliverable for Task 4 of the Montana Department of Transportation (MDT) research project “Rockfall Hazard Rating Process Assessment” (Project No. 15-3059V). As part of Task 4, sites previously visited in the 2004 RHRS study were revisited for RAMP site inspections. These field inspections tested revisions to the rating system, new equations for calculating a TAM-compatible asset condition, and proposed risk calculations. The field inspections also evaluated the use of ESRI’s Collector App, a free iOS or Android application that utilizes MDT’s existing ArcGIS Online (AGOL) platform. The objective of this task was to perform field visits to the highest priority sites determined from the original ratings completed in 2004 and re-rate the sites where conditions had changed.

In the field, laptops have largely been replaced by mobile devices, many of which can use GPS recievers to obtain geographic locations in the field. The rating sheets discussed in Section 1 were specifcally developed to run on a laptop or an Android or iOS tablet running Excel. Within AGOL, LT created a map containing the section start points, milepost markers, and basic roadway information. Using the Collector App, this map could be downloaded for offline use, and edits made during field assessments were appended to the master map at the end of the day.

Following discussions with MDT, rock slopes were selected for 2016 assessment from the existing RHRS data set. The prioritized slopes included all sites along the Interstate system and those ‘A’ sites on highway segments with AADTs above 2,000 vehicles per day. Including the low risk sites in the 2016 assessment work allowed MDT to confirm that its current methodology for subdividing ‘A’ and ‘B’ slopes reasonably captured risk to the transportation corridor while saving the Department time and money. In total 362 sites were selected. Of these sites, 126 were ‘B’ sites that had not received detailed ratings in the 2004 study. Nine of the final sites had been visited in 2015 as part of Task 2 investigation of mitigated sites. LT personnel visited the remaining 353 sites in late May 2016.

1 Creation of Field Forms

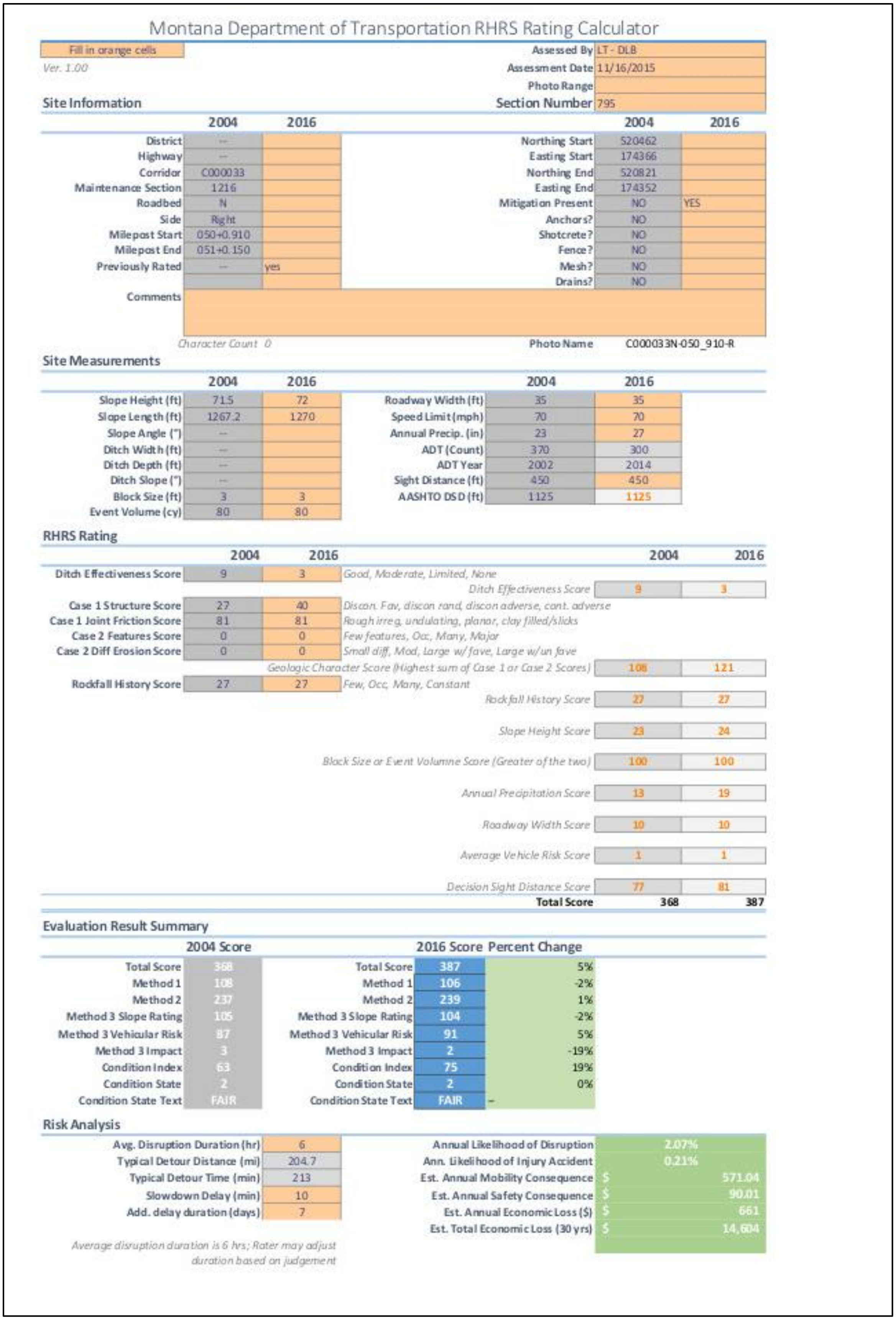
Prior to starting rockfall assessment work in Montana, Landslide Technology (LT) developed field forms for raters to use. The 2004 RHRS ratings were performed using an Access Database loaded onto a laptop. The final product, a database integrated into MDT's Oracle enterprise system, had become obsolete in the intervening decade. The database was also difficult to revise, and no new data was added after the RHRS project was completed in 2004.

For the RAMP program, LT developed field forms and rating tools that can be implemented by the Department in a readily available format to prompt future input and support beyond the initial project. The Access database was replaced with an Excel work sheet that could run on a laptop or a mobile platform, such as a tablet. The transition to Excel also reduced the risk that the new data would be trapped in an older program, which was a concern in Access, where older databases, such as Access 2002 files, can no longer be easily opened by the current version of Access.

The rating categories and related calculations used in the 2004 study remain unchanged. Detailed descriptions of the rating categories and rating procedures can be found in the 2005 report and the original RHRS user manual (Pierson, et al., 2005; Pierson & Van Vickle, 1993). All calculations previously performed mannually or in the Access Database are now performed in the Excel Rating Form. However, unlike in the 2004 ratings, inspectors now collect additional information on slope and ditch geometry. The field form is also one sheet within a larger Excel workbook. This workbook contains rating data and survery responses from the 2004 study, which is referenced in the field rating form based on RHRS section number. This allows the inspector to refer to past data in the field, and note any significant changes in the comments.

In the field form shown in Figure 1, the rater fills in the orange cells. Other cells are populated by refering to other worksheets for section information, and calcaultations required for various rating categories are automatically performed. The total RHRS score, TAM-compatible condition state, and various category combination methods are also calculated and presented. Finally, based on the rock slope Condition State, estimated mitigation costs and monetry risk are calculated for the site. All non-orange cells are locked to prevent the user from accidentaly altering references or equations. The final field rating form is shown in Figure 1.

As the field form is completed, a row at the bottom of the rating sheet is automatically populated. After completing the field assessment, the user copies and pastes this row into a separate worksheet, building a table of site ratings. New data can easily be appended, and if multiple raters are peforming assessments at the same time, their invididual data tables are easily merged at the end of the project. Additionaly, Excel tables can be easily imported into GIS workflow, ultimately arriving on MDT's AGOL platform in a geodatabase.



Montana Department of Transportation RHRS Rating Calculator

Fill in orange cells

Ver. 1.00

Assessed By	LT - DLB
Assessment Date	11/16/2015
Photo Range	
Section Number	795

Site Information

	2004	2016		2004	2016
District	--		Northing Start	520462	
Highway	--		Easting Start	174366	
Corridor	C000033		Northing End	520821	
Maintenance Section	1216		Easting End	174352	
Roadbed	N		Mitigation Present	NO	YES
Side	Right		Anchors?	NO	
Milepost Start	050+0.910		Shotcrete?	NO	
Milepost End	051+0.150		Fence?	NO	
Previously Rated	--	yes	Mesh?	NO	
			Drains?	NO	

Comments

Character Count 0

Photo Name C000033N-050_910-R

Site Measurements

	2004	2016		2004	2016
Slope Height (ft)	71.5	72	Roadway Width (ft)	35	35
Slope Length (ft)	1267.2	1270	Speed Limit (mph)	70	70
Slope Angle (°)	--		Annual Precip. (in)	23	27
Ditch Width (ft)	--		ADT (Count)	370	300
Ditch Depth (ft)	--		ADT Year	2002	2014
Ditch Slope (°)	--		Sight Distance (ft)	450	450
Block Size (ft)	3	3	AASHTO DSD (ft)	1125	1125
Event Volume (cy)	80	80			

RHRS Rating

	2004	2016		2004	2016
Ditch Effectiveness Score	9	3	*Good, Moderate, Limited, None*		
			Ditch Effectiveness Score	9	3
Case 1 Structure Score	27	40	*Discon. Fav, discon rand, discon adverse, cont. adverse*		
Case 1 Joint Friction Score	81	81	*Rough irreg, undulating, planar, clay filled/slicks*		
Case 2 Features Score	0	0	*Few features, Occ, Many, Major*		
Case 2 Diff Erosion Score	0	0	*Small diff, Mod, Large w/ fave, Large w/un fave*		
			Geologic Character Score (Highest sum of Case 1 or Case 2 Scores)	108	121
Rockfall History Score	27	27	*Few, Occ, Many, Constant*		
			Rockfall History Score	27	27
			Slope Height Score	23	24
			Block Size or Event Volumne Score (Greater of the two)	100	100
			Annual Precipitation Score	13	19
			Roadway Width Score	10	10
			Average Vehicle Risk Score	1	1
			Decision Sight Distance Score	77	81
			Total Score	368	387

Evaluation Result Summary

	2004 Score		2016 Score	Percent Change
Total Score	368	Total Score	387	5%
Method 1	108	Method 1	106	-2%
Method 2	237	Method 2	239	1%
Method 3 Slope Rating	105	Method 3 Slope Rating	104	-2%
Method 3 Vehicular Risk	87	Method 3 Vehicular Risk	91	5%
Method 3 Impact	3	Method 3 Impact	2	-19%
Condition Index	63	Condition Index	75	19%
Condition State	2	Condition State	2	0%
Condition State Text	FAIR	Condition State Text	FAIR	-

Risk Analysis

Avg. Disruption Duration (hr)	6	Annual Likelihood of Disruption	2.07%
Typical Detour Distance (mi)	204.7	Ann. Likelihood of Injury Accident	0.21%
Typical Detour Time (min)	213	Est. Annual Mobility Consequence	$ 571.04
Slowdown Delay (min)	10	Est. Annual Safety Consequence	$ 90.01
Add. delay duration (days)	7	Est. Annual Economic Loss ($)	$ 661
		Est. Total Economic Loss (30 yrs)	$ 14,604

Average disruption duration is 6 hrs; Rater may adjust duration based on judgement

Figure 1: Excel-based field rating form developed for MDT's RAMP.

In addition to the field form, slope extent information is collected into a polygon layer stored in AGOL. Within this layer, raters sketched the approximate extents of the rock slope while performing their field ratings. Figure 2 contains an example of this layer.

These polygons provide a more accurate reflection of section dimensions than a simple straight line along the roadway, and may be used to develop more accurate rock slope square footage estimates. Mitigation cost and projected risk are both calculated using rock slope square footage and slope condition. More accurately measured rock slope areas will increase correlation robustness and improve the Department’s estimation tools.

Figure 2: Site extents in the AGOL polygon layer for rock slopes on I-90 east of Butte.

2 Conducting Site Ratings

A set of rock slopes were selected for the 2016 field assessments following consultation with MDT. The initial plan had been to revisit the 368 ‘A’ sites that received detailed ratings in 2004. However, two slopes not rated as ‘A’ slopes in 2004 had since been the source of road-closing events, mostly due to landslide events that delivered large rocks or large volumes of rock to the road. These sites, along I-90 west of St Regis at mileposts (MPs) 6.5 and 24, were a combination of soil and rock slopes with little exposed rock. As a result of the variable slope materials these slopes did not meet the ‘A’ rating criteria in 2004. Based on the activity of these sites, MDT decided to include all interstate ‘B’ sites in the RAMP fieldwork. Re-examining ‘B’ slopes helped the Department better assess risks in the I-90 corridor and allows the evaluation of effectiveness of the 2004 ‘A’ / ‘B’ cutoff criteria and to estimate how to adjust criteria to better capture rockfall risks to the transportation corridor.

The rock slopes from the 2004 RHRS data set were filtered for 2016 fieldwork using the following criteria:

- All sites on Interstate Routes (I-90 and I-15)
- All ‘A’ sites on US 2 between mileposts 153 and 160
- All 2004 ‘A’ sites with an ADT greater than 2,000

The final selections included 362 rock slopes, as shown in Figure 3. Of these sites, 126 were ‘B’ sites along I-15 and I-90 that did not received detailed ratings in the 2004 study. Nine of the final sites had been previously visited in 2015 as part of Task 2 investigation of mitigated sites, and were not re-evaluated in the Task 4 fieldwork. LT personnel visited the remaining 353 sites in late May, 2016.

The basic location information, 2004 ‘A’ or ‘B’ classification, and total RHRS score for each of the 362 sites are summarized in Appendix A. Detailed rating information, including comparison to past ratings, estimated mitigation costs, estimated monetary risks, and initial cost/benefit analyses are contained in the RAMP point shapefile that has been uploaded to MDT’s AGOL space.

2.1 Field Rating Procedure

LT personnel using GPS-enabled Android tablets conducted the fieldwork. The tablets were loaded with Excel and the AGOL Collector Application, discussed previously. The simplified reference map used in the Collector Application included the locations of the selected sites (with different symbols for A and B sites), milepost locations, AADT information, and various base maps. ‘Syncing’ enabled offline data collection so that raters could use the map in areas without cell data coverage.

At each site, raters used laser rangefinders to confirm site measurements collected in 2004 and collect new basic information on slope and ditch geometry. Within the Collector App, raters sketched approximate rock cut slope extent polygons as they walked the site, and entered basic information (e.g., time, date, and RHRS Section Number) into the attribute table for each new polygon. Using the tablets, raters took representative, geospatially-referenced photographs at each site and attached them to the extent polygons within the Collector Application. Raters added the rating date, total RHRS score, and asset condition information to the attribute table associated with the newly created site polygon.

The Excel field form contained information from the 2004 ratings and maintenance survey to help guide the current fieldwork. New ratings were appended to the Site Rating Worksheet in the Excel workbook and was backed up daily. If a cellular connection was not available, all data obtained through the Collector Application was uploaded to MDT’s AGOL server at the end of the day.

2.2 Coordination with MDT Maintenance Staff

During their site visits, LT inspectors also contacted the maintenance supervisors in the various maintenance sections. A phone survey was conducted with the supervisors, with a particular emphasis on any changes that had occurred since the 2004 survey. Maintenance responses were reflected in the site ratings.

In general, maintenance supervisors found themselves concentrating rockfall response on the same sections of roadway in 2016 as they had in 2004. However, based on these conversations, one additional site was added to the data set on I-90 at MP 131.4 in the Clinton Section of the Missoula district. This site was not part of the original RHRS because it borders the I-90 frontage road. However, rockfall has crossed the frontage road, landing in the interstate's westbound travel lane.

2.3 Changes in RHRS Scores

Changes in the total RHRS scores occurred in many of the re-ratings. Some of these changes may be attributed to objective variables such as traffic volumes and different sight distance. Additional information may also be evident at the sites that was not present before, such as larger rock sizes or volume estimations. Other subjective factors may have been reevaluated through the judgement of the rater or through a change in raters. For instance, slope section number 310 with a total 2016 RHRS score of 676 rose from a score of 474 from the previous ratings. In the prior 12 years, AADT has rose from 1,650 to 2,200 and is projected to continue to rise. This 202 point, 43% increase, is the result of a combination of the above factors, including:

- 67 points from judged worse Case 2 differential erosion feature scores;
- 54 points from a larger rock size from 3 feet to 4 feet;
- 31 points from a ditch effectiveness judged less effective;
- 25 point increase from greater average vehicle risk;
- 21 points from a judged worse rockfall history (or correcting a lesser previous score);
- 3 points from a narrower measured road width (20 vs 19 ft); and
- 1 point from an updated rainfall dataset exhibiting a higher rainfall of 15 from 13 inches.

Three of the above factors totaling 29 points are the result of objective data inputs with the remaining score increases being the result of subjective score increases. Note that the Condition Index, which is focused on rockfall activity and ditch effectiveness, did not worsen to the same degree as would be indicated by the RHRS score. The Condition Index decreased from 34 to 25, or 26%. Its Condition State remained a '4', or in Poor condition. This is an illustrative example of how total RHRS scores may exhibit accumulated changes while also exhibiting some resilience of Condition Index and States to changing judgement. Ultimately, the subjective nature of many rating categories while seeking to accommodate rapid assessment of variable geologic terrain makes these shifts unavoidable. In this case, more informed judgement may have made these scores more representative of the hazards posed.

In other cases, the re-rated 'B' slopes may have been judged as not likely to affect the highway. Recent landslides have mobilized large boulders into the travel lanes, illumunating the rockfall risk posed by these largely soil or 'blocks-in-matrix'-type sites. Application of the RHRS score criteria to tall, long, low sight-distance, and high AADT sites such as some of those west of St. Regis on I-90 will assign a moderate to high RHRS score, regardless of the rockfall history or ditch effectiveness. Relying on Condition indicators on these slopes may be more advantageous that RHRS score alone.

Considering all the rerated sites, average RHRS score change was 3% with a 14% standard deviation.

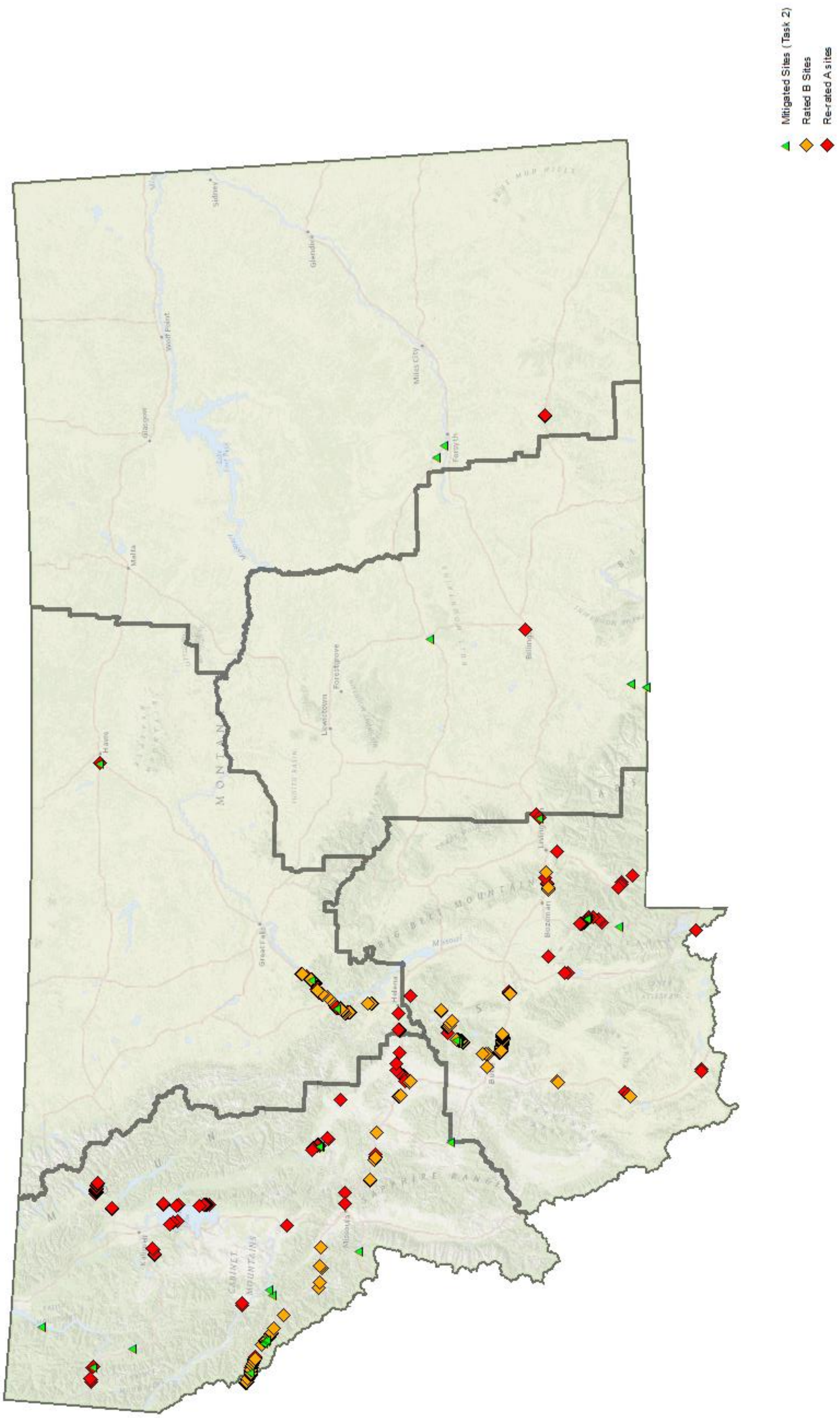


Figure 3: Sites rated as part of 2016 RAMP program

3 Final digital format of field data

Rating data from both the original RHRS project and this current project's activities were combined into a single Excel sheet for export into the RAMP geodatabase. The data extracted from the 2004 Access Database was also appended to this sheet. Sites that had ratings in both 2004 and 2016 are both stored, but with separate data entries. In the "Rating Status" field, the most current ratings are marked as "active" and all historical ratings are marked as "archive." These historical ratings are stored in the GIS database, but filters can be applied in the map space so that only "active" ratings are presented. Finally, the 2004 RHRS section ratings are evaluated for potential mitigation costs and monetary risks based on AADT (both 2002 and 2014) and detour length using techniques described in the Task 3 report. This final dataset contained up to three ratings per RHRS section for a total of 2,085 entries (2004 ratings with 2002 AADT, 2004 ratings with 2014 AADT, and 2016 ratings with 2014 AADT). This master Excel table was imported into ArcGIS and merged to a geodatabase as a point layer, using the starting point of each rockfall section as its location.

QA/QC checks using Excel, ArcGIS Desktop, and the AGOL platform ensured quality and completeness following the completion of fieldwork.

Field photos were downloaded and organized into folders based on corridor code and milepost and combined with 2004 photos, distinguished by year taken in the file name. In the future, these photos will all be stored on MDT's internal document server in a yet to be identified location. A hyperlink in the site information pop-up will take viewers to all photographs available for that site.

The interim geodatabase, composed of site extent polygons for the 2016 sites and point location information for all sites rated in 2004 and 2016, is stored on MDT's AGOL server (http://arcg.is/2edxxDE, MDT AGOL login required). Users can filter the dataset to show only those sites along a certain road, sites scoring above a set cutoff, or many other metrics that could help Department decision making. An AGOL-based map application will be developed near the end of this project to present an overview of the RAMP.

4 Task 4 Recommendations

Maintenance of existing data: By storing the RAMP data using ESRI's AGOL program, to which the Department already maintains a subscription, it will be easy to get IT support from either within MDT or from ESRI, should the need arise. The format of maps and layers in the RAMP will also be familiar to users, and will make the dataset less intimidating to use. ESRI is also constantly engaged in maintenance and improvements of their software and platforms, so the RAMP data is unlikely to become confined in an obsolete system. Note that occasional geodatabase backups are recommended in the event of a subscription lapse or should MDT cancel licensing. We recommend MDT Geotechnical coordinate with the personnel in charge of the AGOL licensing to be sure they are aware of its use in RAMP to reduce the risk of accidental deletion or subscription cancellation.

In the future, data can be edited within the AGOL space in an office environment, or the layers can be added to a map in the Collector App for field use. Either way, the user is viewing/editing data from the same data source. Currently ESRI performs regular updates to improve AGOL. The Collector App is also enabled to work with iOS and Android systems, and a future expansion to Windows Mobile devices has started. We recommend the Department plan to revisit sites, either throughout the State or along specific corridors, on a regular schedule to track changes and asset deterioration.

Use in Planning: Now that the site ratings have been completed and the data prepared for release through the AGOL platform, the rating data can be used to identify critical sites, the next project task. Data can be filtered, to remove sites that pose a low risk to the corridor, or heat maps can be developed to better illustrate where underperforming assets are located. Task 5 will evaluate the various means of identifying critical sites utilizing the Decision Support Tools described in Task 3.

5 References

Pierson, L., Beckstrand, D. & Black, B., 2005. *Rockfall Hazard Classification and Mitigation System*, Helena, Montana: MDT.

Pierson, L. & Van Vickle, R., 1993. *Rockfall Hazard Rating Program - Participants' Manual*, Washington DC: FHWA.

Appendix A
RHRS Scores

Rank	Corridor	MP Start	MP End	Section No.	2004 Site Designation	Total 2016 RHRS Score	2004 RHRS Score	Change 2016 - 2004
1	C000011	013+0.960	014+0.610	310	A	676	474	43%
2	C000090	315+0.260	315+0.500	1261	A	664	641	4%
3	C000001	158+0.470	158+0.640	94	A	655	645	2%
4	C000015	051+0.780	052+0.320	384	A	629	624	1%
5	C000001	156+0.600	156+0.730	85	A	616	601	2%
6	C000015	226+0.980	227+0.230	448	A	614	538	14%
7	C000001	155+0.500	155+0.620	77	A	610	602	1%
8	C000015	219+0.540	219+0.820	426	A	607	641	-5%
9	C000011	013+0.320	013+0.660	307	A	602	654	-8%
10	C000011	013+0.840	013+0.960	309	A	585	569	3%
11	C000050	060+0.730	060+0.960	946	A	583	549	6%
12	C000050	061+0.180	061+0.260	947	A	572	555	3%
13	C000090	231+0.380	231+0.650	1213	A	571	559	2%
14	C000024	003+0.030	003+0.120	532	A	563	564	0%
15	C000011	006+0.570	006+0.960	304	A	548	434	26%
16	C000015	217+0.670	218+0.370	420	A	539	617	-13%
17	C000050	052+0.870	052+0.960	937	A	536	495	8%
18	C000090	231+0.950	232+0.160	1218	A	521	473	10%
19	C000090	237+0.110	237+0.530	1238	A	517	445	16%
19	C000090	350+0.890	351+0.150	1269	A	517	345	50%
21	C000001	154+0.860	155+0.000	76	A	515	440	17%
21	C000090	315+0.070	315+0.190	1260	A	515	443	16%
23	C000001	155+0.700	155+0.800	79	A	504	489	3%
23	C000015	157+0.770	157+0.930	408	A	504	520	-3%
25	C000050	061+0.380	061+0.550	948	A	501	454	10%
26	C000083	005+0.540	005+0.690	1076	A	500	498	0%
27	C000001	020+0.380	020+0.680	26	A	499	494	1%
28	C000050	050+0.680	050+0.800	933	A	495	486	2%
29	C000083	009+0.050	009+0.160	1087	A	489	474	3%
30	C000090	012+0.480	012+0.780	1157	A	484	455	6%
31	C000001	157+0.920	158+0.040	90	A	483	478	1%
32	C000015	225+0.640	225+0.800	447	A	478	466	3%
33	C000090	317+0.560	317+0.780	1265	A	477	406	17%
34	C000090	124+0.680	124+0.880	1196	B	476	0	-
35	C000001	156+0.970	157+0.180	87	A	475	465	2%
36	C000090	232+0.690	232+0.990	1221	A	473	429	10%
37	C000015	158+0.150	158+0.280	409	A	471	431	9%
38	C000001	155+0.810	155+0.880	80	A	470	446	5%
38	C000001	157+0.240	157+0.340	88	A	470	461	2%
40	C000015	222+0.800	223+0.080	439	A	468	450	4%
40	C000050	052+0.730	052+0.870	936	A	468	449	4%
42	C000052	010+0.990	011+0.040	959	A	462	440	5%
43	C000015	218+0.450	218+0.530	421	A	461	499	-8%
44	C000090	136+0.100	136+0.360	1201	A	457	422	8%

Rank	Corridor	MP Start	MP End	Section No.	2004 Site Designation	Total 2016 RHRS Score	2004 RHRS Score	Change 2016 - 2004
45	C000090	008+0.610	008+0.640	1152	A	454	435	4%
46	C000015	250+0.790	250+0.920	488	A	453	456	-1%
47	C000090	237+0.090	237+0.330	1237	A	452	410	10%
48	C000008	010+0.150	010+0.210	273	A	448	438	2%
48	C000015	218+0.620	218+0.770	423	A	448	447	0%
48	C000050	057+0.720	057+0.840	942	A	448	372	20%
48	C000050	062+0.070	062+0.210	949	A	448	445	1%
52	C000050	052+0.050	052+0.160	934	A	447	425	5%
52	C000090	137+0.160	137+0.360	1202	A	447	387	16%
54	C000008	005+0.230	005+0.360	269	A	445	451	-1%
55	C000083	008+0.430	008+0.560	1086	A	442	403	10%
55	C000090	024+0.040	024+0.190	1172	A	442	551	-20%
57	C000015	244+0.760	244+0.930	475	A	439	415	6%
58	C000090	027+0.790	028+0.090	1181	A	438	455	-4%
59	C000090	239+0.520	239+0.830	1246	B	432	0	-
60	C000001	026+0.900	027+0.020	35	A	431	499	-14%
60	C000001	155+0.520	155+0.590	78	A	431	384	12%
62	C000052	009+0.720	009+0.940	957	A	429	422	2%
63	C000090	000+0.530	000+0.660	1136	B	425	0	-
63	C000090	316+0.980	317+0.360	1264	A	425	399	7%
65	C000001	159+0.600	159+0.650	96	A	419	384	9%
65	C000090	026+0.240	026+0.430	1177	A	419	489	-14%
67	C000053	002+0.410	003+0.010	975	A	417	397	5%
68	C000090	023+0.820	023+0.910	1171	B	416	0	-
69	C000001	155+0.880	156+0.000	81	A	413	390	6%
70	C000090	024+0.590	024+0.720	1175	A	411	564	-27%
71	C000083	009+0.540	009+0.630	1089	A	409	441	-7%
72	C000005	097+0.110	097+0.390	153	A	405	330	23%
72	C000024	034+0.950	035+0.260	542	A	405	394	3%
72	C000050	055+0.690	055+0.780	939	A	405	302	34%
72	C000090	260+0.450	260+0.660	1258	A	405	373	9%
76	C000001	158+0.960	159+0.050	95	A	403	394	2%
77	C000090	236+0.770	236+0.820	1235	B	401	0	-
78	C000090	006+0.650	006+0.760	1148	A	400	421	-5%
79	C000015	223+0.740	223+0.860	443	A	399	443	-10%
79	C000090	002+0.800	002+0.880	1142	A	399	397	1%
81	C000011	015+0.710	015+0.840	312	A	398	392	2%
82	C000001	026+0.800	026+0.900	34	A	393	370	6%
82	C000050	052+0.330	052+0.450	935	A	393	383	3%
84	C000001	025+0.920	026+0.100	31	A	392	368	7%
85	C000005	025+0.350	025+0.500	128	A	390	356	10%
85	C000015	245+0.380	245+0.660	483	B	390	454	-14%
87	C000001	156+0.260	156+0.390	83	A	388	363	7%
88	C000090	026+0.830	027+0.010	1178	A	386	398	-3%

Rank	Corridor	MP Start	MP End	Section No.	2004 Site Designation	Total 2016 RHRS Score	2004 RHRS Score	Change 2016 - 2004
89	C000090	236+0.900	237+0.110	1236	A	385	339	14%
90	C000090	231+0.020	231+0.230	1211	B	384	0	-
91	C000084	010+0.560	010+0.670	1112	A	383	312	23%
91	C000090	007+0.460	007+0.580	1150	A	383	360	6%
93	C000008	007+0.360	007+0.490	270	A	381	337	13%
93	C000090	006+0.160	006+0.270	1147	B	381	0	-
95	C000050	062+0.560	062+0.690	950	A	379	380	0%
96	C000090	001+0.080	001+0.220	1138	A	378	278	36%
97	C000015	224+0.780	224+0.930	445	A	376	347	8%
97	C000090	232+0.210	232+0.300	1219	A	376	354	6%
99	C000052	011+0.080	011+0.120	960	A	374	378	-1%
99	C000090	001+0.530	001+0.610	1140	A	374	259	44%
101	C000050	063+0.140	063+0.210	951	A	373	372	0%
102	C000015	220+0.010	220+0.220	428	B	372	401	-7%
102	C000090	353+0.170	353+0.350	1270	A	372	386	-4%
104	C000090	008+0.860	008+0.990	1153	A	369	351	5%
105	C032200	000+0.430	000+0.610	1675	A	366	250	46%
106	C000015	244+0.990	245+0.040	479	A	362	358	1%
107	C000005	095+0.300	095+0.390	147	A	360	268	34%
108	C000052	011+0.230	011+0.370	962	A	359	360	0%
108	C000090	002+0.620	002+0.710	1141	A	359	387	-7%
110	C000015	241+0.870	242+0.060	470	A	358	346	3%
111	C000090	005+0.850	005+0.870	1146	B	355	0	-
112	C000001	141+0.000	141+0.040	71	A	354	311	14%
113	C000005	097+0.110	097+0.280	154	A	352	365	-4%
113	C000052	013+0.120	013+0.180	966	A	352	392	-10%
115	C000090	027+0.350	027+0.560	1180	B	351	0	-
116	C000090	028+0.450	028+0.740	1183	B	350	0	-
117	C000001	159+0.940	160+0.000	97	A	349	329	6%
118	C000008	008+0.700	008+0.800	272	A	347	319	9%
119	C000008	018+0.500	018+0.610	277	A	345	397	-13%
119	C000015	218+0.480	218+0.540	422	A	345	329	5%
119	C000050	059+0.280	059+0.390	945	A	345	323	7%
119	C000090	007+0.900	007+0.980	1151	B	345	0	-
123	C000015	223+0.130	223+0.230	440	A	344	335	3%
124	C000090	072+0.510	072+0.690	1193	B	342	0	-
125	C000013	061+0.810	062+0.320	321	A	339	345	-2%
126	C000001	156+0.430	156+0.520	84	A	337	340	-1%
126	C000090	009+0.990	010+0.100	1154	B	337	0	-
128	C000015	221+0.560	221+0.630	436	A	336	328	2%
128	C000015	235+0.600	235+0.760	460	A	336	339	-1%
128	C000024	034+0.150	034+0.430	538	A	336	326	3%
128	C000090	013+0.320	013+0.410	1163	A	336	332	1%
132	C000090	320+0.760	320+0.840	1266	A	335	404	-17%

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133	C000001	153+0.820	153+0.870	72	A	333	311	7%
134	C000005	097+0.020	097+0.110	152	A	329	314	5%
135	C000008	031+0.050	031+0.290	289	A	327	316	3%
136	C000090	000+0.790	000+0.880	1137	B	326	0	-
136	C000090	148+0.100	148+0.260	1203	B	326	0	-
138	C000052	024+0.400	024+0.500	974	A	323	281	15%
139	C000005	097+0.280	097+0.390	155	A	321	320	0%
140	C000090	028+0.120	028+0.200	1182	B	319	0	-
141	C000090	168+0.950	169+0.150	1206	B	317	0	-
141	C000090	238+0.120	238+0.310	1241	A	317	268	18%
143	C000090	014+0.000	014+0.080	1165	A	316	307	3%
144	C000090	013+0.060	013+0.190	1161	A	315	314	0%
144	C000090	125+0.250	125+0.500	1198	A	315	281	12%
146	C000015	160+0.580	160+0.720	413	B	311	0	-
147	C000001	140+0.700	140+0.820	70	A	310	295	5%
147	C000015	225+0.340	225+0.490	446	A	310	345	-10%
147	C000090	022+0.360	022+0.460	1168	A	310	379	-18%
150	C000005	093+0.360	093+0.520	140	A	309	216	43%
151	C000008	002+0.830	003+0.000	265	A	308	320	-4%
152	C000015	220+0.650	220+0.750	433	A	307	312	-2%
153	C000090	230+0.980	231+0.010	1210	B	305	0	-
154	C000015	146+0.050	146+0.200	401	A	304	308	-1%
154	C000090	315+0.950	316+0.000	1263	B	304	0	-
156	C000090	013+0.010	013+0.070	1160	A	302	273	11%
156	C000090	013+0.440	013+0.740	1164	B	302	0	-
158	C000008	030+0.070	030+0.130	286	A	301	281	7%
159	C000015	221+0.490	221+0.520	435	A	300	294	2%
160	C000084	010+0.380	010+0.460	1111	A	299	223	34%
160	C000090	007+0.290	007+0.460	1149	A	299	288	4%
162	C000015	245+0.570	245+0.730	485	B	297	0	-
162	C000083	006+0.010	006+0.220	1079	A	297	342	-13%
164	C000090	235+0.220	235+0.460	1230	A	296	261	13%
165	C000001	158+0.160	158+0.240	92	A	295	264	12%
166	C000015	134+0.580	134+0.670	394	B	294	0	-
166	C000015	244+0.600	244+0.740	474	A	294	357	-18%
166	C000024	034+0.650	034+0.730	540	A	294	189	56%
166	C000024	055+0.290	056+0.100	543	A	294	341	-14%
170	C000090	005+0.110	005+0.230	1144	B	293	0	-
171	C000090	260+0.300	260+0.420	1257	A	292	327	-11%
172	C000015	245+0.460	245+0.570	484	A	291	263	11%
172	C000052	009+0.560	009+0.700	956	A	291	282	3%
172	C000083	009+0.320	009+0.410	1088	A	291	293	-1%
172	C000090	314+0.680	314+0.800	1259	B	291	0	-
176	C000006	071+0.950	072+0.150	200	A	288	291	-1%

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177	C000015	230+0.820	231+0.030	450	B	287	0	-
178	C000090	030+0.660	030+0.860	1184	B	286	0	-
178	C000090	237+0.900	238+0.120	1240	B	286	0	-
180	C000015	218+0.790	218+0.880	425	A	284	281	1%
180	C000015	245+0.260	245+0.300	482	A	284	280	1%
182	C000015	238+0.360	238+0.430	464	A	283	268	6%
182	C000090	023+0.490	023+0.620	1170	B	283	0	-
182	C000090	236+0.590	236+0.650	1234	A	283	216	31%
185	C000001	026+0.560	026+0.780	33	A	282	258	9%
185	C000052	023+0.470	023+0.700	971	A	282	292	-3%
187	C000090	025+0.000	025+0.090	1176	A	281	263	7%
188	C000090	012+0.790	012+0.930	1158	A	280	284	-1%
189	C000001	020+0.800	021+0.030	27	A	279	272	3%
190	C000005	095+0.300	095+0.400	148	A	278	223	25%
190	C000015	238+0.480	238+0.570	465	A	278	276	1%
192	C000015	234+0.760	234+0.840	456	A	276	279	-1%
192	C000015	242+0.810	243+0.020	473	A	276	267	3%
192	C000083	006+0.290	006+0.440	1081	A	276	275	0%
192	C000090	010+0.880	010+0.990	1155	B	276	0	-
196	C000015	170+0.720	170+0.910	416	A	274	270	1%
197	C000011	013+0.220	013+0.320	306	A	272	275	-1%
198	C000090	083+0.000	083+0.200	1195	B	271	0	-
199	C000015	146+0.450	146+0.660	403	A	270	270	0%
200	C000015	242+0.600	242+0.740	472	A	267	258	3%
200	C000090	231+0.820	231+0.930	1216	A	267	254	5%
200	C000090	236+0.370	236+0.500	1233	A	267	267	0%
203	C000090	062+0.040	062+0.280	1186	B	266	0	-
204	C000209	002+0.060	002+0.130	1314	A	264	257	3%
205	C000015	245+0.060	245+0.140	480	A	263	259	2%
206	C000015	132+0.410	132+0.620	393	B	260	0	-
207	C000011	048+0.990	049+0.170	313	A	258	239	8%
208	C000015	155+0.060	155+0.420	407	A	256	255	0%
208	C000090	012+0.940	013+0.000	1159	A	256	251	2%
208	C000209	001+0.610	001+0.640	1313	A	256	303	-16%
211	C000015	158+0.340	158+0.570	410	B	255	0	-
211	C000090	001+0.400	001+0.530	1139	B	255	0	-
213	C000090	238+0.960	239+0.040	1244	B	254	0	-
214	C000015	242+0.400	242+0.570	471	A	253	280	-10%
215	C000015	146+0.710	146+0.970	404	B	252	0	-
215	C000052	008+0.890	008+0.960	955	A	252	269	-6%
215	C000090	024+0.410	024+0.500	1174	A	252	258	-2%
215	C000090	135+0.580	135+0.680	1200	B	252	0	-
219	C000015	144+0.020	144+0.160	396	B	249	0	-
220	C000001	154+0.660	154+0.780	75	A	248	234	6%

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220	C000015	238+0.170	238+0.300	462	B	248	241	3%
222	C000015	219+0.570	219+0.730	427	A	247	236	5%
223	C000090	023+0.120	023+0.240	1169	B	246	0	-
224	C000090	238+0.540	238+0.830	1242	B	244	0	-
225	C000015	146+0.320	146+0.380	402	A	242	249	-3%
225	C000090	013+0.240	013+0.280	1162	A	242	242	0%
225	C000090	024+0.350	024+0.440	1173	B	242	0	-
228	C000090	169+0.840	169+0.890	1207	B	240	0	-
229	C000015	170+0.460	170+0.890	415	B	239	0	-
230	C000090	014+0.350	014+0.470	1166	A	238	230	3%
231	C000015	238+0.300	238+0.360	463	A	237	227	4%
232	C000015	230+0.490	230+0.630	449	B	236	0	-
232	C000090	012+0.060	012+0.180	1156	B	236	0	-
234	C000001	107+0.760	107+0.780	65	A	234	185	26%
234	C000015	147+0.490	147+0.770	406	B	234	0	-
236	C000090	131+0.4	131+0.6	9001	B	233	385	-39%
237	C000015	223+0.290	223+0.360	441	A	231	305	-24%
237	C000015	239+0.380	239+0.450	468	A	231	291	-21%
239	C000015	053+0.660	053+0.710	385	A	230	208	11%
239	C000015	220+0.630	220+0.720	432	A	230	223	3%
241	C000090	238+0.540	238+0.700	1243	B	229	0	-
242	C000015	132+0.350	132+0.700	392	B	226	0	-
242	C000015	245+0.100	245+0.140	481	A	226	227	0%
244	C000282	001+0.270	001+0.320	1372	A	224	284	-21%
245	C000015	237+0.450	237+0.540	461	B	222	215	3%
246	C000090	259+0.980	260+0.090	1255	A	220	165	33%
247	C000052	010+0.380	010+0.520	958	A	219	218	0%
247	C000090	020+0.710	020+0.840	1167	B	219	0	-
247	C000090	071+0.400	071+0.490	1189	B	219	0	-
250	C000015	204+0.790	204+0.900	417	B	213	0	-
250	C000037	047+0.590	047+0.760	857	A	213	197	8%
250	C000090	003+0.030	003+0.080	1143	B	213	0	-
250	C000090	350+0.690	350+0.890	1268	A	213	365	-42%
254	C000090	125+0.110	125+0.250	1197	B	212	0	-
255	C000015	145+0.310	145+0.570	399	B	211	0	-
256	C000090	168+0.460	168+0.550	1205	A	210	173	21%
257	C000050	058+0.410	058+0.450	943	A	209	425	-51%
257	C000090	005+0.280	005+0.350	1145	B	209	0	-
259	C000015	147+0.170	147+0.340	405	B	207	0	-
259	C000015	238+0.960	239+0.030	467	A	207	205	1%
259	C000015	244+0.950	244+0.970	478	A	207	203	2%
259	C000024	034+0.730	034+0.810	541	A	207	188	10%
259	C000090	026+0.830	027+0.010	1179	B	207	0	-
264	C000012	000+0.350	000+0.490	315	A	205	186	10%

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264	C000015	248+0.530	248+0.640	487	A	205	198	4%
266	C000037	047+0.900	047+0.970	858	A	204	204	0%
267	C000015	131+0.500	131+0.770	391	B	202	0	-
268	C000008	029+0.720	029+0.790	285	A	200	172	16%
268	C000015	223+0.750	223+0.820	444	A	200	181	10%
270	C000001	110+0.600	110+0.710	69	A	198	192	3%
271	C000015	244+0.830	244+0.920	477	A	197	191	3%
272	C000083	005+0.820	005+0.870	1078	A	195	203	-4%
273	C000015	251+0.100	251+0.190	490	A	194	192	1%
274	C000015	159+0.560	159+0.680	412	B	191	0	-
275	C000090	239+0.940	240+0.050	1247	B	190	0	-
276	C000090	231+0.720	231+0.770	1215	A	189	186	2%
277	C000015	158+0.910	159+0.060	411	B	188	0	-
278	C000015	235+0.600	235+0.680	459	B	187	0	-
279	C000015	123+0.580	123+0.770	389	B	185	0	-
279	C000015	162+0.100	162+0.750	414	B	185	0	-
281	C000015	049+0.920	050+0.080	383	B	184	0	-
281	C000015	231+0.490	231+0.520	453	B	184	0	-
283	C000090	040+0.240	040+0.370	1185	B	181	0	-
284	C000090	234+0.390	234+0.480	1227	A	180	179	1%
285	C000015	220+0.550	220+0.560	431	A	179	196	-9%
285	C000090	071+0.790	071+0.880	1191	B	179	0	-
285	C000090	239+0.230	239+0.380	1245	B	179	0	-
288	C000015	145+0.120	145+0.210	398	B	178	0	-
288	C000090	259+0.220	259+0.300	1249	A	178	182	-2%
290	C000015	123+0.910	124+0.010	390	A	177	0	-
291	C000001	107+0.220	107+0.320	64	A	176	150	17%
291	C000008	013+0.510	013+0.680	276	A	176	172	2%
293	C000001	378+0.310	378+0.460	120	A	175	394	-56%
294	C000015	011+0.890	012+0.210	381	A	172	186	-8%
294	C000015	012+0.530	012+0.730	382	A	172	175	-2%
296	C000006	070+0.680	070+0.770	198	A	169	142	19%
296	C000015	239+0.430	239+0.490	469	A	169	158	7%
296	C000090	064+0.790	064+0.890	1187	B	169	0	-
299	C000015	221+0.630	221+0.740	437	B	166	0	-
299	C000090	259+0.800	259+0.870	1254	B	166	0	-
301	C000015	231+0.060	231+0.120	452	B	164	0	-
301	C000015	238+0.570	238+0.760	466	B	164	0	-
303	C000015	205+0.000	205+0.330	418	B	162	0	-
304	C000011	012+0.200	012+0.460	305	A	159	213	-25%
304	C000013	060+0.560	060+0.650	320	A	159	172	-8%
304	C000090	071+0.280	071+0.300	1188	B	159	0	-
307	C000015	086+0.360	086+0.600	386	B	157	0	-
308	C000015	218+0.640	218+0.670	424	B	154	0	-

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308	C000015	220+0.080	220+0.180	429	A	154	144	7%
308	C000090	234+0.000	234+0.080	1225	B	154	0	-
308	C000090	234+0.140	234+0.280	1226	B	154	0	-
312	C000015	143+0.790	144+0.010	395	B	153	0	-
312	C000015	232+0.700	232+0.810	454	B	153	0	-
314	C000090	259+0.630	259+0.680	1253	B	152	0	-
315	C000050	057+0.420	057+0.470	941	A	151	320	-53%
316	C000015	086+0.470	086+0.570	387	B	147	0	-
316	C000090	237+0.410	237+0.460	1239	B	147	0	-
318	C000001	019+0.560	019+0.640	24	A	146	146	0%
318	C000015	245+0.890	246+0.080	486	A	146	136	7%
320	C000015	230+0.850	231+0.040	451	B	145	0	-
320	C000090	072+0.800	072+0.870	1194	B	145	0	-
320	C000090	323+0.460	323+0.550	1267	B	145	0	-
323	C000090	236+0.190	236+0.250	1232	B	144	0	-
324	C000090	177+0.080	177+0.210	1208	B	137	0	-
324	C000090	260+0.130	260+0.210	1256	A	137	132	4%
326	C000090	233+0.970	234+0.060	1224	B	136	0	-
327	C000015	232+0.710	232+0.820	455	B	135	0	-
328	C000008	002+0.520	002+0.760	264	A	134	137	-2%
328	C000090	240+0.070	240+0.200	1248	B	134	0	-
330	C000015	220+0.540	220+0.560	430	B	130	0	-
330	C000090	259+0.530	259+0.700	1252	B	130	0	-
332	C000013	060+0.330	060+0.460	319	A	127	146	-13%
332	C000015	220+0.900	220+0.920	434	B	127	0	-
334	C000015	087+0.080	087+0.380	388	B	126	0	-
335	C000015	235+0.210	235+0.300	458	B	125	0	-
335	C000090	259+0.230	259+0.300	1250	B	125	0	-
337	C000015	144+0.270	144+0.550	397	B	122	0	-
338	C000090	233+0.740	233+0.840	1223	B	119	0	-
339	C000090	071+0.560	071+0.680	1190	B	118	0	-
340	C000090	148+0.180	148+0.260	1204	B	114	0	-
341	C000008	038+0.750	038+0.880	292	A	111	107	4%
341	C000083	004+0.660	004+0.720	1074	A	111	118	-6%
341	C000090	234+0.700	234+0.860	1228	A	111	107	4%
344	C000015	145+0.630	145+0.910	400	A	110	108	2%
345	C000090	134+0.200	134+0.420	1199	B	109	0	-
345	C000090	233+0.230	233+0.440	1222	B	109	0	-
347	C000015	244+0.780	244+0.800	476	A	104	158	-34%
348	C000090	232+0.510	232+0.590	1220	B	103	0	-
349	C000090	259+0.370	259+0.480	1251	B	102	0	-
350	C000015	206+0.740	206+0.780	419	B	101	0	-
350	C000090	231+0.380	231+0.430	1212	B	101	0	-
350	C000090	231+0.480	231+0.570	1214	B	101	0	-

Rank	Corridor	MP Start	MP End	Section No.	2004 Site Designation	Total 2016 RHRS Score	2004 RHRS Score	Change 2016 - 2004
353	C000015	222+0.320	222+0.400	438	B	100	0	-
354	C000090	235+0.610	235+0.690	1231	B	99	0	-
355	C000001	110+0.050	110+0.140	67	A	98	98	0%
356	C000090	072+0.270	072+0.320	1192	B	97	0	-
357	C000015	235+0.160	235+0.230	457	B	94	0	-
358	C000090	178+0.080	178+0.170	1209	B	90	0	-
359	C000015	250+0.800	250+0.860	489	A	82	0	-
360	C000090	315+0.670	315+0.730	1262	B	75	0	-
361	C000015	223+0.360	223+0.440	442	B	74	0	-
362	C000090	231+0.900	231+0.930	1217	B	69	0	-
363	C000090	235+0.090	235+0.120	1229	B	67	0	-

Appendix E

TASK 5 REPORT – DETERMINATION OF CRITICAL SITES

Montana Department
or Transporation

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

Task 5 Report
Determination of Critical Sites

LANDSLIDE
TECHNOLOGY
A DIVISION OF CORNFORTH CONSULTANTS

Prepared for:

Montana Department of Transportation
Helena, Montana

ROCKFALL HAZARD PROCESS ASSESSMENT

TASK 5 REPORT
DETERMINE CRITIAL SITES

May 15, 2017

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Executive Summary

This document is the deliverable for Task 5 of the Montana Department of Transportation (MDT) research project "Rockfall Hazard Rating Process Assessment" (Project No. 15-3059V). This task applied the concepts, select decision support tools, and criteria developed in prior tasks to the entire RAMP database to identify 'Critical Sites' throughout the state.

Application of criteria for 'Minimal Acceptable Conditions' identified 40 RAMP sites that did not meet any of the proposed minimum acceptable conditions. Overlaying these sites with risk calculations developed in prior tasks, where risk was measured as a function of adverse event likelihood multiplied by mobility and safety impacts, exhibited locations where Poor performing sites coincided with relatively high risk corridors. Eleven corridors spread throughout mountainous regions of the state were identified to list in a Candidate Investment File. In some instances, high risk corridors, such as I-90 west of St. Regis had sites that met most minimally acceptable conditions, but the history of long-term closures, traffic slow-downs, and relatively high traffic volumes resulted in high aggregate risk estimates.

MDT Geotechnical personnel reviewed the candidate list and selected four corridors for collection of more detailed conceptual mitigation cost estimates. The map below exhibits these corridors. In total, 74 sites were evaluated at locations along I-90, US 2, and US 191. Conceptual mitigation cost estimates generally corresponded well with programmatic cost estimates applied throughout the state, but did deviate on a site-by-site basis and where site conditions required more costly mitigation approaches due to more difficult site conditions. These cost estimates can be used for decision making by MDT as the RAMP program is implemented.

Figure 1: Location of the four corridors selected for detailed conceptual mitigation cost estimating.

1 Conceptual Design Site Selection Methods

As part of the 2004 Rockfall Hazard Rating System (RHRS) project, Landslide Technology (LT) developed conceptual mitigation designs with estimated cost data for the "Top 100" sites. These sites were defined as the 100 highest-scoring sites in the RHRS database. In the new Rockfall Asset Management Program (RAMP), MDT wanted to revisit the conceptual mitigation designs and develop conceptual mitigation costs for a new set of candidate sites. However, there was concern that picking only the highest scoring sites would not capture which sites that posed the greated risk to the highway system, or areas where mitigation dollars would be best spent. LT applied the decision support tools developed in Task 3 to better determine which sites were best suited for inclusion in a 'Candidate Investment File' the Department could use for future reference. This included filtering the dataset for the lowest performing sites and identifying specific corridor segments where high risk overlapped poor asset conditions. By identifying 'rockfall intensive corridors' and considering mitigation of site groups, an economy of scale can be utilized to more effectively reduce costs while maximizing the corresponding risk-reduction benefit.

1.1 Lowest Performing Sites

In Task 3, minimum acceptable conditions were developed to establish a RAMP Performance Classification Scheme. Each roadway segment was assigned a minimum RAMP Performance Class based on the roadway's functional classification, as shown in Table 1-1. A straightforward way to develop minimum acceptable conditions for individual sites was to determine cutoff scores in the various rating schemes. The cutoff scores vary by RAMP Performance Class (Table 1-2), so sites that are unacceptable on an Interstate route may be acceptable on a Minor Collector.

Table 1-1: Functional Classification and RAMP Performance Class

Roadway Functional Classification	**Example**	**RAMP Class (Target, Minimum Acceptable)**
Principal Arterial – Interstate	I-90, I-15	A, B
Principal Arterial – Non-Interstate	US 191 Belgrade to W. Yellowstone, US 2	B, B
Minor Arterial	MT 56 Troy to Noxon, Beartooth Pass	B, C
Major Collector	Rt 421 Joliet to Columbus, Rt 279 Helena to MT 200	B, C
Minor Collector	Stampede Pass Road Dillion to Rt 357	C, C

Table 1-2: Minimum acceptable conditions for rock slopes based on Performance Class

	Scoring Cutoffs				
RAMP Corridor Class	Condition Index	Total RHRS Score	Method 1	Method 2	Method 3 Slope Rating
A: No sites in the worst 15th percentile	< 37	> 448	> 167	> 273	> 154
B: No sites in the worst 10th percentile	< 32	> 478	> 185	> 297	> 172
C: No sites in the worst 5th percentile	< 28	> 540	> 218	> 340	> 198

Forty sites were identified in the RAMP database that did not meet any of the five rating schemes' Scoring Cutoffs, based on each RAMP Performance Class. Figure 2 shows the 40 sites along with the proposed STIP projects for 2015-2019. The sites are presented as a table in Appendix A. Note that mitigation of the site on I-15 in District 3 (D3) is already incorporated into Phase 3 of the D3 Rockfall Mitigation Project. Of the remaining 39 sites, only one is located on an Interstate Route: a rock slope east of Bozeman on I-90, along Rocky Creek. Three slopes are located on Minor Collectors (RAMP Performance Class C): three rock slopes south of Cardwell on MT 2 near Lewis and Clark Caverns State Park. The remaining 35 sites are located on RAMP Performance Class B routes spread throughout the state.

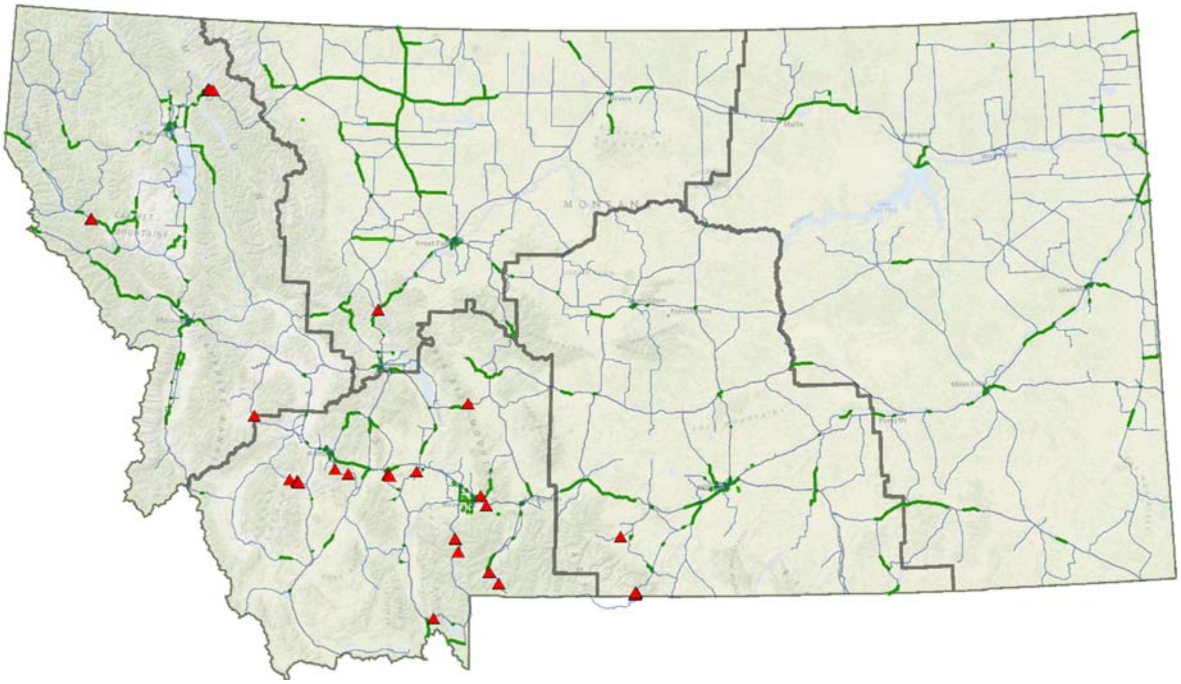

Figure 2: The 40 RAMP sites not meeting the minimum acceptable conditions are shown as red triangles. Green lines are STIP projects proposed for 2015-2019. Note that mitigation is planned for the site on I-15 in D3.

Incorporating mitigation of these poor performing sites into a larger corridor improvement project reduces mitigation costs, creating cost efficiencies for mobilization, traffic control, etc. Addressing rock slopes as part of an improvement project also results in a longer-lasting product, one that will not deteriorate more rapidly due to rockfall damage. To this end, LT also looked for overlap between planned STIP projects and the 40 sites. Sixteen of the sites are located within the extents of proposed STIP projects, as shown in Appendix A. These 16 sites, as well as any adjacent under-performing rock slopes, could be considered for incorporation into the proposed STIP project during initial design.

1.2 High-Risk Corridors

1.2.1 Revised Likelihood Analysis of MDT's Significant Rockfall Events

For the Task 5 work, LT revised the correlation between slope condition and significant event likelihood presented in the Task 3 Report. Following internal discussions and input from Paul Thompson, LT decided that correlations would be more robust if, instead of incorporating events from all sites in Montana, it focused on the districts that responded to the survey with higher-quality data. Responses from District 1 (D1) to the 2016 event survey were the most thorough. They included both specific dates and impacts, and estimates of annual events within high-activity corridors. District 2 (D2) provided estimated event frequency and impacts for some corridors, but no specific events. For the revised likelihood analysis, LT developed correlations between slope condition and event likelihood in D1 first, then extrapolated the results to assess risk at other RAMP sites across the state.

Almost no changes were made to the edits and assumptions used to process the survey dataset in the Task 3 report. The only change adjusted the translation of "possibly" or "???" answers in the Vehicle/Property Damage category into an estimated number of events. In the first correlation, it was assumed that if the respondent answered "possibly" or "???," some vehicle or property damage occurred in 50% of slope failures. Following additional internal discussions, 50% was deemed too high, since people are more likely to remember events requiring damage payouts, police response, etc. We reduced the vehicle/property damage likelihood to 25% for those sites where the respondent was unsure if a specific accident had happened or not. The revised final dataset contains events occurring between 2001 and 2015, and is included in Appendix B. The magnitude of this change in terms of dollar risk is relatively minor, since a significant proportion of the risk cost is due to mobility interruptions rather than property damage.

Following the procedure outlined in Task 3, an annualized rate for the different adverse events was calculated for each RHRS section in the survey. Condition States for each site were also calculated with the equations used in Alaska Department of Transportation and Public Facilities' GAM program. For each Condition State group – 1, 2, 3, 4, and 5 – the annual likelihood of an event somewhere in D1 was calculated by summing all the annual event likelihoods for individual sites. This annual event likelihood was divided by the total inventoried square footage in each condition state in the district to generate a likelihood per square foot based on slope condition. The total square footage is the sum of the areas of rock slopes that generated an adverse event and those that did not. Using a simple 'Odds' approach, where a comparison of slope areas producing rockfall events in a certain Condition State to the total area within that Condition State is conducted, a plot of Condition State and average annual likelihood of a service disruption can be prepared, as shown in Figure 3. A service disruption is defined as a road closure or traffic slowdown, and some rockfall events may trigger both.

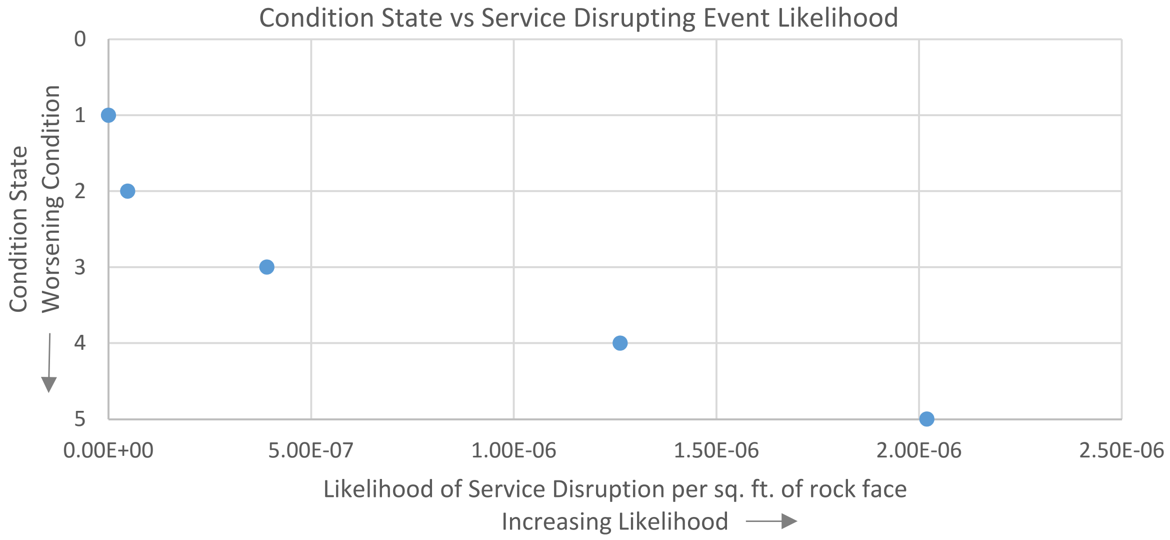

Figure 3: Average annual likelihood of service disruption per square foot of rock slope face, based on revised 2016 MDT survey responses.

Initially, lines of best fit were developed using a linear regression. However, this resulted in negative event likelihoods for Condition State 1 and 2 slopes. Instead, we opted to use the raw calculated likelihoods for Condition States 2, 3, 4, and 5. No adverse events were reported for Condition State 1 slopes, but since nearly all rock slopes are inherently unstable and even Good condition slopes may have hidden features that could produce rock onto the roadway, these Good slopes still pose a minor risk. To account for this risk, the likelihood was set to 25% of the risk posed per square foot posed by a Condition State 2 rock slope.

D1 also provided enough information on vehicle/property damage to develop a correlation between slope condition and likelihood of an event resulting in monetary damages. The data was processed using the same method applied to service disruption likelihood.

As with the service disruption analysis, slopes in poorer conditions are more likely to generate events that cause vehicle/property damage. In general, property damage was reported following 49% of events. However, since the sample size for this analysis was smaller, LT opted not to develop a free-standing condition state – property damage likelihood correlation. Instead, based on the overall event data, the likelihood of an accident per square foot of rock slope face was set as half the risk of a service disruption. The term accidents includes incidents that cause vehicle or property damage, an injury, and cause a fatality. There was not sufficient data to subdivide overall accident likelihood. The final risks per square foot based on rock slope condition state are presented in Table 1-3. These likelihoods were used throughout the Task 5 work. The other equations used to estimate safety and mobility consequence are unchanged from the Task 3 report.

Table 1-3: Condition States and final rates of Adverse Events likelihoods for MDT rock slopes, derived from 2004 rating data and 2016 adverse event data provided by MDT.

Condition State (CS)	Annualized Risk of Service Disruption per sq ft of rock face (AR_{mob})	Annualized Risk of Accident per sq ft of rock face (AR_{acc})
1	1.19E-08	5.94E-09
2	4.75E-08	2.38E-08
3	3.91E-07	1.96E-07
4	1.26E-06	6.31E-07
5	2.02E-06	1.01E-06

1.2.2 Highest Risk Corridors

Using the risk estimating tools, LT developed corridor-level risk assessments. MDT provided a GIS layer in which the state transportation network was split into one-mile segments. By using tools in ArcGIS programs, LT compiled event likelihood, monetary risk estimates, and average slope condition for each corridor segment. When incorporated into maps, this data layer can help visually communicate which corridors pose the highest risk to the State and road users, and exhibits where opportunities to group sites into a mitigation project may exist.

Because risk costs correlate with the number of roadway users affected by an event, costs on a principal arterial tend to be higher than on a minor arterial with rock slopes in the same condition. As in Section 1.1, minimum acceptable conditions may be set for different Functional Classifications. The corridor segments may be filtered to show only those segments which do not meet the Department's targets. Figure 4 shows an example of one such filtering based on event likelihood. In this example, the minimum acceptable annual likelihood of a service-disrupting rockfall was 1% for interstate routes (RAMP Performance Class A), 5% for other arterials and major collectors (RAMP Performance Class B), and 10% for all remaining routes (RAMP Performance Class C). A total of 149 road miles were flagged as potentially returning significant dividends on mitigation dollars in terms of risk reduction.

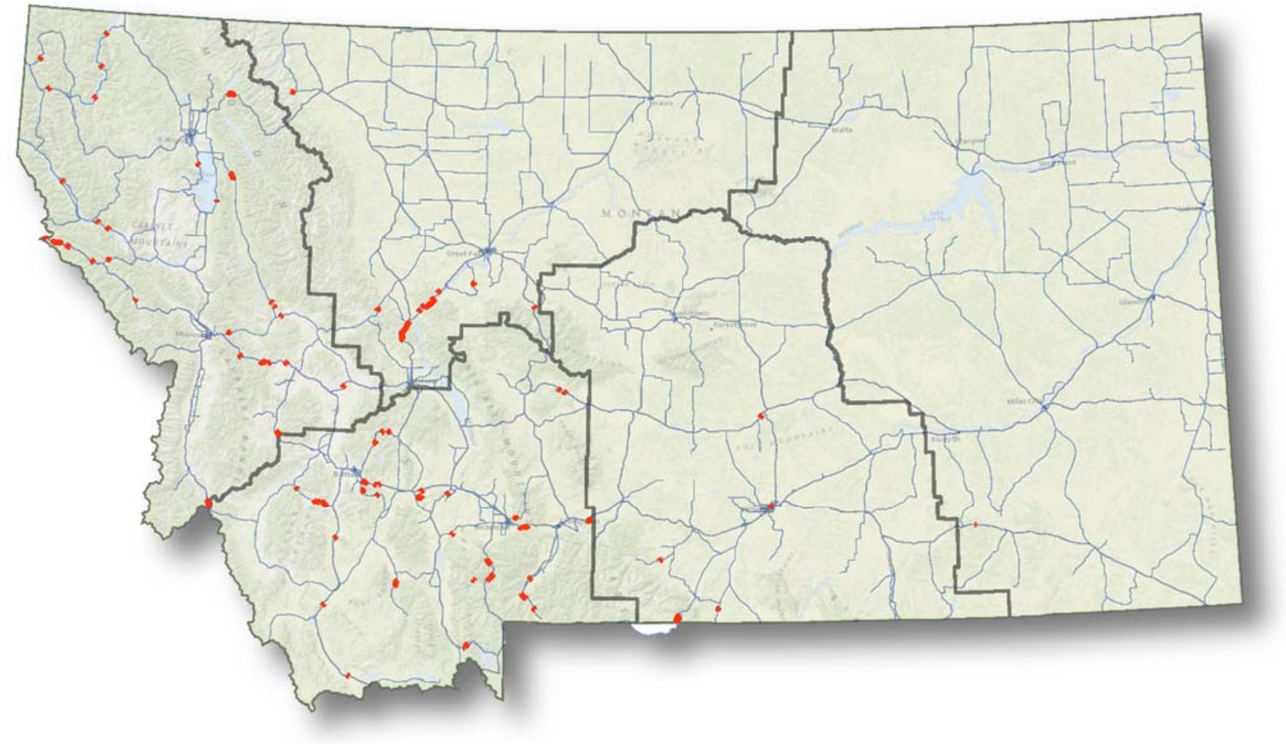

Figure 4: Map of one-mile corridor segments where annual event likelihood is greater than 1% for interstate routes, greater than 5% for non-interstate arterials and major collectors, and greater than 10% for all remaining routes.

1.2.3 Identification of Candidate Critical Sites

The sites identified as the lowest performance sites in Section 1.1 were overlaid on the highest risk corridors (Section 1.2) in an ArcGIS Online application[1]. A Candidate Investment File was generated based on review of the resulting map. This permitted MDT geotechnical staff to review candidate sites and corridors for selection as Task 5 Critical Sites. Table 1-4 contains the subject locations, representing a mix of high risk sites and poor conditions.

Table 1-4: Candidate Critical Corridors. Risk exposure includes all sites in the MP range. Those italicized are the locations selected by MDT for site-specific conceptual cost estimates.

Location	**No. sites below minimum conditions**	**Approximate 30 yr. risk exposure**
Lookout Pass, West of St. Regis, I-90, MP 0 to 31	*0*	*$17.7M*
Gallatin Canyon, Hwy 191, MP 50 to 63	*3*	*$ 7.3M*
Yankee Jim Canyon, Hwy 89 MP 6 to 7, 13 to 16	3	$ 4.6M
Urban Route adjacent to Billings Airport	0	$ 3.9M
Beartooth Pass, US 212, MP 47 to 56	10	$ 3.0M
Rocky Canyon, east of Bozeman, I-90 MP 315	*1*	*$ 2.4M*
East of West Glacier, US 2, MP 154 to 158.5	*5*	*$ 2.3M*
Hwy 43 west of Divide, MT 43, MP 71 to 75	4	$ 1.4M
Kootenai Falls, US 2, MP 20 to 21	0	$ 1.4M
Lewis & Clark Canyon, Route 249/MT 2, ~5 mi SE of Cardwell	3	$ 0.8M
MT 200 West of Weeksville, MP 64 to 65	2	$ 0.6M

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[1] http://mdt.maps.arcgis.com/apps/MapJournal/index.html?appid=6dce7d2a90834ff8873bef833b46b6d0. Membership in MDT's *Rockfall Management* AGOL Group required for access.

2 Development of Site-Specific Conceptual Mitigations

In March 2017, LT and MDT personnel met in Helena, Montana. The main goal of the meeting was to review development of the RAMP program to date, conduct an expert elicitation of rock slope deterioration, obtain additional information on maintenance costs associated with rockfall, and review work done to date with Transportation Asset Management (TAM) personnel to help ensure that the RAMP will be TAM-compatible. Most of this work will be discussed in the upcoming Task 6 and Task 7 reports. However, as part of discussions prior to the meeting, LT presented two main options for selecting conceptual mitigation sites: individual sites or individual corridors.

Selecting individual sites would allow the department to target the “worst-of-the-worst,” similar to what was done in the initial 2004 study. Alternatively, selecting individual corridors would shift the focus to areas with higher concentrations of poorly performing sites, and allow on-site personnel to develop more conceptual mitigations due to reduced driving times. Preliminary planning in the early phase of RAMP estimated that developing conceptual mitigations for 30 individual sites would require roughly the same budget as developing conceptual mitigations for three corridors. Following discussion among the team members, MDT elected to develop conceptual mitigations for sites within four high-risk corridors.

- I-90 West of St Regis; 49 individual sites reviewed
- I-90 through Rocky Canyon east of Bozeman; 2 individual sites
- Hwy 2 East Glacier; 13 individual sites
- US 191 through Gallatin Canyon; 11 individual sites

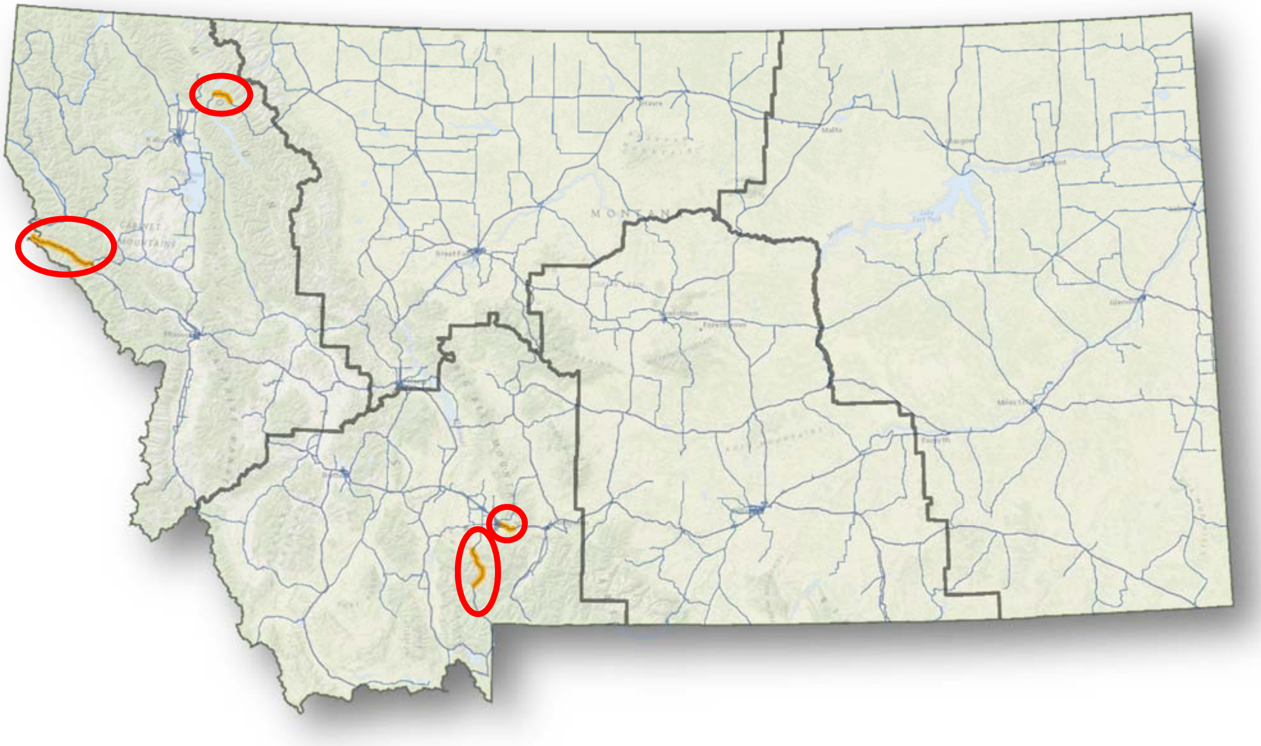

Figure 5: Critical corridors selected for 2017 conceptual mitigation work.

2.1 Approach

LT deployed senior geotechnical staff with extensive rock slope mitigation experience in Montana to each of the selected corridors. Conceptual mitigations were based on a basic site reconnaissance, generally conducted along the roadway, engineering judgement, and application of rock slope mitigation experience. Slopes were snow covered in some cases and previous photos supplemented site observations. On the I-90 corridor west of St. Regis, similar slope conditions permitted a generalized approach. A high number of sites in that corridor had rockfall risks that could be mitigated with rockfall attenuators and roadside barriers. While attenuators and barriers would be effective for the majority of rockfall hazards, some issues observed in this corridor, such as large rockslides and landslides that mobilize large boulders, may not necessarily be addressed with this approach. In all cases, more detailed site investigations are required prior to designing rockfall mitigation measures.

Quantities and unit prices were generalized to estimate order-of-magnitude costs. Unit prices were developed using our experience, a working knowledge of bid history in Montana, but do not include site-specific peculiarities that may be required once a project is selected and designed, such as: haul costs, exceptionally difficult slope access, extraordinary production limitations, or other site/project/stakeholder specific considerations. Table 2-1 contains the unit costs developed, though not all measures were utilized. This table is also included in Appendix C with the detailed site-specific conceptual mitigations.

An 'overhead' escalation factor of 105%, developed from data contained in WSDOT's USMS (Washington Department of Transportation, 2010) program in previous research (Beckstrand, Mines, Thompson, & Benko, 2016), was applied to the rockfall mitigation quantities developed in the field. This factor is another generalized approach intended to capture PS&E, traffic control, construction engineering, mobilization, and etcetera.

Table 2-1: Unit costs utilized for select mitgiation measures.

Mitigation Elements	Unit	Unit Cost
Rock Bolts	lf	$ 160.00
Rock Dowels	lf	$ 113.33
Draped Gabion Mesh	sf	$ 5.33
Draped Tecco Mesh	sf	$ 8.67
Rockfall Attenuator	sf	$ 20.00
General Scaling	hr	$ 175.00
Heavy Scaling	hr	$ 175.00
Ditch Improvement - reshaping	lf	$ 250.00
Ditch Improvement - lower grade	lf	$ 1,000.00
Ditch Improvement - raise grade	lf	$ 450.00
Gabion Baskets – 6ft tall (Ditch Improvement	lf	$ 450.00
Concrete Barrier	lf	$ 166.67
Concrete Barrier w/ fence extension	lf	$ 283.33
Fence extension on existing barrier	lf	$ 150.00
Shotcrete	sf	$ 20.00
Rock Excavation	cy	$ 23.33
Trim Blast	cy	$ 1,080.00
Presplit/Controlled Blasting	lf	$ 15.00
FRB (1000 kJ)	lf	$ 733.33
Low Deflection (no upslope tiebacks) FRB (1000 kJ)	lf	$ 900.00
Other Roadside Barrier (MSE)	sf	$ 85.00
Pinned Tecco	sf	$ 20.00
Cable Lashings	ea	$ 4,000.00
Lashed Cable Netting	ea	$ 7,500.00

2.2 Summary of Conceptual Mitigation Results

In all, conceptual mitigation designs were developed for 74 sites. Many sites, particularly those rated Condition State 3 or worse, received two conceptual mitigations: one to improve the site to Good (Condition State 1), and another to improve the site by a single condition state (i.e. Condition State 4 to Condition State 3). The latter option is often more feasible, given limited financial resources, and can still result in significant risk reductions to roadway users.

Site-specific mitigation costs within each corridor are summarized in Table 2-2 through Table 2-5 below. The conceptual designs developed in the field for each individual site are included in Appendix C. The average cost per square-foot (sf) of rock slope to improve sites by one Condition State was $8.33/sf. This compares well with the average cost/sf calculated from the 2004 conceptual mitigation work, which was $7.30/sf. Both of these costs include an estimated overhead rate of 105%. The average cost/sf to improve a slope by one Condition State is about 15% higher for the 2017 sites. A possible reason for the difference is that the 2017 work focused on four specific corridors, instead of looking at sites spread throughout the state. Specific geology in those corridors may require a mitigation method that is particularly expensive to construct. For example, conceptual mitigation work for many sites within the US Highway 2 corridor included blasting to improve ditch effectiveness and reduce rockfall hazards. A larger conceptual mitigation study of more corridors would likely result in different average costs per square foot.

2.3 Limitations

The conceptual mitigation cost estimates are largely an experience-based initial approach on mitigation measures to reduce the frequency and/or the ability of the roadside ditch to contain rockfall debris. This work was accomplished without the benefit of a full slope reconnaissance, rock structure measurements, stability analysis, or rockfall modelling. Additionally, the timing of the visits in early spring resulted in snow cover on a number of the slopes, especially near Lookout Pass and near West Glacier. This supplemental task was to approximate the requirements to either improve the slope to a Good condition (Condition State 1) or to implement mitigation for an improvement by one Condition State. The latter typically chose between road side improvements to increase ditch effectiveness or improvements on the slope itself (generally via scaling) to reduce rockfall frequency and/or improve existing ditch effectiveness. Improvements to a Good condition slope generally consisted of installation of a concrete barrier, and a note to maintain the existing ditch. Improvements to Fair and Poor slopes included a wide variety of mitigation items, such as excavating a new slope with modern construction techniques and slope/ditch configurations, application of rock bolts or dowels, excavation to a more stable configuration, installation of draped mesh, or other techniques to stabilize the rock cut.

For the I-90 corridor near Lookout Pass, the large number of sites with similar conditions permitted a rapid approximation of mitigation measures applicable to the corridor. However, more detailed field work may be required in this segment to identify conditions that may not have been observed due to the rapid assessment. Despite these limitations, the accomplished work of conceptual field inspection of 74 sites improved upon the original scope, which included office review of 30 sites or 3 corridor segments.

Table 2-2: Conceptual mitigation costs for Fair and Poor RAMP sites on Hwy 2 east of West Glacier, between MP 154 and 159.

RAMP Site	Current Condition State	Estimated 30 yr Risk	Conceptual Cost to Improve Site to CS 1	Conceptual Cost to Improve Site One CS	Cost/Ft^2 to Improve to CS 1	Cost/Ft^2 to Improve by 1 Condition State
75	3	$ 35,447	$ 941,599	$ 274,468	$ 42	$ 12
76	4	$ 159,411	$ 1,198,259	$ 521,252	$ 38	$ 17
77	4	$ 276,629	$ 2,948,754	$ 898,050	$ 54	$ 17
79	4	$ 127,836	$ 982,975	$ 530,438	$ 39	$ 21
80	4	$ 123,959	$ 816,242	$ 445,192	$ 34	$ 18
83	3	$ 42,550	$ 637,106	$ 264,689	$ 24	$ 10
84	3	$ 29,458	$ 405,326	$ 227,659	$ 22	$ 12
85	4	$ 243,347	$ 1,962,397	$ 1,628,042	$ 41	$ 34
87	3	$ 140,424	$ 1,497,867	$ 1,020,729	$ 17	$ 11
88	4	$ 132,202	$ 1,002,963	$ 316,213	$ 39	$ 12
90	4	$ 305,549	$ 2,248,925	$ 1,152,783	$ 37	$ 19
92	3	$ 23,372	$ 630,922	$ 283,577	$ 43	$ 19
94	4	$ 514,505	$ 3,421,518	$ 1,462,316	$ 34	$ 14
TOTAL		**$ 2,154,688**	**$ 18,694,852**	**$ 9,025,408**	**Avg $35.58**	**Avg $16.71**

Table 2-3: Conceptual mitigation costs for Fair and Poor RAMP sites on Hwy 191, between MP 50 to 63 in Gallatin Canyon.

RAMP Site	Current Condition State	Estimated 30 yr Risk	Conceptual Cost to Improve Site to CS 1	Conceptual Cost to Improve Site One CS	Cost/Ft^2 to Improve to CS 1	Cost/Ft^2 to Improve by 1 Condition State
933	4	$ 452,981	$ 963,500	$ 276,750	$ 16	$ 5
934	4	$ 244,267	$ 2,110,988	$ 89,688	$ 65	$ 3
935	3	$ 298,418	$ 811,800	$ 213,200	$ 6	$ 2
936	4	$ 404,708	$ 1,640,000	$ 89,688	$ 31	$ 2
937	4	$ 389,556	$ 2,721,375	$ 740,563	$ 53	$ 14
945	4	$ 236,640	$ 725,700	$ 543,250	$ 23	$ 17
946	5	$ 2,749,250	$ 3,284,100	$ 430,500	$ 14	$ 2
947	4	$ 351,650	$ 1,537,500	$ 143,500	$ 33	$ 3
948	4	$ 786,817	$ 1,141,338	$ 215,250	$ 11	$ 2
949	4	$ 1,102,992	$ 1,346,850	$ 763,113	$ 9	$ 5
950	3	$ 147,865	$ 1,560,563	$ 914,813	$ 25	$ 14
933	4	$ 7,165,143	$ 17,843,713	$ 4,420,313	$ 16	$ 5
934	4	$ 452,981	$ 963,500	$ 276,750	$ 65	$ 3
TOTAL		**$ 244,267**	**$ 2,110,988**	**$ 89,688**	**Avg $25.99**	**Avg 6.27**

Table 2-4: Conceptual mitigation costs for Fair and Poor RAMP sites on I-90, between MP 315 and 316 in Rocky Canyon, east of Bozeman.

RAMP Site	Current Condition State	Estimated 30 yr Risk	Conceptual Cost to Improve Site to CS 1	Conceptual Cost to Improve Site One CS	Cost/Ft^2 to Improve to CS 1	Cost/Ft^2 to Improve by 1 Condition State
1260	3	$ 452,981	$ 1,329,425	$ 526,167	$ 21	$ 8
1261	4	$ 244,267	$ 5,989,588	$ 1,644,271	$ 71	$ 19
TOTAL		**$ 697,247**	**$ 7,319,013**	**$ 2,170,438**	**Avg $46.09**	**Avg $13.95**

Table 2-5: Conceptual mitigation costs for Good, Fair, and Poor RAMP sites on I-90 west of St Regis, between MP 0 and 31.

RAMP Site	Current Condition State	Estimated 30 yr Risk	Conceptual Cost to Improve Site to CS 1	Conceptual Cost to Improve Site One CS	Cost/Ft^2 to Improve to CS 1	Cost/Ft^2 to Improve by 1 Condition State
1136	1	$ 18,998	$ 452,331	$ 230,625	$ 9	$ 5
1137	2	$ 64,613	$ 483,117	$ 187,917	$ 11	$ 4
1138	3	$ 714,855	$ 657,225	$ 406,583	$ 11	$ 7
1139	1	$ 32,784	$ 194,750	$ 194,750	$ 2	$ 2
1140	2	$ 41,890	$ 185,636	$ 185,636	$ 7	$ 7
1141	2	$ 48,615	$ 361,099	$ 361,099	$ 11	$ 11
1142	2	$ 56,652	$ 437,333	$ 437,333	$ 12	$ 12
1143	2	$ 7,754	$ 75,167	$ 75,167	$ 15	$ 15
1144	2	$ 64,906	$ 77,302	$ 77,302	$ 2	$ 2
1145	1	$ 5,994	$ -	$ -	$ -	$ -
1146	3	$ 811,176	$ 356,623	$ 239,167	$ 5	$ 4
1147	2	$ 83,331	$ 97,939	$ 97,939	$ 2	$ 2
1148	3	$ 558,398	$ 418,033	$ 336,883	$ 9	$ 7
1149	1	$ 21,024	$ -	$ -	$ -	$ -
1150	3	$ 1,036,187	$ 513,533	$ 365,925	$ 6	$ 4
1151	2	$ 51,396	$ 170,833	$ 170,833	$ 5	$ 5
1152	3	$ 141,704	$ 133,974	$ 92,933	$ 12	$ 8
1153	3	$ 910,852	$ 1,154,833	$ 377,542	$ 16	$ 5
1154	2	$ 46,364	$ 109,333	$ 109,333	$ 4	$ 4
1155	1	$ 40,602	$ -	$ -	$ -	$ -
1156	2	$ 81,471	$ 170,833	$ 170,833	$ 3	$ 3
1157	3	$ 2,981,812	$ 2,324,008	$ 492,000	$ 10	$ 2
1158	3	$ 1,527,239	$ 1,771,625	$ 435,625	$ 15	$ 4
1159	3	$ 439,734	$ 585,467	$ 174,250	$ 17	$ 5
1160	3	$ 335,671	$ 576,723	$ 130,688	$ 22	$ 5
1161	3	$ 594,895	$ 1,235,703	$ 185,867	$ 27	$ 4
1162	2	$ 28,548	$ 389,612	$ 389,612	$ 22	$ 22
1163	3	$ 432,263	$ 904,837	$ 275,896	$ 27	$ 8
1164	1	$ 25,127	$ 512,500	$ 512,500	$ 8	$ 8
1165	3	$ 337,983	$ 342,884	$ 290,417	$ 13	$ 11
1166	2	$ 103,876	$ 406,727	$ 406,727	$ 6	$ 6
1167	2	$ 57,345	$ 282,712	$ 282,712	$ 8	$ 8
1168	1	$ 18,512	$ -	$ -	$ -	$ -
1169	2	$ 95,002	$ 1,582,613	$ 1,582,613	$ 27	$ 27
1170	2	$ 82,994	$ 328,944	$ 328,944	$ 6	$ 6
1171	2	$ 92,048	$ 547,900	$ 547,900	$ 10	$ 10
1172	2	$ 127,520	$ -	$ -	$ -	$ -
1173	1	$ 12,792	$ 170,833	$ 170,833	$ 5	$ 5
1174	2	$ 61,052	$ 119,583	$ 119,583	$ 3	$ 3
1175	2	$ 98,190	$ -	$ -	$ -	$ -
1176	2	$ 87,412	$ 440,750	$ 440,750	$ 8	$ 8
1177	1	$ 29,039	$ 1,722,000	$ 369,000	$ 23	$ 5
1178	2	$ 264,437	$ 755,083	$ 755,083	$ 4	$ 4
1179	2	$ 105,902	$ 358,750	$ 358,750	$ 5	$ 5
1180	3	$ 1,762,849	$ 1,865,500	$ 1,865,500	$ 14	$ 14
1181	3	$ 2,781,841	$ 2,132,000	$ 697,000	$ 10	$ 3
1182	2	$ 57,107	$ 888,333	$ 290,417	$ 24	$ 8
1183	2	$ 282,407	$ 2,309,667	$ 755,083	$ 13	$ 4
1184	1	$ 30,500	$ 1,385,732	$ 1,385,732	$ 18	$ 18
TOTAL		**$17,693,664**	**$ 29,990,380**	**$ 17,361,281**	**Average $11.31**	**Average $7.22**

3 Recommendations for Task 6 Applications

Task 6 is focused on determining the benefit/cost approaches utilizing TAM-compatible methods. These methods are anticipated to primary focus on deterioration, life cycle cost analysis, and incorporation of maintenance and improvement costs on a network level. Some changes to the risk costs should be expected as the approach is finalized incorporating all the understood fiscal factors.

The site-specific conceptual cost estimates obtained in Task 5 can be compared using the approaches finalized in Task 6 and decision support tools outlined in Task 3.

4 References

Beckstrand, D., Mines, A., Thompson, P., & Benko, B. (2016). Development of Mitigation Cost Estimates for Unstable Soil and Rock Slopes Based on Slope Condition. *The 2016 Annual Meeting Compendium of Papers.* Transportation Research Board.

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Washington Department of Transportation. (2010). *WSDOT's Unstable Slope Management Program.* Retrieved July 1, 2016, from http://www.wsdot.wa.gov/NR/rdonlyres/7D456546-705F-4591-AC5B-7E0D87D15543/78408/UnstableSlopeFinaFolioWEBSMALL.pdf

Appendix A
Filtered RAMP Dataset – Lowest Performing Sites

RAMP Section	Corridor	Corridor Class	Milepoint Start	Total RHRS Score	Method 1 Score	Method 2 Score	Method 3 Slope Rating	Condition Index	STIP Adjacent?
76	C000001	B	154+0.860	515	239	371	218	25	N
77	C000001	B	155+0.500	610	253	390	231	25	N
79	C000001	B	155+0.700	504	222	360	200	30	N
85	C000001	B	156+0.600	616	236	374	215	28	N
94	C000001	B	158+0.470	655	243	395	221	28	N
189	C000006	B	064+0.400	662	232	403	218	30	N
190	C000006	B	064+0.520	609	243	392	229	25	N
304	C000011	B	006+0.570	548	261	363	243	26	N
309	C000011	B	013+0.840	585	241	376	223	26	Y
310	C000011	B	013+0.960	676	261	404	243	25	Y
323	C000013	B	090+0.770	542	203	333	193	30	N
363	C000014	B	020+0.810	510	228	376	222	25	Y
448	C000015	A	226+0.980	614	257	404	221	28	Y
506	C000019	B	027+0.990	681	266	425	261	16	N
588	C000028	B	047+0.630	645	228	383	225	26	Y
600	C000028	B	049+0.720	686	244	410	239	26	Y
601	C000028	B	050+0.390	597	221	363	217	28	Y
602	C000028	B	050+0.500	607	219	363	215	27	Y
605	C000028	B	050+1.080	647	250	396	245	16	Y
614	C000028	B	050+1.940	614	230	369	225	26	Y
615	C000028	B	050+1.960	551	233	331	228	19	Y
616	C000028	B	052+0.000	551	228	337	224	25	Y
617	C000028	B	052+0.030	668	254	404	249	17	Y
627	C000028	B	053+0.450	487	239	368	234	23	Y
674	C000029	B	068+0.490	594	266	405	260	13	N
711	C000029	B	076+0.850	486	206	315	201	28	Y
904	C000046	B	068+0.060	634	273	416	268	3	N
913	C000046	B	072+0.360	525	251	385	247	17	N
914	C000046	B	072+0.900	491	236	366	232	23	N
916	C000046	B	073+0.600	572	217	350	213	28	N
937	C000050	B	052+0.870	536	262	358	223	21	N
946	C000050	B	060+0.730	583	271	389	232	17	N
947	C000050	B	061+0.180	572	282	378	242	25	N
1114	C000086	B	004+0.370	566	240	368	224	27	Y
1132	C000087	B	004+0.020	657	266	405	260	17	N
1261	C000090	A	315+0.260	664	320	450	220	27	N
1436	C000419	B	007+0.160	508	206	299	199	28	N
2001	C022249	C	003+0.070	636	278	453	275	3	N
2002	C022249	C	003+0.390	649	284	425	282	0	N
2006	C022249	C	005+0.080	571	268	377	265	0	N

Appendix B
Final Dataset for Rockfall Survey – District 1

RHRS Section No.	Section	Number of Events 2001-2015	Road Closure?	No. Closures 2001-2015	Road Slowdown?	No. Slowdowns 2001-2015	Vehicle/Property Damage?	No. Damages 2001-2015	Injury Accident?	No. Injuries 2001-2015
54	1213	3.5	No	0	Yes	3.5	Possibly	1.75	no	0
72	1203	0.5	No	0	Yes	0.5	no	0	no	0
75	1203	0.5	No	0	Yes	0.5	no	0	no	0
76	1203	0.5	No	0	Yes	0.5	no	0	no	0
77	1203	0.5	No	0	Yes	0.5	no	0	no	0
78	1203	0.5	No	0	Yes	0.5	no	0	no	0
79	1203	0.5	No	0	Yes	0.5	no	0	no	0
80	1203	0.5	No	0	Yes	0.5	no	0	no	0
81	1203	0.5	No	0	Yes	0.5	no	0	no	0
83	1203	0.5	No	0	Yes	0.5	no	0	no	0
84	1203	0.5	No	0	Yes	0.5	no	0	no	0
85	1203	0.5	No	0	Yes	0.5	no	0	no	0
87	1203	0.5	No	0	Yes	0.5	no	0	no	0
88	1203	0.5	No	0	Yes	0.5	no	0	no	0
90	1203	0.5	No	0	Yes	0.5	no	0	no	0
92	1203	0.5	No	0	Yes	0.5	no	0	no	0
94	1203	0.5	No	0	Yes	0.5	no	0	no	0
95	1203	0.5	No	0	Yes	0.5	no	0	no	0
96	1203	0.5	No	0	Yes	0.5	no	0	no	0
97	1203	0.5	No	0	Yes	0.5	no	0	no	0
109	1204	2	Yes	2	Yes	2	no	0	no	0
179	1118	4.6	No	0	Yes	4.6	Possibly	2.3	no	0
181	1118	4.6	No	0	Yes	4.6	Possibly	2.3	no	0
182	1118	4.6	No	0	Yes	4.6	Possibly	2.3	no	0
189	1118	3.5	No	0	Yes	3.5	Possibly	1.75	no	0
190	1118	3.5	No	0	Yes	3.5	Possibly	1.75	no	0
191	1118	3.5	No	0	Yes	3.5	Possibly	1.75	no	0
500	1106	3	Yes	3	No	0	Yes	3	no	0
500	1106	1	Yes	1	Yes	1	no	0	no	0
501	1106	3	Yes	3	No	0	Yes	3	no	0
502	1106	3	Yes	3	No	0	Yes	3	no	0
503	1106	3	Yes	3	No	0	Yes	3	no	0

RHRS Section No.	Section	Number of Events 2001-2015	Road Closure?	No. Closures 2001-2015	Road Slowdown?	No. Slowdowns 2001-2015	Vehicle/Property Damage?	No. Damages 2001-2015	Injury Accident?	No. Injuries 2001-2015
504	1106	3	Yes	3	No	0	Yes	3	no	0
505	1106	4	Yes	4	No	0	Yes	4	no	0
506	1106	4	Yes	4	No	0	Yes	4	no	0
532	1101	4.2	Yes	4.2	yes	4.2	no	0	no	0
837	1117	1	Yes	1	No	0	yes	1	yes	1
1076	1102	2.3	Yes	2.3	No	0	yes	2.3	no	0
1078	1102	2.3	Yes	2.3	No	0	yes	2.3	no	0
1079	1102	2.3	Yes	2.3	No	0	yes	2.3	no	0
1081	1102	2.3	Yes	2.3	No	0	yes	2.3	no	0
1086	1102	2.3	Yes	2.3	No	0	yes	2.3	no	0
1087	1102	2.3	Yes	2.3	No	0	yes	2.3	no	0
1148	1114	1	Yes	1	Yes	1	No	0	no	0
1168	1114	1	Yes	1	Yes	1	Possibly	0.5	no	0
1172	1114	1	Yes	1		0	Yes	1	no	0
1304	1107	1	Yes	1	Yes	1	no	0	no	0
1316	1104	1	Yes	1	No	0	Yes	1	no	0

Appendix C
Conceptual Mitigation Designs for Selected RAMP Sites

Mitigation Elements	**Unit**	**Unit Cost**
Rock Bolts	lf	$ 160.00
Rock Dowels	lf	$ 113.33
Draped Gabion Mesh	sf	$ 5.33
Draped Tecco Mesh	sf	$ 8.67
Rockfall Attenuator	sf	$ 20.00
General Scaling	hr	$ 175.00
Heavy Scaling	hr	$ 175.00
Bench Cleaning	day	$ 2,000.00
Ditch Improvement - reshaping	lf	$ 250.00
Ditch Improvement - lower grade	lf	$ 1,000.00
Ditch Improvement - raise grade	lf	$ 450.00
Gabion Baskets - 6ft tall (Ditch Improvement)	lf	$ 450.00
Concrete Barrier	lf	$ 166.67
Concrete Barrier w/ Fence Extension	lf	$ 283.33
Shotecrete	sf	$ 20.00
Rock Excavation	cy	$ 23.33
Trim Blast	cy	$ 1,080.00
Presplit/Controlled Blasting	lf	$ 15.00
FRB (1000 kJ)	lf	$ 733.33
Low Deflection (no upslope tiebacks) FRB (1000kJ)	lf	$ 900.00
Other Roadside Barrier (MSE)	sf	$ 85.00
Pinned Tecco	sf	$ 20.00
Cable Lashings	ea	$ 4,000.00
Lashed Cable Netting	ea	$ 7,500.00

East of West Glacier Corridor
US Highway 2; MP 154 to 158.5

Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells	
Ver. 1.00	
Assessed By	BAG
Assessment Date	3/14/2017

Site Information

Section Number 75

Corridor	C000001	**Side**	Right	**Milepost Start**	154+0.660
				Milepost End	154+0.780

Critical Condition Information

Ditch Effectiveness	27	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 328,302
Rockfall Activity Score	50	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 328,302
Total RHRS Score	248	**30 yr Risk Cost**	$ 35,447	**Programmatic Cost Est Imp Two CS**	$ 164,151

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Cut the slope to a 0.25H:1V to widen the ditch to 20-25 ft on a 4H:1V. Install rock bolts in key blocks.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 / 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Rock Excavation	$ 23.33	cy	11,600	$ 270,667
	Presplit/Controlled Blasting	$ 15.00	lf	8,310	$ 124,650
	Rock Bolts	$ 160.00	lf	400	$ 64,000
				Subtotal	$ 459,317
				Total w/ 105% OH	**$ 941,599**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Conduct general scaling across entire slope with targeted heavy scaling. Install draped tecco (high tensile strength) mesh on upper 30 feet of the slope.

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	27	**Improved CI & CS**	63 / 2

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General Scaling	$ 175.00	hr	110	$ 19,250
	Heavy Scaling	$ 175.00	hr	90	$ 15,750
	Draped Tecco Mesh	$ 8.67	sf	11,410	$ 98,887
				Subtotal	$ 133,887
				Total w/ 105% OH	**$ 274,468**

Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells	**Assessed By**	BAG
Ver. 1.00	**Assessment Date**	3/14/2017

Site Information

Section Number 76

Corridor	C000001	**Side**	Left	**Milepost Start**	154+0.860
				Milepost End	155+0.000

Critical Condition Information

Ditch Effectiveness	81	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 686,068
Rockfall Activity Score	81	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 457,379
Total RHRS Score	515	**30 yr Risk Cost**	$ 159,411	**Programmatic Cost Est Imp Two CS**	$ 228,689

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Cut the slope on a 0.5H:1V to widen the ditch to 25 ft on a 4H:1V. Embankments are on both the westbound and eastbound approaches to the slope. Railroad is approximatley 980 ft north of slope. Install rock bolts in key blocks.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	15	**Improved CI & CS**	82
					1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Rock Excavation	$ 23.33	cy	16,070	$ 374,967
	Presplit/Controlled Blasting	$ 15.00	lf	11,570	$ 173,550
	Rock Bolts	$ 160.00	lf	225	$ 36,000
				Subtotal	$ 584,517
				Total w/ 105% OH	**$ 1,198,259**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Conduct general scaling across entire slope with targeted heavy scaling. Install draped tecco (high tensile strength) mesh on the upper 55 ft of slope.

Judgement OK

Improved Ditch Eff. Score	27	**Improved RF Activity Score**	27	**Improved CI & CS**	50
					3

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General Scaling	$ 175.00	hr	145	$ 25,303
	Heavy Scaling	$ 175.00	hr	100	$ 17,500
	Draped Tecco Mesh	$ 8.67	sf	24,400	$ 211,467
				Subtotal	$ 254,269
				Total w/ 105% OH	**$ 521,252**

Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells		**Assessed By**	BAG
Ver. 1.00		**Assessment Date**	3/14/2017

Site Information

Section Number 77

Corridor	C000001	**Side**	Right	**Milepost Start**	155+0.500
				Milepost End	155+0.620

Critical Condition Information

Ditch Effectiveness	81	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 1,190,547
Rockfall Activity Score	81	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 793,698
Total RHRS Score	610	**30 yr Risk Cost**	$ 276,629	**Programmatic Cost Est Imp Two CS**	$ 396,849

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Cut the slope on a 0.5H:1V to widen the ditch to 25 ft on a 4H:1V. Steep embankments are on both the westbound and eastbound approaches to the slope. Railroad is approximatley 475 ft north of slope. Overhead powerlines at the west end of the site cross over and go north of Section #78 through this section. Install rock bolts in key blocks. Drape tecco (high tensile strength) mesh on the upper 60 ft of the slope.
*Consider daylighting the left slope (Section #78) and shift the alignment.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88	1

Mitigation Elements
Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Rock Excavation	$ 23.33	cy	37,180	$ 867,533
Presplit/Controlled Blasting	$ 15.00	lf	20,080	$ 301,200
Rock Bolts	$ 160.00	lf	450	$ 72,000
Draped Tecco Mesh	$ 8.67	sf	22,810	$ 197,683

Subtotal $ 1,438,417
Total w/ 105% OH $ 2,948,754

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Conduct general scaling on the entire slope. Install rock bolts in key blocks. Drape tecco mesh on the upper 90 ft of the slope.

Judgement OK

Improved Ditch Eff. Score	27	**Improved RF Activity Score**	27	**Improved CI & CS**	50	3

Mitigation Elements
Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	260	$ 45,500
Rock Bolts	$ 160.00	lf	600	$ 96,000
Draped Tecco Mesh	$ 8.67	sf	34,220	$ 296,573

Subtotal $ 438,073
Total w/ 105% OH $ 898,050

Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells		**Assessed By**	BAG
Ver. 1.00		**Assessment Date**	3/14/2017

Site Information **Section Number** 79

Corridor	C000001	**Side**	Right	**Milepost Start**	155+0.700
				Milepost End	155+0.800

Critical Condition Information

Ditch Effectiveness	50	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 550,177
Rockfall Activity Score	81	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 366,785
Total RHRS Score	504	**30 yr Risk Cost**	$ 127,836	**Programmatic Cost Est Imp Two CS**	$ 183,392

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Conduct general scaling on the entire slope. Install rock bolts in rock blocks formed by adversely dipping and conjugate discontinuities. Place concrete barrier mounted fence along the edge of pavement (snow removal concern).

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	5	**Improved CI & CS**	82	1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	400	$ 70,000
Rock Bolts	$ 160.00	lf	1,550	$ 248,000
Concrete w/ Fence	$ 283.33	lf	570	$ 161,500
			Subtotal	$ 479,500
			Total w/ 105% OH	**$ 982,975**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Conduct general scaling on the entire slope. Install rock bolts in the upper slope blocks formed by adversely dipping and conjugate discontinuities. Place concrete barrier rail along the edge of pavement (snow removal concern).

Judgement OK

Improved Ditch Eff. Score	18	**Improved RF Activity Score**	50	**Improved CI & CS**	48	3

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	250	$ 43,750
Rock Bolts	$ 160.00	lf	750	$ 120,000
Concrete Barrier	$ 166.67	lf	570	$ 95,000
			Subtotal	$ 258,750
			Total w/ 105% OH	**$ 530,438**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 80

Corridor	C000001	**Side**	Right	**Milepost Start**	155+0.810
				Milepost End	155+0.880

Critical Condition Information

Ditch Effectiveness	50	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 533,491
Rockfall Activity Score	81	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 355,661
Total RHRS Score	470	**30 yr Risk Cost**	$ 123,959	**Programmatic Cost Est Imp Two CS**	$ 177,830

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Conduct general scaling on the entire slope. Install rock bolts in rock blocks formed by adversely dipping and conjugate discontinuities. Place concrete barrier mounted fence along the edge of pavement (snow removal concern).

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	5	**Improved CI & CS**	82 | 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	240	$ 42,000
Rock Bolts	$ 160.00	lf	1,500	$ 240,000
Concrete w/ Fence	$ 283.33	lf	410	$ 116,167
			Subtotal	$ 398,167
			Total w/ 105% OH	**$ 816,242**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Conduct general scaling on the entire slope. Install rock bolts in the upper slope blocks formed by adversely dipping and conjugate discontinuities. Place concrete barrier rail along the edge of pavement (snow removal concern).

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	50	**Improved CI & CS**	55 | 3

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	120	$ 21,000
Rock Bolts	$ 160.00	lf	500	$ 80,000
Concrete w/ Fence	$ 283.33	lf	410	$ 116,167
			Subtotal	$ 217,167
			Total w/ 105% OH	**$ 445,192**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 83

Corridor	C000001	**Side**	Right	**Milepost Start**	156+0.260
				Milepost End	156+0.390

Critical Condition Information

Ditch Effectiveness	27	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 394,093
Rockfall Activity Score	27	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 394,093
Total RHRS Score	388	**30 yr Risk Cost**	$ 42,550	**Programmatic Cost Est Imp Two CS**	$ 197,047

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Conduct general scaling on the entire slope. Install draped gabion (triple twist) mesh on the upper 50 feet of the slope. Install rock bolts in large blocks formed by adversely dipping and conjugate discontinuities. Place concrete barrier rails along the edge of pavement (snow removal concern).

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	3	**Improved CI & CS**	88 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	110	$ 19,250
Draped Gabion Mesh	$ 5.33	sf	20,600	$ 109,867
Rock Bolts	$ 160.00	lf	375	$ 60,000
Concrete Barrier	$ 166.67	lf	730	$ 121,667
			Subtotal	$ 310,783
			Total w/ 105% OH	**$ 637,106**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Conduct general scaling across entire slope. Install gabion (triple twist) mesh on th upper 50 feet of the slope.

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	9	**Improved CI & CS**	75 / 2

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	110	$ 19,250
Draped Gabion Mesh	$ 5.33	sf	20,600	$ 109,867
			Subtotal	$ 129,117
			Total w/ 105% OH	**$ 264,689**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 84

Corridor	C000001	**Side**	Right	**Milepost Start**	156+0.430
				Milepost End	156+0.520

Critical Condition Information

Ditch Effectiveness	15	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 272,834
Rockfall Activity Score	81	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 272,834
Total RHRS Score	337	**30 yr Risk Cost**	$ 29,458	**Programmatic Cost Est Imp Two CS**	$ 136,417

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Conduct general scaling on the entire slope. Install draped gabion (triple twist) mesh on the upper 50 ft of the slope. Install concrete barrier rail along the edge of pavement (snow removal concern).

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	16	**Improved CI & CS**	81 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General Scaling	$ 175.00	hr	200	$ 35,000
	Draped Gabion Mesh	$ 5.33	sf	14,260	$ 76,053
	Concrete Barrier	$ 166.67	lf	520	$ 86,667

Subtotal	$ 197,720
Total w/ 105% OH	**$ 405,326**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Conduct general scaling on the entire slope. Install draped gabion (triple twist) mesh on the upper 50 feet of slope.

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	16	**Improved CI & CS**	68 | 2

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General Scaling	$ 175.00	hr	200	$ 35,000
	Draped Gabion Mesh	$ 5.33	sf	14,260	$ 76,053

Subtotal	$ 111,053
Total w/ 105% OH	**$ 227,659**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 85

Corridor	C000001	**Side**	Right	**Milepost Start**	156+0.600
				Milepost End	156+0.730

Critical Condition Information

Ditch Effectiveness	60	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 1,047,312
Rockfall Activity Score	81	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 698,208
Total RHRS Score	616	**30 yr Risk Cost**	$ 243,347	**Programmatic Cost Est Imp Two CS**	$ 349,104

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Cut the slope on a 0.5H:1V to widen the ditch to 25 ft on a 4H:1V. Steep embankments are on north side of both the westbound and eastbound approaches. Railroad is in a tunnel under the site. Overhead powerlines have a pole at both the west and east ends of the slope. Install rock bolts in key blocks.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	16	**Improved CI & CS**	81 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Rock Excavation	$ 23.33	cy	24,530	$ 572,367
Presplit/Controlled Blasting	$ 15.00	lf	17,660	$ 264,900
Rock Bolts	$ 160.00	lf	750	$ 120,000
			Subtotal	$ 957,267
			Total w/ 105% OH	**$ 1,962,397**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Conduct general scaling on the entire slope. Trim blast launch features in the lower 30 feet of the slope adjacent to ditch and roadway. Install rock bolts in key blocks. Place concrete barrier rail along the edge of pavement (snow removal concern).

Judgement OK

Improved Ditch Eff. Score	27	**Improved RF Activity Score**	60	**Improved CI & CS**	41 / 3

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	300	$ 52,500
Trim Blast	$ 1,080.00	cy	463	$ 500,000
Rock Bolts	$ 160.00	lf	750	$ 120,000
Concrete Barrier	$ 166.67	lf	730	$ 121,667
			Subtotal	$ 794,167
			Total w/ 105% OH	**$ 1,628,042**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 87

Corridor	C000001	**Side**	Right	**Milepost Start**	156+0.970
				Milepost End	157+0.180

Critical Condition Information

Ditch Effectiveness	15	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 1,300,582
Rockfall Activity Score	27	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 1,300,582
Total RHRS Score	475	**30 yr Risk Cost**	$ 140,424	**Programmatic Cost Est Imp Two CS**	$ 650,291

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Conduct general scaling on the slope targeting soil wedges, loose blocks that may not be good candidates for rock bolting. Install rock bolts in the large slabs. Install shotcrete on diced sections to mitigate loss of support for the large slabs. Place concrete barrier rail along the edge of pavement (snow removal concern).

*Consider buttressing similar to existing grouted riprap buttress.

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	5	**Improved CI & CS**	82 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	280	$ 49,000
Rock Bolts	$ 160.00	lf	1,750	$ 280,000
Shotcrete	$ 20.00	sf	10,500	$ 210,000
Concrete Barrier	$ 166.67	lf	1,150	$ 191,667
			Subtotal	$ 730,667
			Total w/ 105% OH	**$ 1,497,867**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Conduct targeted scaling on a few soil wedges and loose blocks. Install rock bolts in the large slabs. Place concrete barrier rail along the edge of pavement (snow removal concern).

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	18	**Improved CI & CS**	67 / 2

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	150	$ 26,250
Rock Bolts	$ 160.00	lf	1,750	$ 280,000
Concrete Barrier	$ 166.67	lf	1,150	$ 191,667
			Subtotal	$ 497,917
			Total w/ 105% OH	**$ 1,020,729**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 88

Corridor	C000001	**Side**	Right	**Milepost Start**	157+0.240
				Milepost End	157+0.340

Critical Condition Information

Ditch Effectiveness	27	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 568,967
Rockfall Activity Score	81	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 379,312
Total RHRS Score	470	**30 yr Risk Cost**	$ 132,202	**Programmatic Cost Est Imp Two CS**	$ 189,656

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Conduct general scaling on the slope targeting soil wedges, loose blocks that may not be good candidates for rock bolting. Install rock bolts in the large slabs. Install shotcrete on diced sections to mitigate loss of support for the large slabs. Place concrete barrier rails along the edge of pavement for the entire length (snow removal concern).

Judgement OK

Improved Ditch Eff. Score	7	**Improved RF Activity Score**	7	**Improved CI & CS**	81 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General Scaling	$ 175.00	hr	150	$ 26,250
	Rock Bolts	$ 160.00	lf	800	$ 128,000
	Shotcrete	$ 20.00	sf	12,000	$ 240,000
	Concrete Barrier	$ 166.67	lf	570	$ 95,000
				Subtotal	$ 489,250
				Total w/ 105% OH	**$ 1,002,963**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Conduct general scaling and install rock bolts.

Judgement OK

Improved Ditch Eff. Score	18	**Improved RF Activity Score**	27	**Improved CI & CS**	55 | 3

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General Scaling	$ 175.00	hr	150	$ 26,250
	Rock Bolts	$ 160.00	lf	800	$ 128,000
				Subtotal	$ 154,250
				Total w/ 105% OH	**$ 316,213**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 90

Corridor	C000001	**Side**	Right	**Milepost Start**	157+0.920
				Milepost End	158+0.040

Critical Condition Information

Ditch Effectiveness	27	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 1,315,013
Rockfall Activity Score	81	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 876,676
Total RHRS Score	483	**30 yr Risk Cost**	$ 305,549	**Programmatic Cost Est Imp Two CS**	$ 438,338

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Make a 0.5H:1V cut on the lower 90 feet of the slope to widen the ditch to ~20-25 ft on a 4H:1V. Railroad is approximately 210 ft north of slope. Install rock bolts in key blocks on the new cut face. Install draped tecco (high tensile strength) mesh on the upper 70 feet.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Rock Excavation	$ 23.33	cy	31,680	$ 739,200
Presplit/Controlled Blasting	$ 15.00	lf	13,690	$ 205,350
Rock Bolts	$ 160.00	lf	400	$ 64,000
Draped Tecco Mesh	$ 8.67	sf	10,210	$ 88,487
			Subtotal	$ 1,097,037
			Total w/ 105% OH	**$ 2,248,925**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Conduct general scaling on the entire slope. Install rock bolts in key blocks on the lower slope and the upper outcrop. Install draped gabion mesh on 80 feet of the lower slope. Place concrete barrier rail along the edge of pavement.

Judgement OK

Improved Ditch Eff. Score	18	**Improved RF Activity Score**	27	**Improved CI & CS**	55 / 3

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	280	$ 49,000
Rock Bolts	$ 160.00	lf	900	$ 144,000
Draped Gabion Mesh	$ 5.33	sf	48,000	$ 256,000
Concrete Barrier	$ 166.67	lf	680	$ 113,333
			Subtotal	$ 562,333
			Total w/ 105% OH	**$ 1,152,783**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 92

Corridor	C000001	**Side**	Right	**Milepost Start**	158+0.160
				Milepost End	158+0.240

Critical Condition Information

Ditch Effectiveness	27	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 216,463
Rockfall Activity Score	27	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 216,463
Total RHRS Score	295	**30 yr Risk Cost**	$ 23,372	**Programmatic Cost Est Imp Two CS**	$ 108,232

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Make a 0.5H:1V cut to widen the ditch to ~20 ft on a 4H:1V. Install rock bolts in key blocks.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Rock Excavation	$ 23.33	cy	7,610	$ 177,567
Presplit/Controlled Blasting	$ 15.00	lf	5,480	$ 82,200
Rock Bolts	$ 160.00	lf	300	$ 48,000
			Subtotal	$ 307,767
			Total w/ 105% OH	**$ 630,922**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Conduct general scaling on the upper 40 feet of the slope. Install rock bolts in key blocks. Drape gabion mesh on the entire slope.

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	9	**Improved CI & CS**	75 / 2

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	70	$ 12,250
Rock Bolts	$ 160.00	lf	450	$ 72,000
Draped Gabion Mesh	$ 5.33	sf	10,140	$ 54,080
			Subtotal	$ 138,330
			Total w/ 105% OH	**$ 283,577**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 94

Corridor	C000001	**Side**	Right	**Milepost Start**	158+0.470
				Milepost End	158+0.640

Critical Condition Information

Ditch Effectiveness	60	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 2,214,312
Rockfall Activity Score	81	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 1,476,208
Total RHRS Score	655	**30 yr Risk Cost**	$ 514,505	**Programmatic Cost Est Imp Two CS**	$ 738,104

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Make a 0.75H:1V cut to widen the ditch to ~25 ft on a 4H:1V: 60-ft height on the western 600 ft of the slope and a 90-ft height on the eastern 300 ft. Railroad is approximately 170 ft north of slopes. Install rock dowels in the large blocks formed from the adversely dipping and conjugate discontinuities on the eastern 300 ft of the slope. Install rock bolts in key blocks on the western 600 ft of the slope. Install draped tecco (high tensile strength) mesh on the upper 45 ft of the western 600 ft of the slope.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88	1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Rock Excavation	$ 23.33	cy	43,750	$ 1,020,833
Presplit/Controlled Blasting	$ 15.00	lf	15,080	$ 226,200
Rock Dowels	$ 113.33	lf	600	$ 68,000
Rock Bolts	$ 160.00	lf	750	$ 120,000
Draped Tecco Mesh	$ 8.67	sf	27,000	$ 234,000
			Subtotal	$ 1,669,033
			Total w/ 105% OH	**$ 3,421,518**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Conduct general scaling on entire slope and targeted heavy scaling. Install rock dowels in the large blocks formed from the adversely dipping and conjugate discontinuities on the eastern 300 ft of slope. Install rock bolts in key blocks on the western 600 ft of slope. Install draped tecco on the entire slope.

Judgement OK

Improved Ditch Eff. Score	27	**Improved RF Activity Score**	27	**Improved CI & CS**	50	3

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	405	$ 70,875
Heavy Scaling	$ 175.00	hr	190	$ 33,250
Rock Dowels	$ 113.33	lf	600	$ 68,000
Rock Bolts	$ 160.00	lf	750	$ 120,000
Draped Tecco Mesh	$ 8.67	sf	48,600	$ 421,200
			Subtotal	$ 713,325
			Total w/ 105% OH	**$ 1,462,316**

Gallatin Canyon Corridor
Highway 131 South of Bozeman; MP 50 to 63

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 933

Corridor	C000050	**Side**	Right	**Milepost Start**	050+0.680
				Milepost End	050+0.800

Critical Condition Information

Ditch Effectiveness	30	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 1,316,738
Rockfall Activity Score	75	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 877,825
Total RHRS Score	495	**30 yr Risk Cost**	$ 452,981	**Programmatic Cost Est Imp Two CS**	$ 438,913

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Northen 350 ft of cut is lower hazard and does not require mitigation. Failing cut slope in till with blocks <1ft in size on shoulder, limited ditch. Transitions to talus slope, then to a large outcrop close to the road. Southernmost 275' of cut has good ditch. Observed rock in ditch 1 to 3 ft in size. To improve: 1) install a low-deflection FRB with no upslope tiebacks near the base/toe of slope; 2) southern most v. tight, install pinned Tecco mesh. There is an underground cable running on the inboard lane/toe of slope.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	15	**Improved CI & CS**	82	1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Low Deflection FRB (1000 kJ)	$ 900.00	lf	300	$ 270,000
	Pinned Tecco	$ 20.00	sf	10,000	$ 200,000
				Subtotal	$ 470,000
				Total w/ 105% OH	**$ 963,500**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Install gabion basket wall (6-ft tall) along base/toe of cut slope.

Judgement OK

Improved Ditch Eff. Score	15	**Improved RF Activity Score**	75	**Improved CI & CS**	45	3

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Ditch Improvement - Gabion Baskets	$ 450.00	lf	300	$ 135,000
				Subtotal	$ 135,000
				Total w/ 105% OH	**$ 276,750**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 934

Corridor	C000050	**Side**	Right	**Milepost Start**	052+0.050
				Milepost End	052+0.160

Critical Condition Information

Ditch Effectiveness	80	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 710,042
Rockfall Activity Score	80	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 473,361
Total RHRS Score	447	**30 yr Risk Cost**	$ 244,267	**Programmatic Cost Est Imp Two CS**	$ 236,681

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Northern-most 200 ft of cut is colluvium/talus. Transitions to bedded outcrop to the south. Average rockfall size is 2ft, with a max. block size of 3ft. No ditch. To improve: 1) cut trees, scale (especially at the crest), and run 8-10' tall attenuator on bench. This will require TRP (MRB) with lane closures and flaggers

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 / 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General scaling	$ 175.00	hr	250	$ 43,750
	Rockfall Attenuator	$ 20.00	sf	49,300	$ 986,000

Subtotal	$	1,029,750
Total w/ 105% OH	**$**	**2,110,988**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Cut trees and scale slope

Judgement OK

Improved Ditch Eff. Score	60	**Improved RF Activity Score**	27	**Improved CI & CS**	41 / 3

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General Scaling	$ 175.00	hr	250	$ 43,750

Subtotal	$	43,750
Total w/ 105% OH	**$**	**89,688**

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Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells		**Assessed By**	BAB
Ver. 1.00		**Assessment Date**	3/15/2017

Site Information

Section Number 935

Corridor	C000050	**Side**	Right	**Milepost Start**	052+0.330
				Milepost End	052+0.450

Critical Condition Information

Ditch Effectiveness	27	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 1,866,772
Rockfall Activity Score	27	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 1,866,772
Total RHRS Score	393	**30 yr Risk Cost**	$ 298,418	**Programmatic Cost Est Imp Two CS**	$ 933,386

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative southern 175' of cut is a long talus slope with outcrops far upslope. This section appears to be low activity/hazard. Northern 365 ft of cut is outcrop with colluvium/talus slope above. To improve: 1) cut trees and scale; 2) install 10' attenuator fence along brow of slope; 3) install 200' gabion basket wall (6-ft tall) at base of slope. If there is a desire to address the southern talus slope, add gabion baskets along the toe.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	80	$ 14,000
Rockfall Attenuator	$ 20.00	sf	14,600	$ 292,000
Ditch Improvement - Gabion Baskets	$ 450.00	lf	200	$ 90,000
			Subtotal	$ 396,000
			Total w/ 105% OH	**$ 811,800**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Cut trees and scale on northern 365' of cut. Add 200' gabion basket wall (6-ft tall) through the southern end if the talus slope appears to be active.

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	3	**Improved CI & CS**	88 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	80	$ 14,000
Ditch Improvement - Gabion Baskets	$ 450.00	lf	200	$ 90,000
			Subtotal	$ 104,000
			Total w/ 105% OH	**$ 213,200**

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Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells	**Assessed By**	BAB
Ver. 1.00	**Assessment Date**	3/15/2017

Site Information

Section Number 936

Corridor	C000050	**Side**	Right	**Milepost Start**	052+0.730
				Milepost End	052+0.870

Critical Condition Information

Ditch Effectiveness	50	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 1,176,417
Rockfall Activity Score	81	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 784,278
Total RHRS Score	468	**30 yr Risk Cost**	$ 404,708	**Programmatic Cost Est Imp Two CS**	$ 392,139

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative South end of cut is talus slope that quickly changes to 10-15 ft tall colluvium cut with talus above. Block size < 1ft maximum imension. North end of cut has bigger blocks and longer talus slopes, but no cut and bigger ditch. To improve: 1) shift alignment to the left for at least 580 ft. This requires about a 10 ft tall embankment (there is room for this), and shift 10-15 ft left. Assume 220 ft more shifted (at this high cost) to account for about 500 ft of additional new road to deal with curves

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88
					1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Shift Road Alignment	$ 1,000.00	ft	800	$ 800,000
				Subtotal	$ 800,000
				Total w/ 105% OH	**$ 1,640,000**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Scale the lower outcrops, with spot scaling of bigger/precarious rock blocks above

Judgement OK

Improved Ditch Eff. Score	50	**Improved RF Activity Score**	27	**Improved CI & CS**	43	3

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General Scaling	$ 175.00	hr	250	$ 43,750
				Subtotal	$ 43,750
				Total w/ 105% OH	**$ 89,688**

Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells		**Assessed By**	BAB
Ver. 1.00		**Assessment Date**	3/15/2017

Site Information

Section Number 937

Corridor	C000050	**Side**	Right	**Milepost Start**	052+0.870
				Milepost End	052+0.960

Critical Condition Information

Ditch Effectiveness	65	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 1,132,373
Rockfall Activity Score	91	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 754,915
Total RHRS Score	536	**30 yr Risk Cost**	$ 389,556	**Programmatic Cost Est Imp Two CS**	$ 377,458

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative This slope is more of a slide/slough problem than a rockfll issue. The southern 225 ft of the cut is a talus slope that transitions to outcrops reachng up to 90ft above the raod. The next 75 ft, transition to a shallow slough that has oversteepened the colluvium/talus slope and undermined the talus slope above, creating the potential for large-volumne events in this area. The slide is about 150 ft wide,; the talus slope is about 250' long. Possible will happen to the north. To improve: 1) add 10ft vertical MSE wall to improve ditch catchment (600ft x 10ft); 2) low-definition FRB on top; 3) rock inlay or pinned tecco in slide area

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88
					1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Other Roadside Barrier (MSE)	$ 85.00	sf	6,000	$ 510,000
Low Deflection FRB (1000 kJ)	$ 900.00	lf	575	$ 517,500
Pinned Tecco	$ 20.00	sf	15,000	$ 300,000
			Subtotal	$ 1,327,500
			Total w/ 105% OH	**$ 2,721,375**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Scale slope and install pin Tecco in slide area, which will require MRB, one lane closure w/flaggers, and a 20 minute delay

Judgement OK

Improved Ditch Eff. Score	65	**Improved RF Activity Score**	15	**Improved CI & CS**	47
					3

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General scaling	$ 175.00	hr	350	$ 61,250
Pinned Tecco	$ 20.00	sf	15,000	$ 300,000
			Subtotal	$ 361,250
			Total w/ 105% OH	**$ 740,563**

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Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells	**Assessed By**	BAB
Ver. 1.00	**Assessment Date**	3/14/2017
	Section Number	945

Site Information

Corridor	C000050	**Side**	Right	**Milepost Start**	059+0.280
				Milepost End	059+0.390

Critical Condition Information

Ditch Effectiveness	38	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 687,872
Rockfall Activity Score	90	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 458,581
Total RHRS Score	345	**30 yr Risk Cost**	$ 236,640	**Programmatic Cost Est Imp Two CS**	$ 229,291

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Cut in till with bench along lower third of slope. Average height of bench is about 25 ft above road grade. Material is falling out of upper and lower slope. To improve: 1) clean off bench; 2) install 10ft tall, 580 ft long attenuator on edge of bench

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Rockfall Attenuator	$ 20.00	sf	17,500	$ 350,000
	Bench Cleaning	$ 2,000.00	day	2	$ 4,000
				Subtotal	$ 354,000
				Total w/ 105% OH	**$ 725,700**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Clean off the bench and install a gabion basket wall (6-ft tall) or berm on outboard side of bench to capture material from the upper source. This includes light scaling of the lower slope, and possible scaling of the upper slope. Scaling the upper slope will also require construction of a berm to capture scaled material.

Judgement OK

Improved Ditch Eff. Score	15	**Improved RF Activity Score**	27	**Improved CI & CS**	57 | 3

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Bench Cleaning	$ 2,000.00	day	2	$ 4,000
	Ditch Improvement - Gabion Baskets	$ 450.00	lf	580	$ 261,000
				Subtotal	$ 265,000
				Total w/ 105% OH	**$ 543,250**

Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells

Ver. 1.00

Assessed By: BAB
Assessment Date: 3/14/2017

Site Information

Section Number 946

Corridor	C000050	**Side**	Right	**Milepost Start**	060+0.730
				Milepost End	060+0.960

Critical Condition Information

Ditch Effectiveness	70	**Current Condition State**	5	**Programmatic Cost Est to CS1**	$ 6,665,861
Rockfall Activity Score	95	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 3,332,931
Total RHRS Score	583	**30 yr Risk Cost**	$ 2,749,250	**Programmatic Cost Est Imp Two CS**	$ 1,665,313

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative High hazard section. Short talus slope with large vertical and active rock outcrops above and on either end of cut. Northern 280ft has a turnout with ditch up to 38 ft wide. All ATT in this corridor will increase cost due to foundation conditions. Bad rock block on slope above, about 200 vertical feet above. Trim blasting may be required. To improve: 1) low-defition FRB (with no upslope tie-backs) at toe of talus in turnout; 2) attenuator fence along base of outcrop and talus; 3) scale vertical elements of slope

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	15	**Improved CI & CS**	82 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Low Deflection FRB (1000 kJ)	$ 900.00	lf	580	$ 522,000
Rockfall Attenuator	$ 20.00	sf	43,500	$ 870,000
General Scaling	$ 175.00	hr	1,200	$ 210,000
			Subtotal	$ 1,602,000
			Total w/ 105% OH	**$ 3,284,100**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Leave turnout area alone. Scale vertical elements of the slope. This will require MRB, one-lane closures, and flaggers.

Judgement OK

Improved Ditch Eff. Score	70	**Improved RF Activity Score**	27	**Improved CI & CS**	39 / 4

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	1,200	$ 210,000
			Subtotal	$ 210,000
			Total w/ 105% OH	**$ 430,500**

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Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells	**Assessed By**	BAB
Ver. 1.00	**Assessment Date**	3/14/2017

Site Information

Section Number 947

Corridor	C000050	**Side**	Right	**Milepost Start**	061+0.180
				Milepost End	061+0.260

Critical Condition Information

Ditch Effectiveness	81	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 1,022,187
Rockfall Activity Score	81	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 681,458
Total RHRS Score	572	**30 yr Risk Cost**	$ 351,650	**Programmatic Cost Est Imp Two CS**	$ 340,729

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Cut slope of very tilted and fractured material. Shallow slough at north end fo cut. Blocks tend to break apart to less than 2ft, though occaisional 5ft+ blocks may be possible. Debris pile in turnout may be from slough area. To improve: 1) scale slope; 2) install 15 ft attenuator along crest off lower bench 80 ft ht; may need to shorten length of attenuator fence to accomadate slough at northern end of cut. Will require MRB, 1-lane closure, and flaggers

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88	1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	400	$ 70,000
Rockfall Attenuator	$ 20.00	sf	34,000	$ 680,000

Subtotal	$ 750,000
Total w/ 105% OH	**$ 1,537,500**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Scale slope

Judgement OK

Improved Ditch Eff. Score	81	**Improved RF Activity Score**	20	**Improved CI & CS**	41	3

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	400	$ 70,000

Subtotal	$ 70,000
Total w/ 105% OH	**$ 143,500**

Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells		**Assessed By**	BAB
Ver. 1.00		**Assessment Date**	3/14/2017

Site Information

Section Number 948

Corridor	C000050	**Side**	Left	**Milepost Start**	061+0.380
				Milepost End	061+0.550

Critical Condition Information

Ditch Effectiveness	50	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 2,287,143
Rockfall Activity Score	50	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 1,524,762
Total RHRS Score	501	**30 yr Risk Cost**	$ 786,817	**Programmatic Cost Est Imp Two CS**	$ 762,381

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Talus slope with trees and bench above ditch (northern and southern 400 ft of cut). Ditch is very limitied, but rocks are mostly smaller than 2 ft; trace up to 5 ft. Middle 120 ft of cut has turnout, but outcrops and larger source rocks 5 to 8ft max dimension. This area appears more active. To improve: 1) installed 120 ft of low deflection FRB with no upslope tiebacks at toe of talus ditch; 2) 900 ft of gabion basket along road; 3) heavy scaling in targeted areas

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	3	**Improved CI & CS**	88	1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Low Deflection FRB (1000 kJ)	$ 900.00	lf	120	$ 108,000
Ditch Improvement - Gabion Baskets	$ 450.00	lf	900	$ 405,000
Heavy Scaling	$ 175.00	hr	250	$ 43,750
			Subtotal	$ 556,750
			Total w/ 105% OH	**$ 1,141,338**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Heavy scaling of outcrop in high-activity middle section, with additional general scaling on the rest of the slope. This assumes MRB, one lane closures, and flaggers.

Judgement OK

Improved Ditch Eff. Score	50	**Improved RF Activity Score**	9	**Improved CI & CS**	55	3

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Heavy Scaling	$ 175.00	hr	250	$ 43,750
General Scaling	$ 175.00	hr	350	$ 61,250
			Subtotal	$ 105,000
			Total w/ 105% OH	**$ 215,250**

Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells		**Assessed By**	BAB
Ver. 1.00		**Assessment Date**	3/14/2017

Site Information

Section Number 949

Corridor	C000050	**Side**	Left	**Milepost Start**	062+0.070
				Milepost End	062+0.210

Critical Condition Information

Ditch Effectiveness	27	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 3,206,209
Rockfall Activity Score	70	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 2,137,473
Total RHRS Score	448	**30 yr Risk Cost**	$ 1,102,992	**Programmatic Cost Est Imp Two CS**	$ 1,068,736

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Talus slope with vertical cliff source above. 6 in to 2 ft talus, with scattered blocks up to 5 ft. To improve: 1) low deflection FRM in northern 400 ft with no upslope anchors (along toe of talus slope), possibly running additional 330 ft for entire length of slope OR 2) construct MSE wall with FRB on top OR 3) raise grade of road.

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	3	**Improved CI & CS**	88 / 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Low Deflection FRB (1000 kJ)	$ 900.00	lf	730	$ 657,000
				Subtotal	$ 657,000
				Total w/ 105% OH	**$ 1,346,850**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Too much outcrop to scale above, but could scale ??? Blocks in talus. Improve catchment with construction of 6ft tall gabions in ditch at toe of slope. Possible concerns about making a ramp.

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	3	**Improved CI & CS**	88 / 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General Scaling	$ 175.00	hr	250	$ 43,750
	Ditch Improvement - Gabion Baskets	$ 450.00	lf	730	$ 328,500
				Subtotal	$ 372,250
				Total w/ 105% OH	**$ 763,113**

Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells

Ver. 1.00

Assessed By	BAB
Assessment Date	3/14/2017
Section Number	950

Site Information

Corridor	C000050	**Side**	Left	**Milepost Start**	062+0.560
				Milepost End	062+0.690

Critical Condition Information

Ditch Effectiveness	27	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 924,979
Rockfall Activity Score	55	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 924,979
Total RHRS Score	379	**30 yr Risk Cost**	$ 147,865	**Programmatic Cost Est Imp Two CS**	$ 462,489

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Talus slope with source outcrops above. Large rock blocks of durable/source rock are typically 1/2ft in size, but can be up to 8 ft. To improve: 1) Improve catchment by using a low-deflection FRB with no tiebacks; 2) heavy scaling of source outcrops and precarious larger blocks. This assumes MRB, one lane closure, and flaggers

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	3	**Improved CI & CS**	88 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Low Deflection FRB (1000 kJ)	$ 900.00	lf	700	$ 630,000
	Heavy Scaling	$ 175.00	hr	750	$ 131,250
				Subtotal	$ 761,250
				Total w/ 105% OH	**$ 1,560,563**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Use gabion baskets (due to wet ditch and limited space) to put a barrier at toe of slope 6ft tall and 700 ft long, though this should be evaluated for the potential to create a ramp. Possibly also scale, as in the previous option

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	3	**Improved CI & CS**	88 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Ditch Improvement - Gabion Baskets	$ 450.00	lf	700	$ 315,000
	Heavy Scaling	$ 175.00	hr	750	$ 131,250
				Subtotal	$ 446,250
				Total w/ 105% OH	**$ 914,813**

Lookout Pass Corridor
I-90 West of St Regis; MP 0 to 31

Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells		**Assessed By**	DLB
Ver. 1.00		**Assessment Date**	March 13-15, 2017
Site Information		**Section Number**	1136

Corridor	C000090	**Side**	Left	**Milepost Start**	000+0.530
				Milepost End	000+0.660

Critical Condition Information

Ditch Effectiveness	3	**Current Condition State**	1	**Programmatic Cost Est to CS1**	$ -
Rockfall Activity Score	15	**G/F/P**	GOOD	**Programmatic Cost Est Imp One CS**	$ -
Total RHRS Score	425	**30 yr Risk Cost**	$ 18,998	**Programmatic Cost Est Imp Two CS**	$ -

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Scale, bolt, install barrier. Slope was largely snow covered at time of visit. GOOD status may not warrant either, but the rock face could benefit from stabilization efforts.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Rock bolts	$ 160.00	lf	400	$ 64,000
General scaling	$ 175.00	hr	252	$ 44,149
Concrete Barrier	$ 166.67	lf	675	$ 112,500

Subtotal	$ 220,649
Total w/ 105% OH	**$ 452,331**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Install barrier. Slope was largely snow covered at time of visit. This is an alternative to the estimate above, though the GOOD status of the site likely does not warrant either mitigation approach.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	15	**Improved CI & CS**	82 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Concrete Barrier	$ 166.67	lf	675	$ 112,500

Subtotal	$ 112,500
Total w/ 105% OH	**$ 230,625**

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Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells		**Assessed By**	DLB
Ver. 1.00		**Assessment Date**	March 13-15, 2017

Site Information

Section Number 1137

Corridor	C000090	**Side**	Left	**Milepost Start**	000+0.790
				Milepost End	000+0.880

Critical Condition Information

Ditch Effectiveness	9	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 313,170
Rockfall Activity Score	15	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 313,170
Total RHRS Score	326	**30 yr Risk Cost**	$ 64,613	**Programmatic Cost Est Imp Two CS**	$ 313,170

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Install concrete barrier. Install short attenutor on bench (15' tail). Slope was snow covered at time of visit.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete Barrier	$ 166.67	lf	550	$ 91,667
	Rockfall Attenuator	$ 20.00	sf	7,200	$ 144,000
				Subtotal	$ 235,667
				Total w/ 105% OH	**$ 483,117**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Install concrete barrier.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	15	**Improved CI & CS**	82 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete Barrier	$ 166.67	lf	550	$ 91,667
				Subtotal	$ 91,667
				Total w/ 105% OH	**$ 187,917**

Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells		**Assessed By**	DLB
Ver. 1.00		**Assessment Date**	March 13-15, 2017

Site Information

Section Number 1138

Corridor	C000090	**Side**	Left	**Milepost Start**	001+0.080
				Milepost End	001+0.220

Critical Condition Information

Ditch Effectiveness	15	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 842,502
Rockfall Activity Score	27	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 842,502
Total RHRS Score	378	**30 yr Risk Cost**	$ 714,855	**Programmatic Cost Est Imp Two CS**	$ 421,251

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Slope was mostly snow covered at time of visit. Scale and install mesh on the upper half of the slope and install barrier at the base.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	15	**Improved CI & CS**	82 / 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Draped tecco mesh	$ 8.67	sf	18,018	$ 156,156
	General Scaling	$ 175.00	hr	273	$ 47,775
	Concrete Barrier	$ 166.67	lf	700	$ 116,667
				Subtotal	$ 320,598
				Total w/ 105% OH	**$ 657,225**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Install concrete barrier with fence to improve catchment.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	27	**Improved CI & CS**	75 / 2

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete w/ fence	$ 283.33	lf	700	$ 198,333
				Subtotal	$ 198,333
				Total w/ 105% OH	**$ 406,583**

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Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells		**Assessed By**	DLB
Ver. 1.00		**Assessment Date**	March 13-15, 2017

Site Information

Section Number 1139

Corridor	C000090	**Side**	Left	**Milepost Start**	001+0.400
				Milepost End	001+0.530

Critical Condition Information

Ditch Effectiveness	3	**Current Condition State**	1	**Programmatic Cost Est to CS1**	$ -
Rockfall Activity Score	3	**G/F/P**	GOOD	**Programmatic Cost Est Imp One CS**	$ -
Total RHRS Score	255	**30 yr Risk Cost**	$ 32,784	**Programmatic Cost Est Imp Two CS**	$ -

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered at the time of visit. A concrete barrier would improve ditch effectiveness, though the site's GOOD status may not warrant this mitigation.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete Barrier	$ 166.67	lf	570	$ 95,000
				Subtotal	$ 95,000
				Total w/ 105% OH	**$ 194,750**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative None

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					
				Subtotal	$ -
				Total w/ 105% OH	**$ -**

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Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells		**Assessed By**	DLB
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Site Information

Section Number 1140

Corridor	C000090	**Side**	Left	**Milepost Start**	001+0.530
				Milepost End	001+0.610

Critical Condition Information

Ditch Effectiveness	5	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 203,034
Rockfall Activity Score	20	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 203,034
Total RHRS Score	374	**30 yr Risk Cost**	$ 41,890	**Programmatic Cost Est Imp Two CS**	$ 203,034

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered. Install concrete barrier and scale outcrop.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	137	$ 23,888
Concrete barrier	$ 166.67	lf	400	$ 66,667

Subtotal	$ 90,554
Total w/ 105% OH	**$ 185,636**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*

Subtotal	$ -
Total w/ 105% OH	**$ -**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1141

Corridor	C000090	**Side**	Right	**Milepost Start**	002+0.620
				Milepost End	002+0.710

Critical Condition Information

Ditch Effectiveness	9	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 235,629
Rockfall Activity Score	27	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 235,629
Total RHRS Score	359	**30 yr Risk Cost**	$ 48,615	**Programmatic Cost Est Imp Two CS**	$ 235,629

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered at the time of visit. Improve with new truck barriers and fence extension. Perform general scaling.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	238	$ 41,563
Concrete w/ fence	$ 283.33	lf	475	$ 134,583

Subtotal	$ 176,146
Total w/ 105% OH	**$ 361,099**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*

Subtotal	$ -
Total w/ 105% OH	**$ -**

Montana Department of Transportation RAMP Mitigation Calculator

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Assessed By	DLB
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Section Number	1142

Site Information

Corridor	C000090	**Side**	Right	**Milepost Start**	002+0.800
				Milepost End	002+0.880

Critical Condition Information

Ditch Effectiveness	15	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 274,587
Rockfall Activity Score	9	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 274,587
Total RHRS Score	399	**30 yr Risk Cost**	$ 56,652	**Programmatic Cost Est Imp Two CS**	$ 274,587

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered at the time of visit. Scale back the rock slide retrogressing into the lower bench, improve barrier and fence extension, and clean out the ditch and rock slide debris. Option to install attenuator. Estimate excavation of retrogressing bench at 15' long and a 10x10' prism of material. There may be more hazard than indicated by the condition state, more indicative by the RHRS score of 399.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88	1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Ditch Improvement - reshaping	$ 250.00	lf	400	$ 100,000
Concrete w/ fence	$ 283.33	lf	400	$ 113,333
Excavation at bench crest			7,500	

Subtotal	$ 213,333
Total w/ 105% OH	**$ 437,333**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**		

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*

Subtotal	$ -
Total w/ 105% OH	**$ -**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1143

Corridor	C000090	**Side**	Left	**Milepost Start**	003+0.030
				Milepost End	003+0.080

Critical Condition Information

Ditch Effectiveness	25	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 37,580
Rockfall Activity Score	9	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 37,580
Total RHRS Score	213	**30 yr Risk Cost**	$ 7,754	**Programmatic Cost Est Imp Two CS**	$ 37,580

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered at the time of the site visit. Add concrete barrier at the ditch.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 / 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete barrier	$ 166.67	lf	220	$ 36,667
	.				

Subtotal	$ 36,667
Total w/ 105% OH	**$ 75,167**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					

Subtotal	$ -
Total w/ 105% OH	**$ -**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1144

Corridor	C000090	**Side**	Left	**Milepost Start**	005+0.110
				Milepost End	005+0.230

Critical Condition Information

Ditch Effectiveness	9	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 314,594
Rockfall Activity Score	20	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 314,594
Total RHRS Score	293	**30 yr Risk Cost**	$ 64,906	**Programmatic Cost Est Imp Two CS**	$ 314,594

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered at the time of the site visit. Add fence extension to existing concrete barrier at the ditch. Perform general scaling. The accumulation of shrubs and bushes in the middle may be indicative of a spring, such as was present at MP 6.5 before the rock slide in 2014.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88	1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General scaling	$ 175.00	hr	215	$ 37,708
Fence extension on existing barrier			650	

Subtotal $ 37,708

Total w/ 105% OH $ 77,302

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*

Subtotal $ -

Total w/ 105% OH $ -

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1145

Corridor	C000090	**Side**	Left	**Milepost Start**	005+0.280
				Milepost End	005+0.350

Critical Condition Information

Ditch Effectiveness	4	**Current Condition State**	1	**Programmatic Cost Est to CS1**	$ -
Rockfall Activity Score	9	**G/F/P**	GOOD	**Programmatic Cost Est Imp One CS**	$ -
Total RHRS Score	209	**30 yr Risk Cost**	$ 5,994	**Programmatic Cost Est Imp Two CS**	$ -

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered. No action except for continued maintenance of the ditch.

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*

Subtotal $ -

Total w/ 105% OH $ -

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*

Subtotal $ -

Total w/ 105% OH $ -

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1146

Corridor	C000090	**Side**	Left	**Milepost Start**	005+0.850
				Milepost End	005+0.870

Critical Condition Information

Ditch Effectiveness	22	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 956,023
Rockfall Activity Score	20	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 956,023
Total RHRS Score	355	**30 yr Risk Cost**	$ 811,176	**Programmatic Cost Est Imp Two CS**	$ 478,011

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered at the time of the site visit. Add a barrier at the ditch and perform minor scaling of loose blocks.

Judgement OK

Improved Ditch Eff. Score	5	**Improved RF Activity Score**	9	**Improved CI & CS**	82 / 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General scaling	$ 175.00	hr	327	$ 57,296
	Concrete barrier	$ 166.67	lf	700	$ 116,667
				Subtotal	$ 173,963
				Total w/ 105% OH	**$ 356,623**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Install a concrete barrier

Judgement OK

Improved Ditch Eff. Score	5	**Improved RF Activity Score**	20	**Improved CI & CS**	73 / 2

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete barrier	$ 166.67	lf	700	$ 116,667
				Subtotal	$ 116,667
				Total w/ 105% OH	**$ 239,167**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1147

Corridor	C000090	**Side**	Left	**Milepost Start**	006+0.160
				Milepost End	006+0.270

Critical Condition Information

Ditch Effectiveness	6	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 403,894
Rockfall Activity Score	27	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 403,894
Total RHRS Score	381	**30 yr Risk Cost**	$ 83,331	**Programmatic Cost Est Imp Two CS**	$ 403,894

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered at the time of site visit. Site was the location of a large rock slide in 2014. The slope still produces rock fall, but most is contained in the ditch. Reduce rockfall activity with general slope scaling and continue to maintain ditch.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	16	**Improved CI & CS**	81 | 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General scaling	$ 175.00	hr	273	$ 47,775

Subtotal	$ 47,775
Total w/ 105% OH	**$ 97,939**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*

Subtotal	$ -
Total w/ 105% OH	**$ -**

Montana Department of Transportation RAMP Mitigation Calculator

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Assessed By	DLB
Assessment Date	March 13-15, 2017
Section Number	1148

Site Information

Corridor	C000090	**Side**	Left	**Milepost Start**	006+0.650
				Milepost End	006+0.760

Critical Condition Information

Ditch Effectiveness	20	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 658,108
Rockfall Activity Score	20	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 658,108
Total RHRS Score	400	**30 yr Risk Cost**	$ 558,398	**Programmatic Cost Est Imp Two CS**	$ 329,054

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered at the time of the visit. Perform general scaling, add barrier and extension fence.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	226	$ 39,585
Concrete w/ fence	$ 283.33	lf	580	$ 164,333

Subtotal $ 203,918

Total w/ 105% OH $ 418,033

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Postpone scaling, add barrier with fence extension.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	20	**Improved CI & CS**	78 / 2

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Concrete w/ fence	$ 283.33	lf	580	$ 164,333

Subtotal $ 164,333

Total w/ 105% OH $ 336,883

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1149

Corridor	C000090	**Side**	Left	**Milepost Start**	007+0.290
				Milepost End	007+0.460

Critical Condition Information

Ditch Effectiveness	3	**Current Condition State**	1	**Programmatic Cost Est to CS1**	$ -
Rockfall Activity Score	3	**G/F/P**	GOOD	**Programmatic Cost Est Imp One CS**	$ -
Total RHRS Score	299	**30 yr Risk Cost**	$ 21,024	**Programmatic Cost Est Imp Two CS**	$ -

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered at the time of the visit. Maintain existing barrier.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100	1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*

Subtotal $ -

Total w/ 105% OH $ -

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**		

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*

Subtotal $ -

Total w/ 105% OH $ -

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1150

Corridor	C000090	**Side**	Left	**Milepost Start**	007+0.460
				Milepost End	007+0.580

Critical Condition Information

Ditch Effectiveness	40	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 1,221,213
Rockfall Activity Score	27	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 1,221,213
Total RHRS Score	383	**30 yr Risk Cost**	$ 1,036,187	**Programmatic Cost Est Imp Two CS**	$ 610,606

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered when visited. Perform general scaling and add a new barrier with fence extension.

Judgement OK

Improved Ditch Eff. Score	5	**Improved RF Activity Score**	9	**Improved CI & CS**	82	1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General scaling	$ 175.00	hr	411	$ 72,004
Concrete w/ fence	$ 283.33	lf	630	$ 178,500

Subtotal	$ 250,504
Total w/ 105% OH	**$ 513,533**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Replace existing barrier with new barrier and fence extension.

Judgement OK

Improved Ditch Eff. Score	5	**Improved RF Activity Score**	27	**Improved CI & CS**	69	2

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Concrete w/ fence	$ 283.33	lf	630	$ 178,500

Subtotal	$ 178,500
Total w/ 105% OH	**$ 365,925**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1151

Corridor	C000090	**Side**	Left	**Milepost Start**	007+0.900
				Milepost End	007+0.980

Critical Condition Information

Ditch Effectiveness	12	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 249,113
Rockfall Activity Score	9	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 249,113
Total RHRS Score	345	**30 yr Risk Cost**	$ 51,396	**Programmatic Cost Est Imp Two CS**	$ 249,113

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered at the time of the site visit. Add a concrete barrier.

Judgement OK

Improved Ditch Eff. Score	5	**Improved RF Activity Score**	9	**Improved CI & CS**	82 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Concrete barrier	$ 166.67	lf	500	$ 83,333

Subtotal	$ 83,333
Total w/ 105% OH	**$ 170,833**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*

Subtotal	$ -
Total w/ 105% OH	**$ -**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1152

Corridor	C000090	**Side**	Left	**Milepost Start**	008+0.610
				Milepost End	008+0.640

Critical Condition Information

Ditch Effectiveness	25	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 167,007
Rockfall Activity Score	12	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 167,007
Total RHRS Score	454	**30 yr Risk Cost**	$ 141,704	**Programmatic Cost Est Imp Two CS**	$ 83,504

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered at the time of the site visit. Scale the upper portion of the slope and add a barrier with fence at the bottom.

Judgement OK

Improved Ditch Eff. Score	5	**Improved RF Activity Score**	9	**Improved CI & CS**	82 / 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete w/ fence	$ 283.33	lf	160	$ 45,333
	General scaling	$ 175.00	hr	114	$ 20,020
				Subtotal	$ 65,353
				Total w/ 105% OH	**$ 133,974**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Add a concrete barrier with a fence extension.

Judgement OK

Improved Ditch Eff. Score	5	**Improved RF Activity Score**	12	**Improved CI & CS**	78 / 2

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete w/ fence	$ 283.33	lf	160	$ 45,333
				Subtotal	$ 45,333
				Total w/ 105% OH	**$ 92,933**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1153

Corridor	C000090	**Side**	Left	**Milepost Start**	008+0.860
				Milepost End	008+0.990

Critical Condition Information

Ditch Effectiveness	27	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 1,073,497
Rockfall Activity Score	15	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 1,073,497
Total RHRS Score	369	**30 yr Risk Cost**	$ 910,852	**Programmatic Cost Est Imp Two CS**	$ 536,748

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered at the time of the site visit. Add a short attenuator on the bench and a barrier at the bottom.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Rockfall Attenuator	$ 20.00	sf	22,750	$ 455,000
	Concrete barrier	$ 166.67	lf	650	$ 108,333
				Subtotal	$ 563,333
				Total w/ 105% OH	**$ 1,154,833**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Add a barrier with a fence extension only

Judgement OK

Improved Ditch Eff. Score	5	**Improved RF Activity Score**	15	**Improved CI & CS**	76 | 2

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete w/ fence	$ 283.33	lf	650	$ 184,167
				Subtotal	$ 184,167
				Total w/ 105% OH	**$ 377,542**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1154

Corridor	C000090	**Side**	Left	**Milepost Start**	009+0.990
				Milepost End	010+0.100

Critical Condition Information

Ditch Effectiveness	15	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 224,723
Rockfall Activity Score	9	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 224,723
Total RHRS Score	337	**30 yr Risk Cost**	$ 46,364	**Programmatic Cost Est Imp Two CS**	$ 224,723

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered at the time of the visit. Add a concrete barrier at the base of the slope for its width.

Judgement OK

Improved Ditch Eff. Score	4	**Improved RF Activity Score**	9	**Improved CI & CS**	84 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete barrier	$ 166.67	lf	320	$ 53,333

Subtotal	$ 53,333
Total w/ 105% OH	**$ 109,333**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					

Subtotal	$ -
Total w/ 105% OH	**$ -**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1155

Corridor	C000090	**Side**	Left	**Milepost Start**	010+0.880
				Milepost End	010+0.990

Critical Condition Information

Ditch Effectiveness	5	**Current Condition State**	1	**Programmatic Cost Est to CS1**	$ -
Rockfall Activity Score	5	**G/F/P**	GOOD	**Programmatic Cost Est Imp One CS**	$ -
Total RHRS Score	276	**30 yr Risk Cost**	$ 40,602	**Programmatic Cost Est Imp Two CS**	$ -

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Snow covered during visit. Continue to maintain ditch.

Judgement OK

Improved Ditch Eff. Score	5	**Improved RF Activity Score**	5	**Improved CI & CS**	88	1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*

Subtotal $ -

Total w/ 105% OH $ -

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	#NUM!	#NUM!

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*

Subtotal $ -

Total w/ 105% OH $ -

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1156

Corridor	C000090	**Side**	Left	**Milepost Start**	012+0.060
				Milepost End	012+0.180

Critical Condition Information

Ditch Effectiveness	5	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 377,512
Rockfall Activity Score	15	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 377,512
Total RHRS Score	236	**30 yr Risk Cost**	$ 81,471	**Programmatic Cost Est Imp Two CS**	$ 377,512

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Install concrete barrier to improve catchment

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	15	**Improved CI & CS**	82 / 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete barrier	$ 166.67	lf	500	$ 83,333
				Subtotal	$ 83,333
				Total w/ 105% OH	**$ 170,833**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					
				Subtotal	$ -
				Total w/ 105% OH	**$ -**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1157

Corridor	C000090	**Side**	Left	**Milepost Start**	012+0.480
				Milepost End	012+0.780

Critical Condition Information

Ditch Effectiveness	25	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 3,359,688
Rockfall Activity Score	40	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 3,359,688
Total RHRS Score	484	**30 yr Risk Cost**	$ 2,981,812	**Programmatic Cost Est Imp Two CS**	$ 1,679,844

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Install FRB/Concrete barrier fence extension at base. No bench on slope, but install attenuator, but could be an avalanche issue with it being taken out by snow. Pinned tecco the entire slop?...may reduce interface friction with snow...more avalanches. A bunch of bolts?

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88
					1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Barrier fence extension	$ 150.00	lf	1,600	$ 240,000
	General scaling	$ 175.00	hr	1,450	$ 253,663
	(scaling at a reduced production rate)				$ -
	rock bolts	$ 160.00	lf	4,000	$ 640,000
					$ -
					$ -
					$ -
				Subtotal	$ 1,133,663
				Total w/ 105% OH	**$ 2,324,008**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative install barrier fence extension at base of slope.

Judgement OK

Improved Ditch Eff. Score	6	**Improved RF Activity Score**	40	**Improved CI & CS**	63	2

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Barrier fence extension	$ 150.00	lf	1,600	$ 240,000
				Subtotal	$ 240,000
				Total w/ 105% OH	**$ 492,000**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1158

Corridor	C000090	**Side**	Left	**Milepost Start**	012+0.790
				Milepost End	012+0.930

Critical Condition Information

Ditch Effectiveness	20	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 1,720,781
Rockfall Activity Score	27	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 1,720,781
Total RHRS Score	280	**30 yr Risk Cost**	$ 1,527,239	**Programmatic Cost Est Imp Two CS**	$ 860,391

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Attenuator on bottom bench and add barrier. 5-foot tall with a 30 ft long tail, general scaling. Possible bolting.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Rockfall Attenuator	$ 20.00	sf	24,500	$ 490,000
concrete barrier	$ 166.67	lf	700	$ 116,667
general scaling	$ 175.00	hr	557	$ 97,541
Rock bolts	$ 160.00	lf	1,000	$ 160,000
			Subtotal	$ 864,207
			Total w/ 105% OH	**$ 1,771,625**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Concrete barrier with fence extension

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	27	**Improved CI & CS**	63 / 2

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Concrete w/ fence	$ 283.33	lf	750	$ 212,500
			Subtotal	$ 212,500
			Total w/ 105% OH	**$ 435,625**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1159

Corridor	C000090	**Side**	Left	**Milepost Start**	012+0.940
				Milepost End	013+0.000

Critical Condition Information

Ditch Effectiveness	15	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 495,460
Rockfall Activity Score	27	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 495,460
Total RHRS Score	256	**30 yr Risk Cost**	$ 439,734	**Programmatic Cost Est Imp Two CS**	$ 247,730

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Attenuator on bottom bench and add barrier. 5-foot tall with a 30 ft long tail

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	15	**Improved CI & CS**	82 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Rockfall Attenuator	$ 20.00	sf	10,500	$ 210,000
	concrete barrier	$ 166.67	lf	300	$ 50,000
	general scaling	$ 175.00	hr	146	$ 25,594
				Subtotal	$ 285,594
				Total w/ 105% OH	**$ 585,467**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Fence extension on existing barrier

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	27	**Improved CI & CS**	63 | 2

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete w/ fence	$ 283.33	lf	300	$ 85,000
				Subtotal	$ 85,000
				Total w/ 105% OH	**$ 174,250**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1160

Corridor	C000090	**Side**	Left	**Milepost Start**	013+0.010
				Milepost End	013+0.070

Critical Condition Information

Ditch Effectiveness	15	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 378,209
Rockfall Activity Score	27	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 378,209
Total RHRS Score	302	**30 yr Risk Cost**	$ 335,671	**Programmatic Cost Est Imp Two CS**	$ 189,105

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Attenuator on bottom bench and add concrete barrier. 5-foot tall with a 30 ft long tail

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	15	**Improved CI & CS**	82 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Rockfall Attenuator	$ 20.00	sf	10,500	$ 210,000
	Concrete barrier	$ 166.67	lf	300	$ 50,000
	general scaling	$ 175.00	hr	122	$ 21,328
				Subtotal	$ 281,328
				Total w/ 105% OH	**$ 576,723**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Install barrier and extension

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	27	**Improved CI & CS**	63 | 2

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete w/ fence	$ 283.33	lf	225	$ 63,750
				Subtotal	$ 63,750
				Total w/ 105% OH	**$ 130,688**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1161

Corridor	C000090	**Side**	Left	**Milepost Start**	013+0.060
				Milepost End	013+0.190

Critical Condition Information

Ditch Effectiveness	12	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 670,284
Rockfall Activity Score	27	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 670,284
Total RHRS Score	315	**30 yr Risk Cost**	$ 594,895	**Programmatic Cost Est Imp Two CS**	$ 335,142

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Attenuator on bottom bench and maintain existing barrier. 5-foot tall with a 30 ft long tail

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	15	**Improved CI & CS**	82 / 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Rockfall Attenuator	$ 20.00	sf	22,750	$ 455,000
	Concrete barrier	$ 166.67	lf	650	$ 108,333
	general scaling	$ 175.00	hr	225	$ 39,449
				Subtotal	$ 602,782
				Total w/ 105% OH	**$ 1,235,703**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Add barrier

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	27	**Improved CI & CS**	63 / 2

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete w/ fence	$ 283.33	lf	320	$ 90,667
				Subtotal	$ 90,667
				Total w/ 105% OH	**$ 185,867**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1162

Corridor	C000090	**Side**	Left	**Milepost Start**	013+0.240
				Milepost End	013+0.280

Critical Condition Information

Ditch Effectiveness	9	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 132,283
Rockfall Activity Score	9	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 132,283
Total RHRS Score	242	**30 yr Risk Cost**	$ 28,548	**Programmatic Cost Est Imp Two CS**	$ 132,283

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Scale, install attenuator, barrier

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100 / 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Rockfall Attenuator	$ 20.00	sf	7,000	$ 140,000
	General Scaling	$ 175.00	hr	96	$ 16,721
	Concrete barrier	$ 166.67	lf	200	$ 33,333
				Subtotal	$ 190,055
				Total w/ 105% OH	**$ 389,612**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly				500	
				Subtotal	$ -
				Total w/ 105% OH	**$ -**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1163

Corridor	C000090	**Side**	Left	**Milepost Start**	013+0.320
				Milepost End	013+0.410

Critical Condition Information

Ditch Effectiveness	20	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 487,042
Rockfall Activity Score	25	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 487,042
Total RHRS Score	336	**30 yr Risk Cost**	$ 432,263	**Programmatic Cost Est Imp Two CS**	$ 243,521

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Scale, install attenuator, barrier

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Rockfall Attenuator	$ 20.00	sf	16,625	$ 332,500
General Scaling	$ 175.00	hr	170	$ 29,717
Concrete barrier	$ 166.67	lf	475	$ 79,167
			Subtotal	$ 441,384
			Total w/ 105% OH	**$ 904,837**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Barrier with fence extension

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	25	**Improved CI & CS**	76 / 2

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Concrete w/ fence	$ 283.33	lf	475	$ 134,583
			Subtotal	$ 134,583
			Total w/ 105% OH	**$ 275,896**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1164

Corridor	C000090	**Side**	Left	**Milepost Start**	013+0.440
				Milepost End	013+0.740

Critical Condition Information

Ditch Effectiveness	5	**Current Condition State**	1	**Programmatic Cost Est to CS1**	$ -
Rockfall Activity Score	9	**G/F/P**	GOOD	**Programmatic Cost Est Imp One CS**	$ -
Total RHRS Score	302	**30 yr Risk Cost**	$ 25,127	**Programmatic Cost Est Imp Two CS**	$ -

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Concrete barrier only to improve ditch effectivness and mitigate against the minor raveling.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 / 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete barrier	$ 166.67	lf	1,500	$ 250,000
				Subtotal	$ 250,000
				Total w/ 105% OH	**$ 512,500**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative add barrier and fence only

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					
				Subtotal	$ -
				Total w/ 105% OH	**$ -**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1165

Corridor	C000090	**Side**	Left	**Milepost Start**	014+0.000
				Milepost End	014+0.080

Critical Condition Information

Ditch Effectiveness	20	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 380,815
Rockfall Activity Score	20	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 380,815
Total RHRS Score	316	**30 yr Risk Cost**	$ 337,983	**Programmatic Cost Est Imp Two CS**	$ 190,407

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative General scaling and concrete barrier with fence

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 / 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General Scaling	$ 175.00	hr	146	$ 25,594
	Concrete w/ fence	$ 283.33	lf	500	$ 141,667
				Subtotal	$ 167,260
				Total w/ 105% OH	**$ 342,884**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative add barrier and fence only

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	20	**Improved CI & CS**	78 / 2

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete w/ fence	$ 283.33	lf	500	$ 141,667
				Subtotal	$ 141,667
				Total w/ 105% OH	**$ 290,417**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1166

Corridor	C000090	**Side**	Left	**Milepost Start**	014+0.350
				Milepost End	014+0.470

Critical Condition Information

Ditch Effectiveness	6	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 481,330
Rockfall Activity Score	9	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 481,330
Total RHRS Score	238	**30 yr Risk Cost**	$ 103,876	**Programmatic Cost Est Imp Two CS**	$ 481,330

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative General scaling and concrete barrier

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	15	**Improved CI & CS**	82 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General Scaling	$ 175.00	hr	400	$ 70,070
	Concrete barrier	$ 166.67	lf	770	$ 128,333

Subtotal	$ 198,403
Total w/ 105% OH	**$ 406,727**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative none

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					

Subtotal	$ -
Total w/ 105% OH	**$ -**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1167

Corridor	C000090	**Side**	Left	**Milepost Start**	020+0.710
				Milepost End	020+0.840

Critical Condition Information

Ditch Effectiveness	5	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 265,720
Rockfall Activity Score	15	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 265,720
Total RHRS Score	219	**30 yr Risk Cost**	$ 57,345	**Programmatic Cost Est Imp Two CS**	$ 265,720

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative General scaling and concrete barrier

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	15	**Improved CI & CS**	82	1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General Scaling	$ 175.00	hr	169	$ 29,575
	Concrete barrier	$ 166.67	lf	650	$ 108,333

Subtotal	$ 137,908
Total w/ 105% OH	**$ 282,712**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative none

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**		

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					

Subtotal	$ -
Total w/ 105% OH	**$ -**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1168

Corridor	C000090	**Side**	Left	**Milepost Start**	022+0.360
				Milepost End	022+0.460

Critical Condition Information

Ditch Effectiveness	3	**Current Condition State**	1	**Programmatic Cost Est to CS1**	$ -
Rockfall Activity Score	6	**G/F/P**	GOOD	**Programmatic Cost Est Imp One CS**	$ -
Total RHRS Score	310	**30 yr Risk Cost**	$ 18,512	**Programmatic Cost Est Imp Two CS**	$ -

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Maintain existing

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	6	**Improved CI & CS**	92 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*

Subtotal $ -

Total w/ 105% OH $ -

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative none

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*

Subtotal $ -

Total w/ 105% OH $ -

`

Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells		**Assessed By**	DLB
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Site Information

Section Number 1169

Corridor	C000090	**Side**	Right	**Milepost Start**	023+0.120
				Milepost End	023+0.240

Critical Condition Information

Ditch Effectiveness	12	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 424,203
Rockfall Activity Score	12	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 424,203
Total RHRS Score	246	**30 yr Risk Cost**	$ 95,002	**Programmatic Cost Est Imp Two CS**	$ 424,203

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Drape tecco net over slope, scale, replace barrier. Spot bolt where needed.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100 / 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General scaling	$ 175.00	hr	322	$ 56,306
	Concrete barrier	$ 166.67	lf	660	$ 110,000
	Draped Tecco Mesh	$ 8.67	sf	64,350	$ 557,700
	Rock bolts	$ 160.00	lf	300	$ 48,000
				Subtotal	$ 772,006
				Total w/ 105% OH	**$ 1,582,613**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative none

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					
				Subtotal	$ -
				Total w/ 105% OH	**$ -**

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Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells		**Assessed By**	DLB
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Site Information

Section Number 1170

Corridor	C000090	**Side**	Left	**Milepost Start**	023+0.490
				Milepost End	023+0.620

Critical Condition Information

Ditch Effectiveness	9	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 370,585
Rockfall Activity Score	20	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 370,585
Total RHRS Score	283	**30 yr Risk Cost**	$ 82,994	**Programmatic Cost Est Imp Two CS**	$ 370,585

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Scale loose blocks and install concrete barrier

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	12	**Improved CI & CS**	84 | 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General scaling	$ 175.00	hr	250	$ 43,794
Concrete barrier	$ 166.67	lf	700	$ 116,667
			Subtotal	$ 160,460
			Total w/ 105% OH	**$ 328,944**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative none

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
			Subtotal	$ -
			Total w/ 105% OH	**$ -**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1171

Corridor	C000090	**Side**	Left	**Milepost Start**	023+0.820
				Milepost End	023+0.910

Critical Condition Information

Ditch Effectiveness	9	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 411,012
Rockfall Activity Score	20	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 411,012
Total RHRS Score	416	**30 yr Risk Cost**	$ 92,048	**Programmatic Cost Est Imp Two CS**	$ 411,012

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Scale loose blocks and improve triple rail with concrete with fence or low energy FRB at base

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	12	**Improved CI & CS**	84	1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	General scaling	$ 175.00	hr	353	$ 61,852
	Concrete w/ fence	$ 283.33	lf	725	$ 205,417

Subtotal	$ 267,268
Total w/ 105% OH	**$ 547,900**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative none

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**		

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					

Subtotal	$ -
Total w/ 105% OH	**$ -**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1172

Corridor	C000090	**Side**	Left	**Milepost Start**	024+0.040
				Milepost End	024+0.190

Critical Condition Information

Ditch Effectiveness	3	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 569,400
Rockfall Activity Score	20	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 569,400
Total RHRS Score	442	**30 yr Risk Cost**	$ 127,520	**Programmatic Cost Est Imp Two CS**	$ 569,400

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Repair reactivating landslide at east end. Maintain existing rockfall mitigation

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 / 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Repair Landslide with excavation			10,000	
	Rock buttress			10,000	

Subtotal $ -

Total w/ 105% OH $ -

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative none

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					

Subtotal $ -

Total w/ 105% OH $ -

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1173

Corridor	C000090	**Side**	Left	**Milepost Start**	024+0.350
				Milepost End	024+0.440

Critical Condition Information

Ditch Effectiveness	3	**Current Condition State**	1	**Programmatic Cost Est to CS1**	$ -
Rockfall Activity Score	5	**G/F/P**	GOOD	**Programmatic Cost Est Imp One CS**	$ -
Total RHRS Score	242	**30 yr Risk Cost**	$ 12,792	**Programmatic Cost Est Imp Two CS**	$ -

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Concrete barrier at roadside for general improvement, through GOOD status may not warrant mitigation

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	5	**Improved CI & CS**	94 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete barrier	$ 166.67	lf	500	$ 83,333

Subtotal	$ 83,333
Total w/ 105% OH	**$ 170,833**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative none

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					

Subtotal	$ -
Total w/ 105% OH	**$ -**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1174

Corridor	C000090	**Side**	Left	**Milepost Start**	024+0.410
				Milepost End	024+0.500

Critical Condition Information

Ditch Effectiveness	9	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 272,608
Rockfall Activity Score	9	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 272,608
Total RHRS Score	252	**30 yr Risk Cost**	$ 61,052	**Programmatic Cost Est Imp Two CS**	$ 272,608

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Concrete barrier at roadside

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete barrier	$ 166.67	lf	350	$ 58,333

Subtotal	$ 58,333
Total w/ 105% OH	**$ 119,583**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative none

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					

Subtotal	$ -
Total w/ 105% OH	**$ -**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1175

Corridor	C000090	**Side**	Left	**Milepost Start**	024+0.590
				Milepost End	024+0.720

Critical Condition Information

Ditch Effectiveness	6	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 438,438
Rockfall Activity Score	9	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 438,438
Total RHRS Score	411	**30 yr Risk Cost**	$ 98,190	**Programmatic Cost Est Imp Two CS**	$ 438,438

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Maintain existing

Judgement OK

Improved Ditch Eff. Score	5	**Improved RF Activity Score**	9	**Improved CI & CS**	82	1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly				450	
				500	

Subtotal	$	-
Total w/ 105% OH	**$**	**-**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative none

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**		

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					

Subtotal	$	-
Total w/ 105% OH	**$**	**-**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1176

Corridor	C000090	**Side**	Left	**Milepost Start**	025+0.000
				Milepost End	025+0.090

Critical Condition Information

Ditch Effectiveness	9	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 390,310
Rockfall Activity Score	20	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 390,310
Total RHRS Score	281	**30 yr Risk Cost**	$ 87,412	**Programmatic Cost Est Imp Two CS**	$ 390,310

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Concrete barrier with fence at roadside. Perform general scaling with one five-person crew for 2 weeks

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	20	**Improved CI & CS**	78 / 2

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete w/ fence	$ 283.33	lf	450	$ 127,500
	General Scaling	$ 175.00	hr	500	$ 87,500
				Subtotal	$ 215,000
				Total w/ 105% OH	**$ 440,750**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative none

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					
				Subtotal	$ -
				Total w/ 105% OH	**$ -**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1177

Corridor	C000090	**Side**	Left	**Milepost Start**	026+0.240
				Milepost End	026+0.430

Critical Condition Information

Ditch Effectiveness	8	**Current Condition State**	1	**Programmatic Cost Est to CS1**	$ -
Rockfall Activity Score	5	**G/F/P**	GOOD	**Programmatic Cost Est Imp One CS**	$ -
Total RHRS Score	419	**30 yr Risk Cost**	$ 29,039	**Programmatic Cost Est Imp Two CS**	$ -

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Concrete barrier present, add attenuator to improve ditch effectivness.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Rockfall Attenuator	$ 20.00	sf	42,000	$ 840,000
				Subtotal	$ 840,000
				Total w/ 105% OH	**$ 1,722,000**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Add fence extension to existing barrier as an alternative to the above approach.

Judgement OK

Improved Ditch Eff. Score	6	**Improved RF Activity Score**	5	**Improved CI & CS**	86 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Fence extension to existing barrier	$ 150.00	lf	1,200	$ 180,000
		#N/A	#N/A		
		#N/A	#N/A		
		#N/A	#N/A		
		#N/A	#N/A		
		#N/A	#N/A		
		#N/A	#N/A		
				Subtotal	$ 180,000
				Total w/ 105% OH	**$ 369,000**

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Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1178

Corridor	C000090	**Side**	Left	**Milepost Start**	026+0.510
				Milepost End	026+0.750

Critical Condition Information

Ditch Effectiveness	20	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 1,244,062
Rockfall Activity Score	7	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 1,244,062
Total RHRS Score	386	**30 yr Risk Cost**	$ 264,437	**Programmatic Cost Est Imp Two CS**	$ 1,244,062

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Concrete barrier with fence at roadside, add attenuator as an option to further improve ditch effectivness.

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	3	**Improved CI & CS**	88 | 1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete w/ fence	$ 283.33	lf	1,300	$ 368,333

Subtotal $ 368,333

Total w/ 105% OH $ 755,083

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative none

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**	

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					

Subtotal $ -

Total w/ 105% OH $ -

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Site Information

Section Number 1179

Corridor	C000090	**Side**	Left	**Milepost Start**	026+0.830
				Milepost End	027+0.010

Critical Condition Information

Ditch Effectiveness	9	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 498,225
Rockfall Activity Score	9	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 498,225
Total RHRS Score	207	**30 yr Risk Cost**	$ 105,902	**Programmatic Cost Est Imp Two CS**	$ 498,225

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Concrete barrier at roadside

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100	1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Concrete barrier	$ 166.67	lf	1,050	$ 175,000

Subtotal $ 175,000

Total w/ 105% OH $ 358,750

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative none

Judgement OK

Improved Ditch Eff. Score		**Improved RF Activity Score**		**Improved CI & CS**		

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly					

Subtotal $ -

Total w/ 105% OH $ -

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Site Information

Section Number 1180

Corridor	C000090	**Side**	Left	**Milepost Start**	027+0.350
				Milepost End	027+0.560

Critical Condition Information

Ditch Effectiveness	15	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 2,016,625
Rockfall Activity Score	27	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 2,016,625
Total RHRS Score	351	**30 yr Risk Cost**	$ 1,762,849	**Programmatic Cost Est Imp Two CS**	$ 1,008,313

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Site has been improved with FRB at base of slope. Place attenuator to reduce bouncing rocks and improve fence effectivness. Install 5-foot attenuator 50 feet above ditch with 30 foot tail.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100	1

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly	Rockfall Attenuator	$ 20.00	sf	45,500	$ 910,000
				Subtotal	$ 910,000
				Total w/ 105% OH	**$ 1,865,500**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Maintain new fence as is.

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	9	**Improved CI & CS**	75	2

Mitigation Elements	*Element*	*Unit Cost*	*Units*	*Qty*	*Total*
Match text exactly				1,200	
				Subtotal	$ -
				Total w/ 105% OH	**$ -**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1181

Corridor	C000090	**Side**	Left	**Milepost Start**	027+0.790
				Milepost End	028+0.090

Critical Condition Information

Ditch Effectiveness	20	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 3,182,308
Rockfall Activity Score	27	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 3,182,308
Total RHRS Score	438	**30 yr Risk Cost**	$ 2,781,841	**Programmatic Cost Est Imp Two CS**	$ 1,591,154

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Place attenuator to reduce bouncing rocks and improve fence. Install 5-foot attenuator 50 feet above ditch with 30 foot tail.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Rockfall Attenuator	$ 20.00	sf	42,000	$ 840,000
Concrete barrier	$ 166.67	lf	1,200	$ 200,000
			Subtotal	$ 1,040,000
			Total w/ 105% OH	**$ 2,132,000**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Concrete barrier with fence

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	9	**Improved CI & CS**	75 / 2

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Concrete w/ fence	$ 283.33	lf	1,200	$ 340,000
			Subtotal	$ 340,000
			Total w/ 105% OH	**$ 697,000**

Montana Department of Transportation RAMP Mitigation Calculator

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Site Information

Section Number 1182

Corridor	C000090	**Side**	Left	**Milepost Start**	028+0.120
				Milepost End	028+0.200

Critical Condition Information

Ditch Effectiveness	6	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 268,662
Rockfall Activity Score	27	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 268,662
Total RHRS Score	319	**30 yr Risk Cost**	$ 57,107	**Programmatic Cost Est Imp Two CS**	$ 268,662

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Place attenuator to reduce bouncing rocks and improve fence. Install 5-foot attenuator 50 feet above ditch with 30 foot tail.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100 | 1

Mitigation Elements
Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Rockfall Attenuator	$ 20.00	sf	17,500	$ 350,000
Concrete barrier	$ 166.67	lf	500	$ 83,333
			Subtotal	$ 433,333
			Total w/ 105% OH	**$ 888,333**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Concrete barrier with fence. Alternative to the above option with no CS improvement.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	27	**Improved CI & CS**	75 | 2

Mitigation Elements
Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Concrete w/ fence	$ 283.33	lf	500	$ 141,667
			Subtotal	$ 141,667
			Total w/ 105% OH	**$ 290,417**

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Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells	
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Site Information

Section Number 1183

Corridor	C000090	**Side**	Left	**Milepost Start**	028+0.450
				Milepost End	028+0.740

Critical Condition Information

Ditch Effectiveness	5	**Current Condition State**	2	**Programmatic Cost Est to CS1**	$ 1,328,600
Rockfall Activity Score	35	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 1,328,600
Total RHRS Score	350	**30 yr Risk Cost**	$ 282,407	**Programmatic Cost Est Imp Two CS**	$ 1,328,600

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Place attenuator to reduce bouncing rocks and improve fence. Install 5-foot attenuator 50 feet above ditch with 30 foot tail.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Rockfall Attenuator	$ 20.00	sf	45,500	$ 910,000
Concrete barrier	$ 166.67	lf	1,300	$ 216,667
			Subtotal	$ 1,126,667
			Total w/ 105% OH	**$ 2,309,667**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Concrete barrier with fence

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Concrete w/ fence	$ 283.33	lf	1,300	$ 368,333
			Subtotal	$ 368,333
			Total w/ 105% OH	**$ 755,083**

Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells		**Assessed By**	DLB
Ver. 1.00		**Assessment Date**	March 13-15, 2017

Site Information

Section Number 1184

Corridor	C000090	**Side**	Left	**Milepost Start**	030+0.660
				Milepost End	030+0.860

Critical Condition Information

Ditch Effectiveness	3	**Current Condition State**	1	**Programmatic Cost Est to CS1**	$ -
Rockfall Activity Score	15	**G/F/P**	GOOD	**Programmatic Cost Est Imp One CS**	$ -
Total RHRS Score	286	**30 yr Risk Cost**	$ 30,500	**Programmatic Cost Est Imp Two CS**	$ -

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Add roadside barrier, drape tecco mesh. A big rock was in the ditch on the north end of the slope at the time of the visit. This activity may warrant additional attention.

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100 | 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Draped Tecco Mesh	$ 8.67	sf	50,400	$ 436,800
General Scaling	$ 175.00	hr	300	$ 52,500
Concrete Barrier	$ 166.67	lf	1,120	$ 186,667

Subtotal $ 675,967

Total w/ 105% OH $ 1,385,732

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Concrete Barrier

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	9	**Improved CI & CS**	88 | 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Concrete Barrier	$ 166.67	lf	1,120	$ 186,667

Subtotal $ 186,667

Total w/ 105% OH

Rocky Creek Corridor
I-90 East of Bozeman; MP 315

Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells		**Assessed By**	BAB
Ver. 1.00		**Assessment Date**	3/13/2017

Site Information

Section Number 1260

Corridor	C000090	**Side**	Left	**Milepost Start**	315+0.070
				Milepost End	315+0.190

Critical Condition Information

Ditch Effectiveness	18	**Current Condition State**	3	**Programmatic Cost Est to CS1**	$ 911,040
Rockfall Activity Score	50	**G/F/P**	FAIR	**Programmatic Cost Est Imp One CS**	$ 911,040
Total RHRS Score	515	**30 yr Risk Cost**	$ 451,628	**Programmatic Cost Est Imp Two CS**	$ 455,520

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Bedded (tilted)/differential weathering at site. Bench or break about 35 ft above highway, at lower third of slope height. To improve: 1) scale slope above bench (approximately 3/4 of total slope area) or scale critial portion of that area (approximately 2/3 of total slope area); 2) clean lower bench and install an attenuator. This option would require MRB and RCNs with lane shifts

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	15	**Improved CI & CS**	82 / 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Rockfall Attenuator	$ 20.00	sf	28,800	$ 576,000
General Scaling	$ 175.00	hr	380	$ 66,500
Clean Lower Bench	$ 2,000.00	day	3	$ 6,000
			Subtotal	$ 648,500
			Total w/ 105% OH	**$ 1,329,425**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative Clear bench and install concrete barriers with a fence extension along the edge of the road

Judgement OK

Improved Ditch Eff. Score	9	**Improved RF Activity Score**	15	**Improved CI & CS**	69 / 2

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
Concrete Barrier w/ fence extension	$ 283.33	lf	650	$ 184,167
General Scaling	$ 175.00	hr	380	$ 66,500
Clean Lower Bench	$ 2,000.00	day	3	$ 6,000
			Subtotal	$ 256,667
			Total w/ 105% OH	**$ 526,167**

Montana Department of Transportation RAMP Mitigation Calculator

Fill in orange cells

Ver. 1.00

Assessed By BAB

Assessment Date 3/13/2017

Section Number 1261

Site Information

Corridor	C000090	**Side**	Left	**Milepost Start**	315+0.260
				Milepost End	315+0.500

Critical Condition Information

Ditch Effectiveness	70	**Current Condition State**	4	**Programmatic Cost Est to CS1**	$ 1,850,550
Rockfall Activity Score	81	**G/F/P**	POOR	**Programmatic Cost Est Imp One CS**	$ 1,233,700
Total RHRS Score	664	**30 yr Risk Cost**	$ 1,974,200	**Programmatic Cost Est Imp Two CS**	$ 616,850

Cost Estimate No 1: Objective: Improve to CS 1 ('Good' Catchment AND 'Low' Activity)

Narrative Tilted bedding with less differential weathering than 1260. Some colluvium at cut crest. Potential for rockfall from above and larger block failures. To improve: 1) scale the slope, with particularly heavy scaling at the brow of the middle section of the slope in the colluvium; 2) 8-10' attenuator at top with cable nets drapped to within 5 ft of ground; 3) use rock dowels to pin bad spots in bedding, with about 20 bolts in the north end, 10 in the mid-east end, and 20 on the east end; 4) transition from attenuator fence to cable net drape on middle eastern outcrop; 5) excavate/remove knob on eastern end (will require temporary closure of I-90).

Judgement OK

Improved Ditch Eff. Score	3	**Improved RF Activity Score**	3	**Improved CI & CS**	100 | 1

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	650	$ 113,750
Rockfall Attenuator	$ 20.00	sf	123,750	$ 2,475,000
Rock Bolts	$ 160.00	lf	1,250	$ 200,000
Rock Excavation	$ 23.33	cy	5,700	$ 133,000
			Subtotal	$ 2,921,750
			Total w/ 105% OH	**$ 5,989,588**

Cost Estimate No 2: Objective: Improve one CS (i.e. 'Limited' to 'Moderate' Catchment, 'Constant' to 'Few' Activity)

Narrative 1) scale the slope, as in previous estimate; 2) bolt "knob" on east end of cut; 3) place concrete barrier with fence extension. Trim blasting/rock excavation may still be required to address the "knob"

Judgement OK

Improved Ditch Eff. Score	27	**Improved RF Activity Score**	27	**Improved CI & CS**	50 | 3

Mitigation Elements

Match text exactly

Element	*Unit Cost*	*Units*	*Qty*	*Total*
General Scaling	$ 175.00	hr	650	$ 113,750
Rock bolts	$ 160.00	lf	2,000	$ 320,000
concrete barrier w/ fence extension	$ 283.33	lf	1,300	$ 368,333
			Subtotal	$ 802,083
			Total w/ 105% OH	**$ 1,644,271**

Appendix F

TASK 6 REPORT – DEVELOP COST / BENEFITS

Montana Department
or Transporation

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

Task 6 Report
Develop Cost/Benefits

LANDSLIDE
TECHNOLOGY
A DIVISION OF CORNFORTH CONSULTANTS

Prepared for:

Montana Department of Transportation
Helena, Montana

ROCKFALL HAZARD PROCESS ASSESSMENT

TASK 6 REPORT
DEVELOP COST/BENEFITS

August 29, 2017

Prepared by:

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Executive Summary

This document is the deliverable for Task 6 of the Montana Department of Transportation (MDT) research project “Rockfall Hazard Rating Process Assessment” (Project No. 15-3059V). It covers the development of benefit/cost scenarios and analysis approaches for life-cycle cost and return on investment.

The work accomplished in this task is one of the final steps in implementing a complete, full-featured Transportation Asset Management program that incorporates rock slopes as a critical transportation network asset. Application of the benefit/cost analyses in the long-term planning process permits understanding of the value that rock slopes provide and the risks of not addressing them in a proactive manner.

The cost/benefit analyses prepared integrate the data collected in previous tasks, (asset condition, corridor importance, etc.) into a single metric allowing straightforward and defensible project prioritization. The need for this prioritization arises from the funding limitations faced by every agency, where the total cost of all deserving projects always exceeds the available funds. These calculations enable planners to consistently determine the maximum benefit achievable for a given amount of funding, based on the quality and comprehensiveness of data in the asset management database. In a final list of projects, the projects that provide maximum benefit for minimum funding will be prioritized when allocating budget resources.

A reactive approach that addresses the highest-hazard sites first as a budget allocation method is a common way to prioritize work when risk reduction is the primary motivation. However, in a Return on Investment (ROI) model, preservation to reduce life-cycle cost is given some priority over reconstruction and hazard reduction. This approach, applied to rock slopes in the RAMP program, enables MDT to rationally prioritize maintenance and mitigation rather than reliance on service interruptions or tragedy to drive response.

For the nearly 1,000 rock slopes in the fully evaluated inventory, spread through the western and southern parts of the state, the research team found that an average Condition Index is 63, out of a possible 100 points. To maintain this index and prevent further worsening conditions, an annual funding level of $28 million is found to be sufficient to maintain the current statewide condition after ten years based on these initial models. It is noted that this figure includes not only projects identified explicitly as slope mitigation and reconstruction work, but also work affecting rock slopes that are built within other corridor rehabilitation projects, and not necessarily broken out separately. If rock slope funding is applied on a reactive, worst-first basis, the modeling indicates maintaining current conditions would require higher funding levels of approximately $35 million per year. By incorporating proactive preservation actions, MDT can save $7 million per year by taking a proactive approach to prevent excessive slope deterioration.

Compared to a strategy where no preservation work is done, the desired preservation investment reduces life cycle costs by 19%, a savings which is 114% of the preservation investment over the analysis period. Applying these recommendations, particularly in the life cycle cost and project selection areas, will help the Department derive maximum benefit from limited budget dollars. This model, which considers preservation, indicates that $1 spent improving rock slopes not only pays for itself, but returns an additional $1.14 to the Department and its road users.

Moreover, incorporating a proactive approach of rock slope preservation into programmed projects directly reduces limited Montana state maintenance funding of approximately $170,000 annually by using federal participation. Increasing the number of rock slopes treated as part of programmed safety and/or corridor improvement projects improves MDT’s return on investment by reducing life cycle costs.

Applying the recommendations contained in this task report, particularly in the life cycle cost and project selection areas, will help the Department effectively provide a highway network that fulfills its Mission Statement of emphasizing quality, safety, cost effectiveness, economic vitality, and sensitivity to the environment.

The current models developed in this research project are reliant on quantitative estimates and expert judgement. By collecting and incorporating additional, uniformly collected data, MDT will improve its decision support tools and budget forecasting capabilities. Ongoing research recommendations that can be undertaken at either the Agency or Geotechnical Group level to support TAM-compatibility including:

- Develop routine annual budget for geotechnical asset inspection, commensurate with the inspection intervals specified in the inspection policy.
- Enhance the inventory database to support the inspection process, including inspection crew and equipment scheduling, quality assurance review, storage of historical data, issuance of work requests, and management reports.
- Improve prototype asset-level analysis of risk and life cycle cost described in Section 8 for use in project planning and programming with continued data collection and event tracking.
- Publish annual reports of geotechnical asset condition to management and on a public-facing performance dashboard on the Department’s web site.
- Improve accident reporting procedures to indicate when rockfall or geotechnical asset limitations or failures are contributing factors, ideally by encouraging use of the AGOL-based Event Tracker developed as part of the RAMP research project.

1 Introduction

One of the final steps in implementing a complete, full-featured RAMP program is the application of benefit/cost analysis in the long-term planning process. These analyses integrate the data collected in previous steps, (asset condition, corridor importance, etc.) into a single metric allowing straightforward and defensible project prioritization. The need for this prioritization arises from the funding limitations faced by every agency, where the total cost of all deserving projects always exceeds the available funds. Benefit/cost calculations enable planners to consistently determine the maximum benefit achievable for a given amount of funding, based, of course, on the quality and comprehensiveness of data in the asset management database. In a final list of projects, the projects that provide maximum benefit for minimum funding will be prioritized when allocating budget resources.

The life cycle agency benefit is a combination of the life cycle benefit and the recovery benefit of addressing a given site. The life cycle benefit is a function of condition state and slope size describing the net benefit to the agency in terms of increased slope life span, since slope replacement generally becomes more expensive with time. The recovery benefit represents the savings to the state in decreased maintenance/event response costs. The risk reduction user benefit is a combination of the mobility and safety benefits. Both of the user benefits are tied to risk, frequently presented as the annual likelihood of an adverse event and the probable impacts of that event. Potential user mobility impacts include increased travel distances and time, or the complete inability of travelers to reach their desired destinations. The safety impact term estimates damages from accidents, typically providing a per-accident average cost that includes both injury and non-injury accidents.

When these cost and benefit concepts are quantified and applied in an objective and consistent way, the agency will be provided with a relatively simple tool for use in multiple aspects of decision support. However, when making funding decisions, the agency should bear in mind any assumptions or estimates made when calculating benefits and costs. Initial costs and benefits should be refined by more detailed studies during the planning process, which may lead to funding allocation adjustments.

This task incorporates the RAMP inventory, site-specific condition and risk assessments performed in 2003-2004 and updated with additional ratings performed in 2015 and 2016, and applies updated network-level programmatic costs estimates and deterioration estimates generated as part of the March 2017 meetings in Helena to estimate investment scenarios to maintain current rock slope conditions at the statewide, network level. These applications provide a clear example of how carefully applying funding proactively rather than reacting to the worst sites first reduces long term costs in maintaining current conditions on the order of millions per year.

The report sections describe the factors that have been updated for better capture of MDT specific-costs as well as incorporation of cost estimating generated from MDT data during other research activities, starting with the incorporation of maintenance costs and updating network-level slope improvement costs.

Additionally, the procedures described in this Task report have been applied to the sites visited as part of Task 5 and are described in Section 8.1. This example application of the procedures exhibits their function and usefulness for assisting MDT in project selection and transitioning from the network level programmatic estimates to the more site-specific cost estimates generated in Task 5.

2 Determination of Average Annual Maintenance Costs Based on Site Condition State

In March 2017, MDT's maintenance personnel provided Landslide Technology with annual costs for the two job codes reported to contain maintenance costs associated with rockfall, subdivided down by Maintenance section. The two codes were 1203 (Debris Removal) and 3106 (Clean/Shape Ditches). Annual costs were provided by MDT for 2009 to 2016. The average annual costs per section are shown graphically in Figure 2-1. Red sections charged the highest amount to these codes, while green sections charged the least. The job codes did not only contain rockfall-related maintenance work. For example, Debris Removal, in addition to clearing rocks, covered removing deceased wildlife, tire debris, and cleaning gravel off the road at the end of winter, among other things. In the initial examination of average annual costs per maintenance section, some sections in eastern Montana had relatively high charges to these job codes, and there were no inventoried rock slopes in these sections.

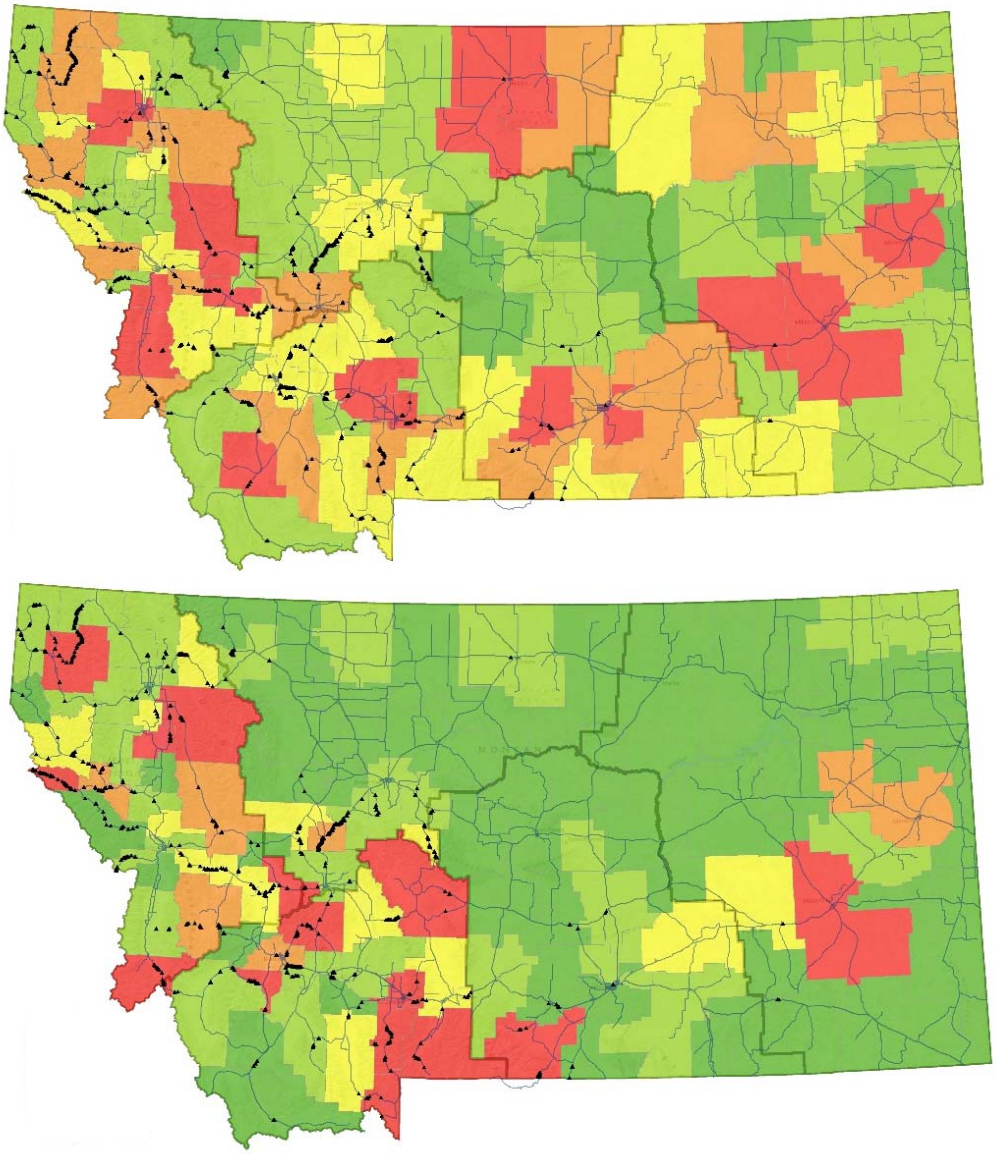

Figure 2-1: Relative average annual dollar amount spent by each maintenance section between 2009 and 2016 for maintenance code 1203 (top) and Code 3106 (bottom). Section color is based on relative dollar amount spent. Black dots show inventoried RAMP sites.

In a March 2017 Helena meeting, participants discussed the likely percentage of each code spent on rockfall-related maintenance. A former maintenance supervisor for the Wolf Creek Station reported that approximately 75% of his 3106 costs, and about 20-30% of his 1203 costs, were related to rockfall. Landslide Technology then worked to develop a correlation between rock slope prevalence and condition with the percentage of 3106 or 1203 costs the section spends on rockfall-related maintenance.

2.1 Average Annual Costs from Maintenance Code 3106 – Clean/Shape Ditches

LT analyzed several parameters at the Maintenance Section level using a combination of GIS and spreadsheet analyses. GIS analysis provided the number of corridor segments (each approximately 1 mile long) containing rock slopes in Fair or Poor condition, and compared this to the total number of road miles in the section. Road miles not maintained by MDT were removed. These analyses indicate that MDT expends approximately $170,000 annually on rockfall-related ditch cleaning. This expenditure is entirely reactive and is sourced from state maintenance funds.

Wolf Creek Section had the highest percentage of road miles with rock slopes in Fair or Poor condition: 48%, and reported spending about 75% of their 3106 dollars on rockfall-related ditching. LT assumed that even sections with only Good Condition rock slopes would still spend some money on rockfall-related ditching, in order to maintain good catchments. We assumed districts with only Good condition rock slopes still spent 5% of their 3106 charges on rockfall-related maintenance. A simple linear correlation was then developed and used to predict the proportion of 3106 spent on rockfall based on the percentage of maintenance section corridor road miles next to rock slopes in Fair or Poor condition. During Task 5 field work and follow-up work for Task 6, LT also surveyed Maintenance Section supervisors from Lookout Pass, West Glacier, and Bozeman sections, obtaining an estimate of the percentage of 3106 dollars they spent on rockfall-related maintenance. Their responses correlated very well with the predicted values, as shown in Figure 2-2 below.

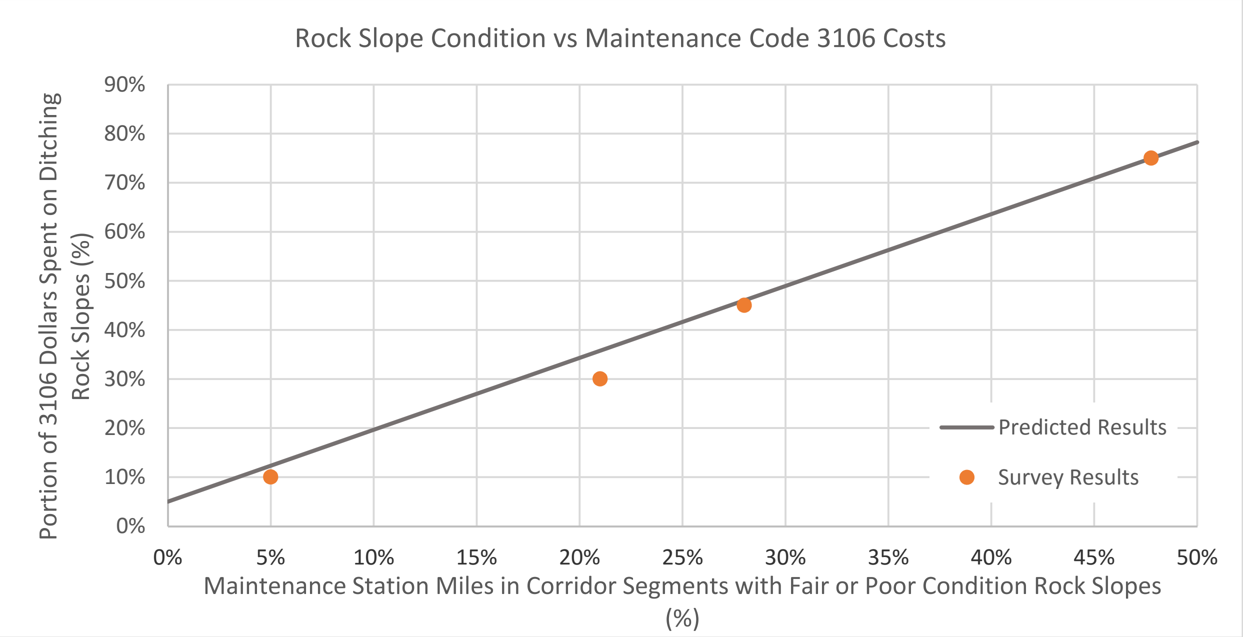

Figure 2-2: Predicted percentage of 3106 dollars spent on rockfall-related maintenance based on the percentage of maintenance section corridor miles with rock slopes in Fair or Poor condition. Orange dots are the estimates provided by individual section supervisors.

The goal of this work was to develop maintenance costs based on asset condition. To extract this from the initial correlation, additional work was needed. Using the correlation shown in Figure 2-2, we estimated the average annual amount spent on cleaning and shaping ditches related to rockfall. Then, using GIS analyses, we summarized the estimated square footage of Good, Fair, and Poor condition rock slopes in each section and divided the funding between each group based on percentage of total footage. This initial work resulted in near-equal costs for all asset conditions, which was unreasonable. Although maintenance did not provide information on the proportion of 3106 spent on Good, Fair, or Poor slopes within the section, past interviews have indicated the Poor condition slopes require much more maintenance time and effort than Good condition slopes. We therefore weighted the estimated square footage in each condition state based on the following assumptions:

- Fair Condition slopes were assumed to require 4 times more maintenance work than Good Condition Slopes.
- Poor Condition slopes were assumed to require 4 times more maintenance work than Fair condition slopes.

Using these relative weights, we calculated annual maintenance costs/square foot for each maintenance section, and then averaged these costs statewide. The resulting maintenance costs are presented in Table 2-1 in the following section.

2.2 Average Annual Costs for Maintenance Code 1203 – Debris Removal

Applying the same expert elicitation methods used for Code 3106, LT developed a similar correlation between rock slope condition, section miles and the proportionate amount spent on rockfall-related debris removal, which is shown in Figure 2-3. The consensus from MDT personnel at the March meeting was that about 15-30% of a station's 1203 budget went to clearing rockfall debris. We further assumed that in stations where all rock slopes were in Good condition, at most 5% of the debris removal budget would be related to rockfall, since by definition, Good condition slopes have good catchment, and rockfall rarely reaches the road. These analyses indicated that approximately $120,000 is expended on rockfall-related debris removal annually.

The correlation between the predicted percentages and the percentages reported in the field survey were not as strong as for code 3106. Three of the four surveyed section managers reported spending 30-40% of their 1203 costs on rockfall cleanup, even though the relative percentage of Fair and Poor condition rock slopes varied significantly between the sections. However, setting the percentage spent on rockfall removal at 35% statewide did not result in reasonable maintenance costs per square foot of rock slope face. Linear correlation between the new survey data was poor, so we opted to retain the correlation developed during the expert elicitation meeting when estimating average per square foot maintenance costs under 1203. An average annual amount spent on rockfall debris removal was calculated from a station's reported annual 1203 expenditures and its inventoried rock slopes.

As with maintenance code 3106, it was assumed that Poor sites require more maintenance attention than Fair or Good sites. As in the previous section, the estimated square footage in each condition state was weighted. The weights differ from those used in 3106 because even though Good condition slopes require regular, though infrequent, ditch cleaning, they are less unlikely to generate rocks on the roadway. The estimated square footage in each condition state based on the following assumptions:

- Fair Condition slopes were assumed to require 5 times more maintenance work than Good Condition Slopes, with rockfall reaching the road once or twice a year
- Poor Condition slopes were assumed to require 10 times more maintenance work than Fair condition slopes, with rockfall reaching the road multiple times per year

Using these relative weights, we calculated annual maintenance costs/square foot for each maintenance section, and then averaged these costs statewide. The resulting maintenance costs are presented in Table

2-1, and are summed with the results from the 3106 work to estimate a total maintenance cost per square foot of rock slope face based on asset condition.

Note that the unit costs, while apparently low, will accumulate over time and worsen when current conditions are not maintained. Also note that costs to respond to rockfall (Code 1203) are approximately double the costs to maintain an effective ditch (Code 3106).

Using the above estimations, a combined sum of maintenance expenditures on rock slope maintenance is approximately $290,000 of state-funded maintenance dollars annually. Figure 2-4 exhibits a distribution of estimated annual rock slope maintenance costs per section.

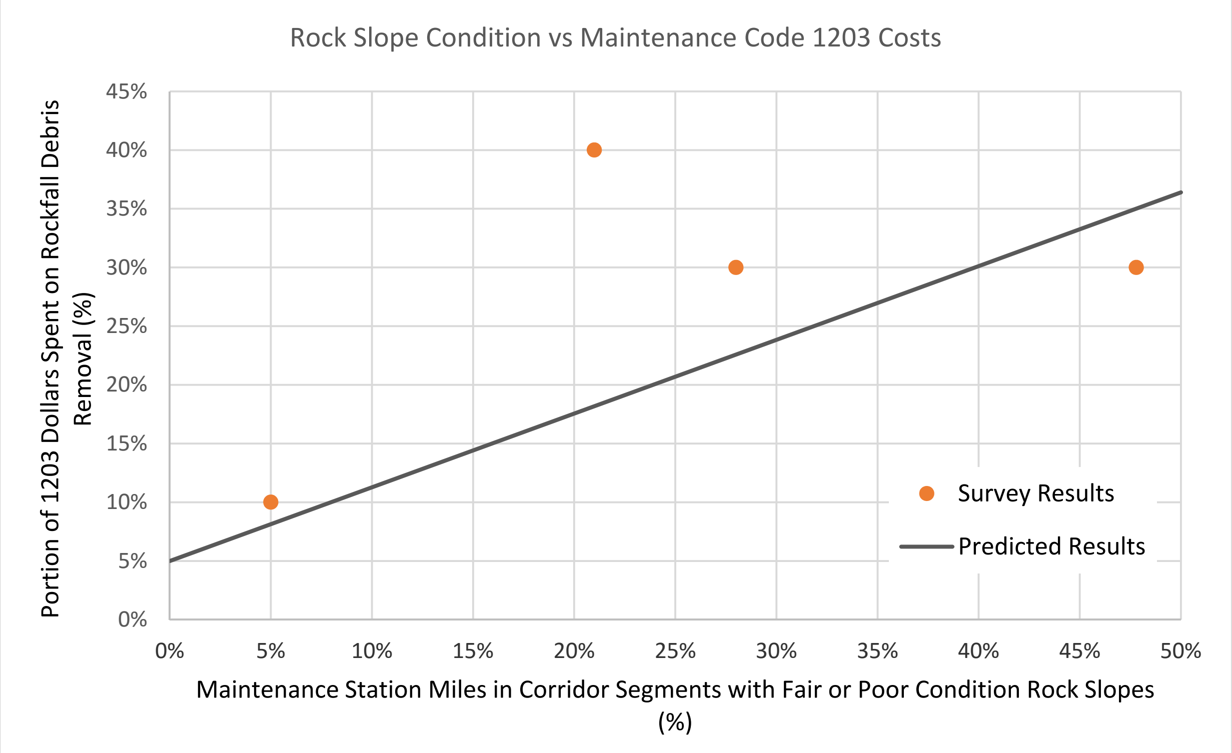

Figure 2-3: Predicted percentage of 1203 dollars spent on rockfall-related maintenance based on the percentage of maintenance section corridor miles with rock slopes in Fair or Poor condition. Orange dots are the estimates provided by individual section supervisors.

Table 2-1: Estimated annual maintenance costs per square foot of rock slope face captured by maintenance codes 1203 and 3106.

	Relative Weight in Maintenance Work		Annual Maintenance cost/square foot		
Condition State	Code 1203	Code 3106	Code 1203	Code 3106	Total
Good	1	1	$0.0015	$0.0006	$0.0021
Fair	5	4	$0.0086	$0.0046	$0.0132
Poor	50	16	$0.0127	$0.0077	$0.0204

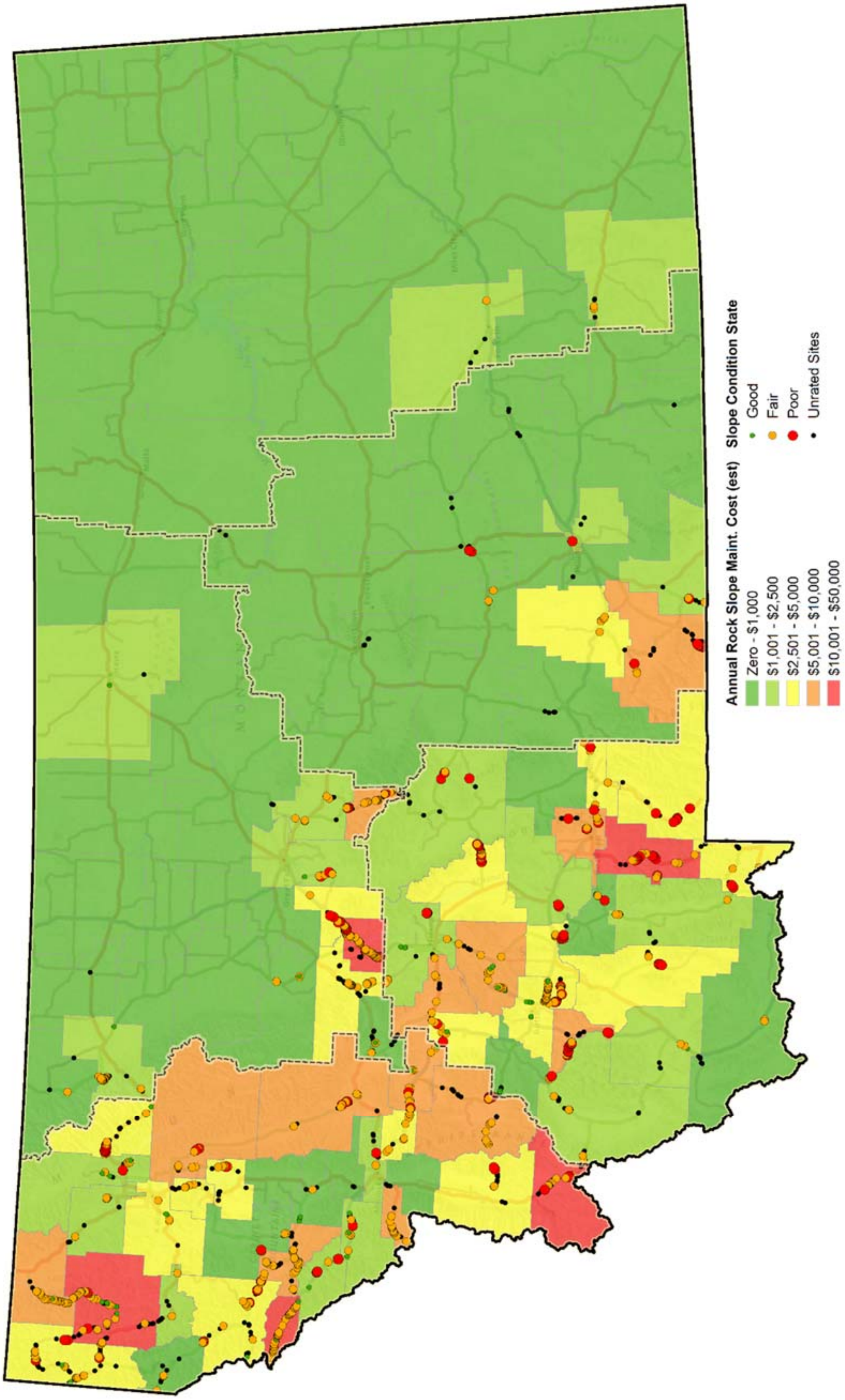

Figure 2-4: Estimated annual rock slope maintenance costs per Section.

3 Updating Programmatic Unit Improvement Costs

In 2015, Landslide Technology used MDT's 2004 conceptual mitigation costs and 2004 rock slope ratings to develop a linear correlation between rock slope condition and improvement costs, as described in Task 2. The estimated cost, including overhead, to improve one square foot of rock slope face one condition state, was $7.30. Note that the 'overhead' multiplier is applied to the sum total rockfall mitigation-specific elements such as scaling, rock bolts, attenuator fences, etcetera and intends to capture additional costs such as design efforts, traffic control, contractor mobilization, construction engineering, and other costs. Site-specific needs will change these 'overhead' costs significantly and the estimates do not replace site-specific conceptual design efforts.

In 2017, Landslide Technology revised that earlier work to incorporate the 75 conceptual mitigation plans developed as part of Task 5. The 2004 unit costs for various mitigation items were also updated. In 2004, double and triple-rail guardrail was recommended as a mitigation component at multiple sites. Other mitigation options in lieu of guardrail are recommended for mitigation work, and where guardrail may have been considered in the past, concrete barriers are now typically recommended. All guardrail used in the 2004 conceptual mitigation designs were replaced with concrete barriers. New conceptual mitigation costs were calculated for each site. Sixteen sites which received a conceptual mitigation design in 2004 were revisited in 2017. For these sixteen sites, only the newer 2017 conceptual design was used in the final dataset.

In 2004, there were very few Condition State 1 and Condition State 2 sites in the conceptual mitigation dataset. In order to fill this gap in 2015, Landslide Technology developed general mitigation designs for Condition State 1 and 2 sites, and applied them to sites which had been rated, but had not received a site-specific conceptual mitigation design. Because the 2017 work was done on a corridor basis, multiple new Condition State 1 and Condition State 2 sites were added, particularly along I-90. The general mitigation designs developed in 2015 were removed from the final 2017 dataset. Every site in the dataset has now had a site-specific conceptual mitigation design developed by an engineering geologist or geotechnical engineer. The final dataset consists of 159 sites. For those Condition State 1 slopes where "maintain ditch" was the only recommended mitigation work, the annual maintenance cost developed in Section 2 was applied to that site. This final dataset was analyzed using the same methods described in Task 2. The revised estimated mitigation unit cost is $8.20/sq ft. This unit cost includes a 105% overhead rate.

As a further check, LT recalculated the conceptual mitigation costs utilizing bid tab data provided by MDT. Not all mitigation components specified in the conceptual designs were reflected in the bid tabs. Therefore, a mixed approach was adopted: using average bid prices where available, and LT's own engineering estimates where necessary. This check results in a difference of $0.01 per square foot from the $8.20 above, building confidence in the $8.20/sq ft value utilized in the analyses.

4 Monetizing Risk: User Costs of Mobility and Safety

An objective of geotechnical asset management is to set priorities among geotechnical investments in a way that minimizes agency life cycle agency cost at the same time that it maximizes safety and mobility. These are competing objectives: when the funding level is fixed, adding money to safety-related improvements means taking money away from preservation, and vice versa. The framework requires a fair way to balance these objectives. One common way to do this is to monetize safety and mobility in the form of social cost. The models for this kind of analysis are well established (AASHTO 2010). Bridge and pavement management systems use these models for the same purpose. A good description with example application to risk analysis can be found in a recent Florida DOT research report (Sobanjo and Thompson 2013).

Social cost models can convert estimates of accident count and road closure duration in hours per year into consistent estimates of social cost as long as traffic volume and detour route or alternative mode information is available. For the present application, AASHTO's 'Red Book' (AASHTO 2010) has a very detailed presentation of alternative methods, including quantitative parameters derived from dozens of studies. MDT conducted a survey of geotechnical personnel, obtaining event records and impacts that were used to correlate asset condition and event likelihood. However, the data available for analysis was still scarce, so a relatively simple adaptation of the Red Book models was used for the necessary computations.

4.1.1 Likelihood of service disruption

When a rockfall incident takes place, there may be a delay or interruption of traffic flow until the debris can be cleared from the road and any necessary repairs can be made. Traffic slowdowns may continue even after the road is reopened as crews work to remove debris and repair damaged assets such as guardrails. Accidents resulting in vehicle damage or personal injury may also occur, either during the failure itself, or when a roadway user attempts to avoid rock on the road. The likelihood that this type of disruption might take place is dependent on rock slope condition. Probabilities of future adverse events are impossible to know with certainty, but can be estimated from past experience and professional judgment of a rock slope's current condition.

In the Task 5 report, rockfall event survey data collected by MDT in 2015 was processed to develop mobility and safety risks per square foot based on rock slope condition. The results were used in the Task 6 models and analyses, and are briefly summarized in Table 4-1 below. The total number of accidents reported in the survey was about half the total number of service disruptions, but due to the small total number, a robust correlation between rock slope condition and accident likelihood could not be obtained. Instead, the annual likelihood of an accident was set as half the annual likelihood of a service disruption.

Table 4-1: Condition States and final rates of Adverse Events likelihoods for MDT rock slopes, derived from 2004 rating data and 2016 adverse event data provided by MDT.

Condition State (CS)	Annualized Likelihood of Service Disruption per sq ft of rock face (AR_{mob})	Annualized Likelihood of Accident per sq ft of rock face (AR_{acc})
1	1.19E-08	5.94E-09
2	4.75E-08	2.38E-08
3	3.91E-07	1.96E-07
4	1.26E-06	6.31E-07
5	2.02E-06	1.01E-06

Using the estimated area of the rock slope face and the event likelihood correlation, an annual probability of both a service-disrupting event and an accident was estimated for each site. The average annual event probabilities for each asset class are presented in the table below, along with the average number of service disrupting events modelled state-wide in each year. This table is for statistical reference only and is not intended as a 'prediction' of rockfall hazard on a site-specific basis. The models and analyses used the site-specific estimates calculated using the unit likelihoods in Table 4-1.

Table 4-2: Likelihood of service disruption based on condition state and the resulting number of estimated events statewide each year

Condition State	Number of sites with full condition assessments	Average Annual Probability of Service Disruption per site	Predicted Annual Number of Service Disrupting Events Statewide
1 – Good	147	0.1%	0.07
2 – Fair	313	0.3%	0.8
3 – Fair	333	1.7%	5.7
4 – Poor	191	7.1%	13.5
5 – Poor	13	22.7%	3.0

4.1.2 Mobility impacts

Mobility impacts of a rock slope event are a combination of the number of vehicles affected, potential detour length, and the amount of time the roadway is closed or otherwise impacted. In the absence of specific research performing a statistical analysis on complete datasets, the following opinions were incorporated into the analyses:

- Based on the MDT survey response, the average duration of a road closure following a service-disrupting event was 6 hours, which appeared to be independent of rock slope condition. A 6-hour disruption duration was therefore applied at all sites.
- Even after the road is reopened, additional work may require traffic slowdowns (e.g., lane closures, flagging). We assumed that all slowdowns added 10 minutes to a user's trip. Based on past performance, we assumed that slowdowns continued for 30 days on I-90 west of St Regis, and generally for 7 days on other routes, with only a few exceptions.
- The majority of impacted travellers are through-traffic, not local traffic, resulting in shorter overall detours. With this assumption in place, researchers used online mapping websites to estimate an average detour length and detour time for each site or group of adjacent sites.

Annual daily traffic (ADT) was provided by MDT. For a very few sites, 2014 data was not available, so data from 2002 was used. The other values were obtained from the AASHTO 'Red Book'.

Because the assumed closure duration was greater than one hour, the impact is likely to be travellers using an alternate route. For all sites in the RAMP database, an alternate detour route was assumed to be available. Using the AASHTO equations, the mobility disruption cost is:

$$M\$ = ADT \times DD \times (DL \times VOC\$ + DL/DS \times TT\$ \times VO)$$

Where ADT is the number of vehicles per day which normally use the route
DD is the number of days that traffic is detoured (0.25 days for all sites)
DL is the detour length in miles
$VOC\$$ is the average vehicle operating cost per mile (\$0.213 in 2017\$[1])
DS is the detour speed in mph
$TT\$$ is travel time cost, the value per hour of a vehicle occupant's time (\$31.40 in 2017\$)
VO is the average vehicle occupancy rate (1.3)

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[1] AASHTO Red Book, page 5-10. This is based on the "large car" column and includes fuel, oil, maintenance, and tires. It is updated to 2017 dollars using the Consumer Price Index.

To incorporate mobility impacts from slowdowns, the AASHTO equation was adjusted as follows:

$$M\$ = \left(ADT \times DD \times (DL \times VOC\$ + DL/DS \times TT\$ \times VO)\right) + (ADT\ \times SD \times SDD \times TT\$ \times VO)$$

Where:

SD is the number of days that the slowdown lasts, and
SDD is the time added to the trip by the slowdown, in days

Because a slowdown increases the duration of a trip without adding any miles, vehicle operating costs are not included when estimating the mobility impacts of a traffic slowdown.

4.1.3 Safety impacts

Slope characteristics affect the potential of a rockfall incident to cause crashes, which may result in property damage or injuries. Safety consequences can entail vehicles being struck by falling debris, vehicles striking debris that is already lying in the road, or vehicles that lose control or are damaged due to debris avoidance or pavement damage. Because the number of accidents reported in the MDT survey was small, researchers used the average single vehicle crash value from the AASHTO Red Book, which has procedures and research-based metrics that take into account typical crash injury severity rates and property damage. The safety disruption cost for an accident at all sites is:

$$S\$ = ACC\$$$

Where $ACC\$$ is the average cost per crash ($44,831 in 2017$[2])

4.1.4 Total risk cost

The total cost of a transportation service disruption is estimated as the sum of mobility cost and safety cost. However, a service disruption and/or accident is not likely to occur at a given site every year. Instead, the annual social risk cost is a product of event likelihood and event consequence. Using the service disruption and accident likelihood estimates in Table 3-1, annual likelihoods for service disruptions and accidents were calculated for all RAMP sites that received a detailed rating. Combining all these factors, the annual risk cost is:

$$Annual\ Risk\ Cost =\ (Likelihood\ of\ Service\ Disruption\ \times M\$) +\ (Likelihood\ of\ Accident \times S\$)$$

This is expressed in dollars per year for each site. It represents an estimate of the cost to the public of each year that a slope’s rockfall hazard is not mitigated. When evaluating the cost-benefit ratio of a mitigation option, it is common to sum the annual risk cost over many years, typically equal to the lifespan of the proposed mitigation project. In the RAMP geodatabase, annual risk costs and projected 30-year risk costs are presented for each site that received a detailed rating. The projected costs do not include changes in ADT or any changes in average vehicle occupancy, operating cost, etc., that might be related to inflation or changing social practices.

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[2] AASHTO Red Book, page 5-24. This figure is an average over all vehicle classes and accident types. It excludes insurance reimbursement to avoid double-counting of costs. It is updated to 2017 dollars using the Consumer Price Index.

5 Prototype Life Cycle Cost Analysis

Over time, rock slopes deteriorate, some faster than others. The effect of deterioration is to increase the likelihood of service disruptions, and to increase the frequency and cost of routine, reactive maintenance such as cleaning of catchment ditches and debris removal.

Choices between preservation and risk mitigation treatments for geotechnical assets have important tradeoffs; decisions made today limit future options, analogous to preservation of pavements and bridges. In many cases a small timely investment in mitigation can extend the life of a slope and postpone the day when a major reconstruction might be necessary. If such a treatment is feasible but is not accomplished in a timely way, further deterioration may render it infeasible or increase the rehabilitation cost substantially. Life cycle cost analysis informs these tradeoffs.

In the GAM life cycle cost analysis, all of these costs are expressed in dollars and combined in a framework where tradeoffs in scope and timing of work can be evaluated. Figure 5-1shows the ingredients:

- A treatment model forecasts the costs and effects of mitigation and preservation activities in each condition state. The amount of each treatment is guided by a treatment policy and constrained by available funding.
- A deterioration model forecasts the change in condition from year to year when no treatment is applied, starting with current conditions from the most recent inspection. Since this is a network-level model, the conditions are expressed as the fraction of the inventory in each condition state. There is a cause-and-effect relationship between funding and policy on the one hand, and 10-year condition outcomes on the other hand. When funding is set at an expected or proposed level, the outcome is a fiscally-constrained condition target in the same sense as in the new federal regulations for performance management (FHWA 2017).
- The risk model uses a site assessment along with data on traffic and detour routes, as discussed in Chapter 3. The condition of each asset affects the likelihood of service disruptions, thus affecting the expected value of disruption costs.
- Risk costs are included in life cycle cost so that the appropriate balance between agency and user costs can be determined, and the total can be minimized. All costs are discounted, based on the year in which the costs are incurred, to reflect the time value of money. By comparing different policy and funding alternatives, the Department can compute economic metrics such as life cycle social cost savings and return on investment.

The primary forecasting models (deterioration, treatment cost and effect, and disruption likelihood) are meant to be research-based in the long term. The best such models used in pavement and bridge management rely on many years of quality-assured data, which the Department does not yet have for rock slopes. As was the case for pavements and bridges, the Department will need to start with what research and data can be found, some from other agencies, along with the best available expert judgment. If the program is sustained, and good records are maintained of the conditions observed, treatments accomplished, and adverse events, then the forecasting models can be gradually improved. In time MDT will be able to optimize its program, particularly able to optimize its policies on mitigation and preservation resource allocation, and its selection of projects, to minimize life cycle cost.

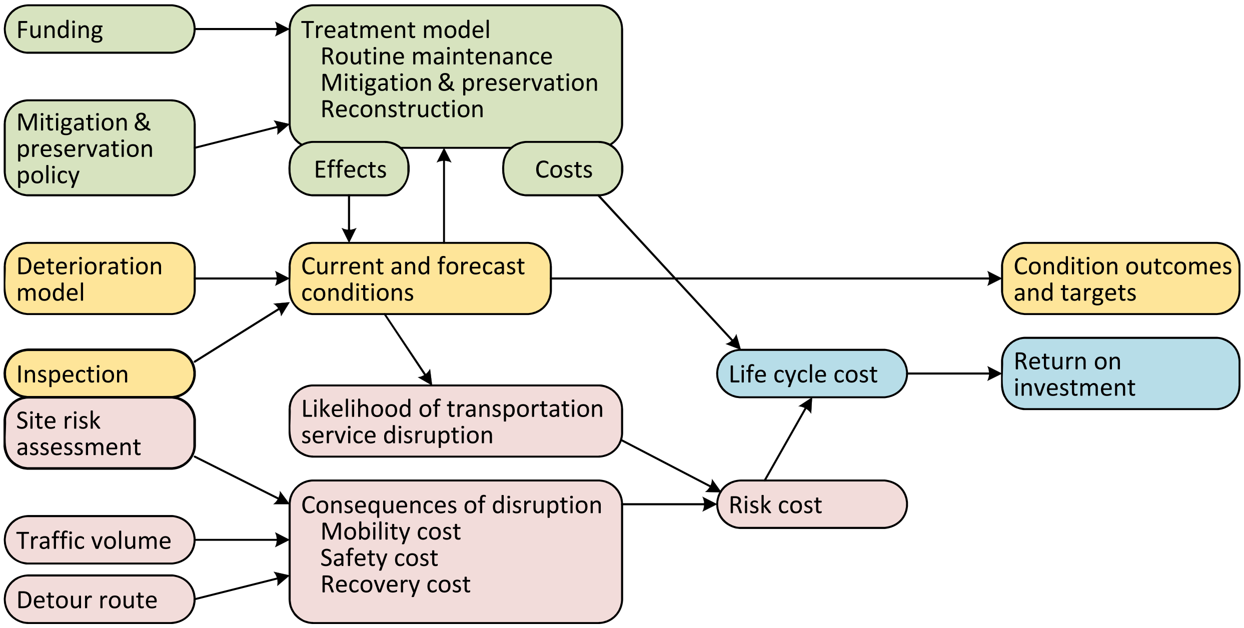

Figure 5-1: Analytical framework for implementing the RAMP, including investment and tradeoff analyses.

5.1 Modeling of treatment selection and cost

For the initial cost analysis, a single generic treatment was defined for each condition state, to represent the combined effect of all feasible mitigation and preservation activities that may be applicable to a given site. Each generic treatment was associated with an improvement by an integral number of condition states. In the life cycle cost analysis, three types of treatments are represented in different ways:

- Routine maintenance, such as debris removal and ditch cleaning, occur every year on a reactive or programmed basis. Unit costs and application rates of these treatments vary by condition state. The application rates were set so that, under current conditions, routine maintenance costs sum up to the estimated current expenditure level of $290,000 per year.
- Corrective action, which includes preservation and risk mitigation such as scaling or construction of barrier fences, is programmed work, the scope of which is determined by condition in the most recent inspection, and site characteristics. This category of work occurs infrequently, typically once every 20-65 years at a given site. The total amount of such work is constrained by annual budgets.
- Reconstruction may entail complete reconstruction of the slope, and/or realignment of the road. This takes place when slope deterioration is so extensive that preservation or mitigation activities become cost-prohibitive or insufficiently effective. Reconstruction shares the same budget constraint as corrective action, and uses the remaining funding available after all corrective action needs have been met.

Table 5-1 summarizes the unit costs and application rates modeled in the life cycle cost analysis. Application rates indicate the fraction of sites, in a given condition state, receiving each treatment each year. A rate less than 1 indicates that a site may remain in the indicated condition state for more than a year before corrective action is taken, or that some sites never receive corrective action. A rate greater than 1 indicates that some sites receive more than one application in a year. This rate is represented as the 'Percent acted upon' and is function of back calculating from the total estimated annual maintenance costs, the total estimated rock slope area, and the estimated per unit area costs for the two maintenance codes. In other words, applying the 'Percent acted upon' by the unit costs in

Table 2-1 by the total area in each condition state returns the estimated total annual costs of $290,000.

Table 5-1: Maintenance treatment unit costs and application rates.

Routine maintenance	**Percent acted upon each year, starting in each state**				
	State 1	State 2	State 3	State 4	State 5
Debris removal - $/sq. ft.	0.0003	0.0056	0.0056	0.011	0.011
Percent acted upon	0.42%	3.16%	10.55%	105.47%	210.93%
Ditch cleaning - $/ sq. ft.	0.0006	0.0046	0.0046	0.0077	0.0077
Percent acted upon	7.60%	15.20%	30.41%	80.58%	190.05%

Table 5-2: Mitigation treatment unit costs and application rate model.

Corrective action	**Percent acted upon each year, starting in each state**					**Unit cost**	**Total cost**
	State 1	State 2	State 3	State 4	State 5	$/sq.ft	$k/year
Improve by 1 state		0.00%	0.99%	1.30%	5.00%	8.20	2,922
Improve by 2 states			0.01%	0.37%	0.01%	16.40	660
Improve by 3 states				0.98%	0.00%	24.60	2,584
Improve by 4 states					0.84%	32.80	405
Total % improved	0.00%	0.00%	1.00%	2.65%	5.85%		6,572

Reconstruct/relocate $ 65.60/sq.ft

The life cycle cost analysis and investment analysis depend on assumptions about the allocation of agency effort among various types of preservation activity. In general, the Department chooses from among mitigation, repair, and rehabilitation approaches, and applies them to assets in the five condition states, based in part on site-specific factors that are not addressed in the investment model. The combined effect of these factors is represented in Table 5-2 in a summary fashion using application rates which vary by treatment category and condition state. In this example, the rightmost column of Table 5-2 is a calculation of the total mitigation costs (excluding reconstruction and maintenance costs) that would be incurred this year ($6,572,000) based on current conditions, if the indicated unit costs and application rates are applied.

Determination of these application rates is a matter of judgment. There is considerable uncertainty in this judgment, but application rates are constrained by the requirement that they be sufficient to maintain current conditions over the long-term at realistic cost, given the costs and deterioration rates that have been established in the project's research. In other words, the application rates must represent an economically sustainable policy.

Selecting actual sites to mitigate or improve either as stand-alone projects or as part of larger corridor improvement projects is facilitated by use of the various decision support tools and benefit/cost tools outlined in previous Task reports.

In the investment model the application rates were established first by judgment, then by an iterative fitting process to ensure that the fraction of the inventory in each condition state would be capable of maintaining a steady level over the analysis period of 200 years, thus satisfying the sustainability requirement.

It should be noted that a sustainable policy is not necessarily an optimal one, because it is unknown whether current conditions are at an optimal level. Further research, especially on treatment effectiveness, would be necessary to find the optimal conditions and optimal treatments to maintain those conditions based on economic criteria.

Further, it is unknown whether the estimated cost of the sustainable policy is affordable to the Department. This is for two reasons. First, past expenditure levels have not been systematically tracked, so it is uncertain what expenditure levels have been considered affordable in the past. Second, the slope rating process is new, so it will take repetition of the process to ascertain whether conditions are increasing or decreasing under current funding and policies.

5.2 Deterioration

The simplest possible deterioration model using condition state data is a Markov model, which expresses deterioration rates as probabilities of transitions among the possible condition states each year. This type of model is used in nearly all bridge management systems, and in a few pavement management systems as well. For long-lived assets, a Markov model can be expressed as the vector of median transition times from each state to the next.

In the absence of detailed condition histories, a very simple method of expert judgment elicitation has been developed to estimate reasonable transition times in the absence of inspection data. Almost every state transportation agency used this method when first getting started with their bridge management system, in order to gain experience in using the system early on, and many states have used this method more recently for developing life cycle cost analyses for all their Transportation Asset Management Plans.

The method entails dividing the inventory into relatively uniform groups of slopes with similar conditions, represented as Condition States for this RAMP study. For each group, the Condition States are considered separately by asking the following question:

> *Imagine there are 100 assets in the indicated Condition State. After how many years will 50 of them have deteriorated to the next Condition State or worse, if no maintenance or corrective action is taken?*

This question was posed to the near entirety of MDT's Geotechnical staff and select rock slope designers in a March 2017 meeting; a group of 10 experienced experts with extensive experience with Montana's rock cuts. Each person records their answers individually and then discuss them as a group in a Delphi-style process. After discussion a final estimate of the median transition time is the result.

These methods for developing and using these models are documented in NCHRP Report 713 (Thompson et al 2012). Table 4-2 shows the models that were developed for geotechnical assets using the methods described below.

Table 5-3: Markov deterioration model for MDT rock slopes based on expert elicitation exercises.

Deterioration model	**Markov model - starting condition state**				
	State 1	State 2	State 3	State 4	State 5
Transition time (years)	36.0	25.0	15.9	8.6	
Same-state probability	0.9809	0.9727	0.9573	0.9226	1.0000
Next-state probability	0.0191	0.0273	0.0427	0.0774	0.0000

In this table the transition time is the number of years that it takes for 50% of a representative population of assets to deteriorate from each condition state to the next-worse one; for example, from state 1 to state 2. The same-state probability is the statistical probability in any one year that a given asset will remain in the same condition state one year later. The next-state probability is then the probability that a given asset will deteriorate to the next-worse condition state. In the models used here, the sum of the same-state probability and next-state probability is always 1.0000.

If the transition time is known or estimated, the same-state probability can be computed using the formula:

$$p_{jj} = 0.5^{\left(\frac{1}{t}\right)}$$

Where j is the condition state (before and after 1 year)
t is the transition time in years

The forecast condition of the inventory in any given year is expressed as the fraction in each condition state. These fractions must sum to 1.0000 over the five condition states. For any given condition state k, the fraction in that state after one year is computed from:

$$y_k = \sum_j x_j p_{jk}$$

Where x_j is the starting fraction in state j
p_{jk} is the transition probability from state j to state k

This calculation can be repeated as many times as needed in order to extend the forecast for additional years in the future.

The condition state data being computed in this project for rock slopes are very similar to data sets that are maintained by most state DOTs for their bridge elements. These data sets are ideal for statistical modeling of deterioration. Florida DOT has documented a complete example of the development of such models (Sobanjo and Thompson 2011).

The Department has two sets of condition data spaced 12 years apart for 235 rock slopes. The Florida research found that, in general, 500 inspection pairs are necessary for a statistically-valid deterioration model for bridges, where inspections are spaced two years apart. However, for the present study it was informative to attempt to develop a rough statistical model as a starting point, even if normal statistical criteria could not be satisfied.

A maximum-likelihood statistical model was set up as a spreadsheet analysis using Excel's Solver feature. The problem structure attempted to find a set of transition times (as in the top row of Table 5-3) that could take the inventory of 235 sites from its overall condition in 2005 to its overall condition in 2017, minimizing the sum of squares of deviation between actual and predicted 2017 conditions.

The result of this analysis was presented to a panel of MDT and consultant experts in a meeting in Helena on March 16, 2017. The panel was asked a series of structured questions such as the following: "Suppose 100 rock slopes are currently in condition state 2. After how many years will 50 of the slopes reach state 3 or worse, if no action is taken?" Each panelist was asked to answer the questions independently, then the results were tabulated and discussed. Panelists were then allowed to change their answers, which helped to improve the level of common understanding and consensus. For each question, the mean response was used as the transition time. Transition probabilities were then computed from this information as shown above.

For communication using simple graphs, it is common with condition state data to compute a condition index as a normalized, weighted average of the distribution of the inventory among condition states. Figure 4-2 shows the combined effect of the deterioration and treatment models, expressed as a condition index where 100 is a new asset and 0 is the worst possible condition. This example reconstructs the asset when the probability of condition state 5 reaches 50%, and has periodic mid-life corrective actions. The weight given to each condition state was proportional to the mean condition index found in each condition state, as computed individually for each site in the inventory. As a result, the computation gives an estimate of future condition index values likely to be found in the field in future inspections.

Figure 5-2: Deterioration, reconstruction, and preservation.

6 Return on investment

In a life cycle cost analysis, the deterioration model forecasts conditions from year to year over an extended period. In each year, the forecast conditions determine routine maintenance, corrective action, and reconstruction treatments with their costs and effects. Forecast condition also determines the likelihood of service disruption and thence the expected value of economic consequences.

Costs that are assigned to future years are discounted according to accepted net present value methods. The discount rate reflects the value to the Department of postponing these costs, thereby making the money available for other, higher-priority needs. Reconstruction costs are especially large, so there is particular value in postponing these costs as long as possible. The formula for computing life cycle social costs is as follows:

$$LCSC = \sum_{y=0}^{N} df_y \, Q \sum_j x_{jy} \left(mc_j + \sum_a ca_{jay} cc_a + ra_{jy} rc + lhd_j csq \right)$$

Where df_y is the discount factor for year *y*, computed from

$$df_y = \frac{1}{(1+d)^y}$$

N	is the analysis period, 200 years
d	is the discount rate, currently 2.5% as discussed below
Q	is the quantity of asset in the inventory (sq.ft)
x_{jy}	is the fraction of the inventory forecast to be in state *j* in year *y*
mc_j	is the unit cost of routine maintenance in state *j* ($/sq.ft)
ca_{jay}	is the treatment application rate for state *j*, action *a*, and year *y*, adjusted for budget constraint as described below
cc_a	is the unit cost of corrective action *a* ($/sq.ft)
ra_{jy}	is the application rate for reconstruction in state *j* and year *y*, described below
rc	is the unit cost of reconstruction ($/sq.ft)
lhd_j	is the likelihood (probability) of service disruption for condition state *j*
csq	is the consequence of service disruption ($/sq.ft)

When computing this formula in a given year, the model first computes the full value of corrective action needs using a portion of the life cycle social cost formula:

$$Need = Q \sum_j x_{jy} \sum_a ce \times ca_{jay} cc_a$$

It is possible that this result might be more than the budget constraint. To test and adjust for this, the model computes a Financial Sustainability Index from

$$FSI = if\ Budget \geq Need\ then\ 1.0\ else\ Budget/Need$$

Then if FSI<1 the application rate is reduced by

$$ca'_{jay} = FSI \times ca_{jay}$$

In this way all condition states are adjusted by the same proportion for cost and effectiveness. All money remaining in the budget, if any, after this adjusted corrective action cost, is applied to reconstruction by setting the application rate for reconstruction to be

$$ra_{jy} = \frac{Budget - FSI \times Need}{Q \times rc}$$

A worst-first approach to budget allocation is usually the best way to prioritize work when risk reduction is the primary motivation. However, in the ROI model, preservation, which is based on life-cycle cost, is given priority over reconstruction. Referring back to the formulas for FSI and Need, if the budget required to fully meet corrective action needs is greater than the available budget, then the numerator in this equation will be zero. Essentially, the reconstruction application rate calculation is a way to indicate mathematically that no money will be spent on reconstruction work until corrective action needs are satisfied. However, because preservation is based on life-cycle cost, at the network level (though potentially not at the project level) it may still include some reconstruction work due to average life cycle cost savings in each condition state.

When risk reduction is the pursued policy goal behind project funding, if there is budget available for reconstruction work, it is applied first to condition state 5. If there is enough reconstruction money to address all of state 5, then the remainder is applied to state 4, then state 3, and so on. All reconstructed quantities are moved to state 1. The sum of corrective action and reconstruction cost is always equal to the annual capital budget.

The calculation of the average consequence of service disruption uses the methods described in Section 4. Since the life cycle cost analysis is at the network level, the consequence formulas use a network average value of each of the input variables including duration of service disruption, number of accidents, traffic volume, and detour length/time. These are expressed as an incident cost per asset, so they must also be converted to a cost per unit quantity by dividing by the average quantity per asset.

NCHRP Report 483 (Hawk 2003) has a thorough discussion of how discount rates are determined. In short, they are determined by agency policy, which should be consistent across all types of assets and all investments of similar lifespan. A common source of guidance is The White House Office of Management and Budget (OMB) Circular A-94[3]. Typically inflation is omitted from life cycle cost analyses because this practice simplifies the computations. A riskless and inflationless cost of capital for long-lived investments may use 30-year US Treasury bonds for guidance, with a 2018 real interest rate of 0.7%[4]. Transportation agencies usually specify higher discount rates than this, in the 2-5 percent range, because of uncertainties in long-term future travel demand and infrastructure requirements.

MDT has not yet selected a discount rate for its asset management applications, and advised the researchers to choose an appropriate conservative rate, interpreted as a rate that is within the normal range found in Transportation Asset Management Plans that gives relatively high weight to the avoidance of future risks. The researchers judged that a discount rate of 2.5 percent would best meet these criteria.

In net present value analysis it is necessary to establish an analysis period long enough, that subsequent discounted costs are too small to affect near-term decision making. The choice of analysis period depends on the discount rate and on the typical time interval between the most expensive agency actions, namely slope reconstruction or roadway realignment. An analysis period of 200 years was judged to be sufficient.

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[3] http://www.whitehouse.gov/omb/circulars_a094/

[4] http://www.whitehouse.gov/omb/circulars_a094/a94_appx-c/

The ROI worksheet compares life cycle costs between a worst-first reconstruction-only policy, and a policy featuring timely corrective action as described above. The annual budget for both scenarios is set at a level that maintains current conditions over ten years.

These return-on-investment figures are calculated based on the entire inventory, including roads which may have very low traffic volume and/or detour length. The portion of life cycle cost associated with mobility benefits is proportional to traffic volume and detour length, so the social cost savings and return-on-investment are higher than these averages for roads which have higher ADT and longer detours.

The funding level of $28 million is found to be sufficient to maintain the current statewide condition index of 63 after ten years. It is noted that this figure includes not only projects identified explicitly as slope mitigation and reconstruction work, but also work affecting rock slopes that are built within other corridor rehabilitation projects, and not necessarily broken out separately. At this funding level, preservation and risk mitigation work make up 18% of the budget, with reconstruction making up the rest. Compared to a strategy where no preservation work is done, the desired preservation investment reduces life cycle costs by 19%, a savings which is 114% of the preservation investment over the analysis period.

This model, which considers preservation, indicates that $1 spent improving rock slopes not only pays for itself, but returns an additional $1.14 to the Department and its road users.

6.1 Sensitivity of Required Funding to Deterioration Rates

A critical component of the ROI model is the rate at which the existing inventory deteriorates. As described in Section 5.2, deterioration rates are based on an expert elicitation model. This is a common first step until an adequate number of repeat surveys permits a statistically valid analysis. Analysis of other bridge management systems, initially built upon expert elicitation, found that when followed up with condition survey analysis revealed that the elicitation process estimated deterioration rates at approximately twice the actual rates. This indicated that the bridge components lasted twice as long as initially estimated (Sobanjo & Thompson, 2011)

Despite MDT's advanced RAMP program when compared to other states, the repeat surveys for a statistically valid model do not exist in Montana, or any other state for that matter. In this project, the research team mitigated this estimation error by starting with transition times approximated from available data, so the error is likely not as large. However, it is not unreasonable to examine what the required investment levels would look like if transition times were 50% longer. Table 6-1 exhibits the results at various multipliers of the transition times. The 1.0 line is the cost to maintain current condition using current modeling results. Other factors, from double the current rate (0.5 multiplier) to half the rate (2.0 multiplier) are included. This sensitivity and the cost magnitudes involved indicate additional research is warranted.

Table 6-1: Return on investment model sensitivity to transition times.

Deterioration Rate Multiplier	Cost ($M/yr)	Example state 1 to 2 transition time (years)
0.50	59.8	18.0
0.75	38.9	27.0
1.00	28.1	36.0*
1.25	21.4	45.0
1.50	16.9	53.9
1.75	13.7	62.9
2.00	11.2	71.9

*Consensus model result

7 Long-Term Investment Planning

A by-product of the life cycle cost analysis described in Section 5 is a forecast of condition states each year. These conditions will vary depending on the budget constraint that is selected, since the budget affects the amount of corrective action and reconstruction that can be done.

Transportation Asset Management Plans require the establishment of fiscally-constrained targets for condition after ten years. If the Section 6 equations are used, the models can provide a reasonable estimate of ten-year condition outcomes at any feasible budget level, which may form the basis for condition targets. This kind of parametric analysis is often called a Tradeoff Analysis.

For the purpose of this model, the funding necessary to maintain current conditions, developed in the return-on-investment analysis described in Section 6, was assumed to correspond to the desired long-term condition level. A range of round-number budget constraints was selected above and below this desired level.

Figure 7-1 shows the result. The horizontal axis is a range of fiscal scenarios, labeled according to the first-year funding level, which is assumed to increase 2.8% per year due to inflation. The left vertical axis is the statewide condition index forecast after ten years, and the right vertical axis shows the percent good and percent poor after ten years. These show reasonable performance targets for each level of funding. As expected, higher levels of funding produce better conditions.

A desired funding level of $28 million is sufficient to maintain the current statewide Condition Index of 63 after ten years. At this level, the ten-year performance targets for TAM Plan purposes would be 30% Good and 20% Poor. The total 10-year funding requirement, including inflation, is $319 million.

A number of Decision Support Tools were prepared for this project, presented in the Task 3 Report. One of these tools was proposing expectations of rock slope performance, termed *RAMP Performance Classes*. Applying this approach to the Interstate network, or the Highest Performance Class, the model predicts that the cost to maintain current conditions on Interstate routes only (Highest Performance Class) would be approximately $8.5 million, or about $85.5 million over 10 years, including inflation.

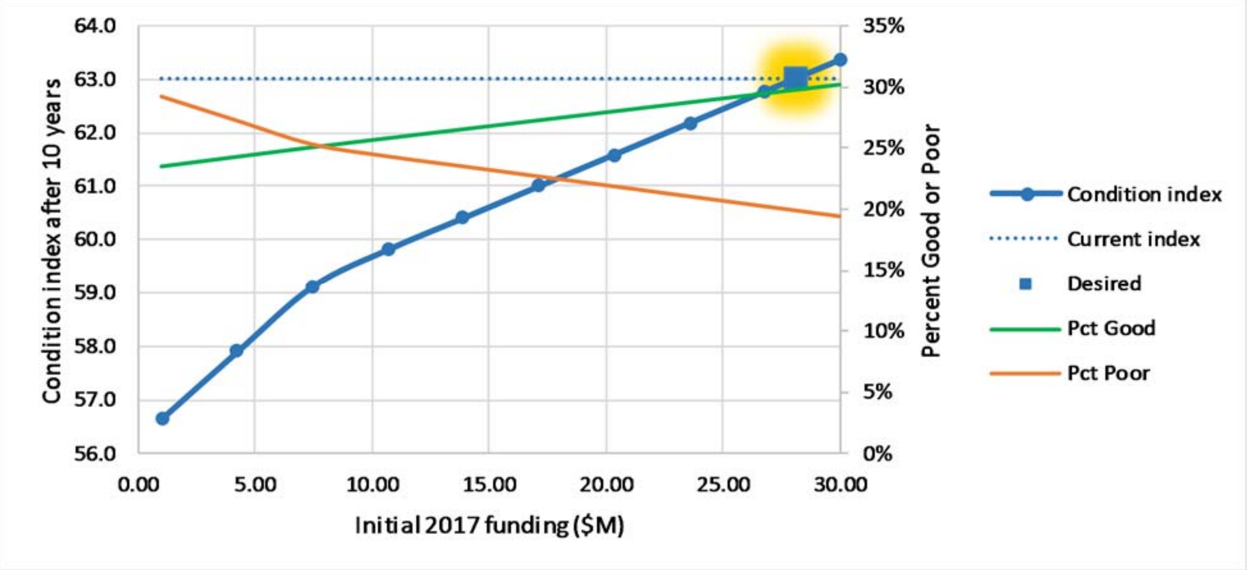

Figure 7-1: Network-Level RAMP Slope Condition Index versus Funding.

8 Determining Costs and Benefits for Site or Corridor Selection

In a transportation agency's capital programming, a prioritization process results in a set of projects that together maximize total benefits to all stakeholders (including road users and taxpayers), for any given level of annual funding. The project selection process for a transportation agency can be complex, with many factors, including risk management and performance management considerations, benefit/cost analysis, regional or corridor grouping, availability of funds, immediate safety concerns, etc. Prioritization analysis is generally done on a year-by-year basis. The list of potential project candidates is sorted by numerous factors, including benefit/cost ratios. If, or preferably, when MDT's RAMP is eventually integrated into its TAM process, there could be a number of methods to assess the relative priority of slope projects compared with other projects.

For a stand-alone rock slope management program as currently envisioned for MDT for the near future, slope rehabilitation or reconstruction projects with the highest benefit/cost ratios, among other factors, would be considered for implementation. Lower benefit/cost ratio sites would likely be postponed for consideration in the following budget cycle. When a candidate is postponed, road users are exposed to another cycle of mobility and safety costs, the agency incurs another cycle of elevated routine maintenance costs, and the slope is given another cycle to deteriorate, which may increase mitigation costs. Thus, when prioritization is repeated in the following year, the list of candidates and their benefit/cost ratios may change.

8.1 Incremental Benefit/Cost Ratios

A potentially useful by-product of the life cycle cost analysis in this research is a benefit factor that can be used in a simplified benefit/cost analysis of project priorities for slope projects. A general equation for the prioritization analysis is:

$$Incremental\ Benefit/Cost\ Ratio = \frac{Annualized\ preservation\ benefit + Annualized\ User\ Benefit}{Programmatic\ Mitigation\ Cost\ or\ Site\ Specific\ Cost\ Estimate} \times 1{,}000$$

Where:

Annualized preservation benefit found in Table 8-1,

and

$$Annualized\ User\ Benefit = Annual\ Monetary\ Risk\ in\ Current\ Condition - Annual\ Monetary\ Risk\ in\ Projected\ Mitigated\ Condition$$

Not all mitigation projects result in improvement to Condition State 1, due to cost constraints. Many mitigation projects, particularly those for Poor condition sites (CS 4 or 5) result in improvement to Fair Condition (CS 2 or 3). The user benefit equation allows planners to compare mitigation projects that will result in different levels of improvement at various sites around the state. It also captures the fact that even Good condition rock slopes continue to pose a risk to roadway users, albeit one that is very small.

They are not the benefit/cost ratios that the Department may expect to see over the life cycle of the mitigation project. In this approach, a project competes with all the other projects for available funding in that year and potential variations in the lifespan of different mitigation projects are not considered.

It is assumed in this analysis that all rock slope needs will eventually be met, and at least a portion of the total life cycle benefits of the work will be realized. Projects of highest priority will have their benefits fully realized because the work is done right away. Projects of lower priority will lose some of their benefits based on the length of time that the work is postponed.

This benefit/cost ratio is an "incremental benefit/cost ratio" because the numerator is an increment of benefit (taken out of the total life cycle project benefit) and the denominator is an increment of cost (taken from the annual agency budget). But in common practice the term "benefit/cost ratio" is used, with the understanding that if it is used for annual priority-setting then the numerator must be one year deducted from the project's total benefit, and the denominator must be the cost deducted from one year of the agency's total budget.

The user cost portion of annual project benefit is exactly as described in Chapter 3 above, computed individually for each site.

For the agency cost portion, it is common practice (and now required under federal rules) (FHWA 2016) that pavement and bridge management systems perform a life cycle cost analysis for each asset to determine agency benefits of preservation work. This is not required for any other asset class, including rock slopes. A simpler method could be used in order to gain an approximate idea of the potential annual savings to the agency when a preservation project is implemented. Table 8-1 shows the results.

Table 8-1: Project agency benefit factors

	State 1	State 2	State 3	State 4	State 5
Annual agency benefit ($/sq.ft)	0	0.148	0.074	0.009	0

The agency benefit shown for condition state 1 is zero, because no preservation treatments have been defined for that state. For state 5, where reconstruction is likely, the benefits of preservation work are primarily in the reduction of user costs, and no agency benefit is recognized. Reconstruction projects by definition have zero agency benefit since the object is to postpone that class of work.

8.2 Improved Traditional Geotechnical Benefit/Cost Ratio

The incremental approach described above is different than the technique more familiar to the geotechnical divisions of many DOT's where the cost of mitigating a site is compared to the costs of owning and maintaining it, including the consequences of adverse safety consequences. This approach is illustrated in the equation below.

$$Old\ Benefit/Cost\ Ratio = \frac{Owner\ Cost + Incurred\ Safety\ Related\ Consequence}{Site\ Specific\ Cost\ Estimate}$$

Typically, this equation would only provide a ratio above 1.0 after experiencing fatal accident events. This equation could be improved by utilizing the data generated by the RAMP program to not rely on tragedy to justify rockfall mitigation.

Using the event likelihoods, risk costs, and either programmatic or site-specific cost estimates, and extending the benefit of performing mitigation out over an expected lifespan of 30 years provides the following improved equation:

$$Improved\ Benefit/Cost\ Ratio = \frac{\Delta\, 30\ \times (annual\ year\ risk\ cost + annual\ maintenance\ cost)}{Site\ Specific\ Cost\ Estimate}$$

This improved ratio compares the risk reductions gained by improving site condition with the costs to improve the site. This factors in traffic volumes, detour lengths, standard AASHTO user cost values, the slope's condition and size, and expectations of long-term performance. This approach is included in Table 8-2.

8.3 Example Application of Benefit/Cost Tool in Project Selection

As part of Task 5, researchers visited 75 sites in 4 high-risk corridor segments. A pair of conceptual mitigation design and cost estimates were developed for each site: one that would improve the site to Condition State 1, and one that would improve the site by one Condition State (e.g. CS 4 to CS 3). Annual mobility and safety risks for each site were calculated using the methods described previously for current conditions, improvement to Condition State 1, and improvement of one Condition State (e.g. CS 3 to CS 2). The annual agency benefit of mitigation work was calculated using the values in . An incremental benefit/cost for each of the Task 5 sites was then calculated using the method outlined in the previous portion of this section. Because this method compares an annual benefit to the total project cost, the benefit/cost ratios are very low. This tool is intended for use in prioritizing among multiple mitigation projects that already have a benefit/cost ratio that is acceptable to the Department over the projected lifespan of the proposed mitigation.

A table of all 75 sites is presented as Appendix A. The table includes RAMP section number, current Condition State, the incremental benefit/cost ratio to improve the site either to Good Condition or by one Condition State, and the relative ranking of each site in the group for those two options. The sites are presented in order of benefit/cost rank if mitigated to Condition State 1 using the incremental benefit/cost approach.

Within the group as a whole, mitigation projects on Condition State 2 and 3 sites on I-90 west of St. Regis have the greatest benefit/cost ratios. This is a combination of the high number of roadway users on that portion of the Interstate system, the generally lower cost to improve a Condition State 2 or 3 site, and the inherent benefit to MDT of proactively mitigating sites before they deteriorate further. Also of note in this appendix, multiple Condition State 1 (Good) sites were visited on I-90 because the conceptual mitigation work was conducted at the corridor level. The mitigation recommendation for these sites was generally to continue routine maintenance. Since a rock slope cannot be improved beyond Condition State one, the benefit/cost ratio for these sites is at or near zero.

Interstate sites are likely to dominate the project prioritization tool, due to the higher traffic volumes. However, this decision support tool can also be used within a specific corridor that has been selected for work. In Table 8-2 below, rock slopes on US 2 between MP 154.5 and 158.5 are used as an example. These sites were all visited as part of the Task 5 field work. Sites in the table are sorted by rank based on the incremental benefit/cost ratio for improving the site to Good condition. The three additional site rankings based on improvement by one Condition State and using an improved benefit/cost ratio more familiar to geotechnical personnel. These approaches could help MDT visualize the benefits obtained from a less expensive mitigation project that still reduces risk to roadway users and that may also allow the Department to address a greater number of sites. For example, RAMP Section 88, a Poor condition site at MP 157.25, is near the middle of the pack when prioritizing projects based on improvement to Good Condition but if MDT instead opts to try and improve sites in this corridor by one Condition State, RAMP Section 88 has the highest benefit/cost ratio in this corridor segment. The favorable results hold true for the ‘Improved’ criteria. Other sites near the top of the ranking, such as RAMP Section 94, have similar identical benefit/cost ratio in all four scenarios, indicating that they are good candidates for improvement under any prioritization criteria.

			Incremental Benefit/Cost Method				**Improved Benefit/Cost Method**			
RAMP Section	**Start Hwy MP**	**Current Condition State**	Improved to CS 1	Improved by 1 CS	Rank – Improved to CS 1	Rank - Improved by 1 CS	Improved to CS 1	Improved by 1 CS	Rank – Improved to CS 1	Rank - Improved by 1 CS
87	156.97	3	8.7	12.1	1	3	0.11	0.12	8	9
80	155.81	4	7.3	9.4	2	9	0.17	0.21	1	5
94	158.47	4	7.2	11.9	3	4	0.17	0.26	2	2
84	156.43	3	6.7	11.4	4	5	0.08	0.12	10	10
90	157.92	4	6.5	9.0	5	10	0.15	0.20	3	6
76	154.86	4	6.4	10.4	6	8	0.15	0.23	4	4
88	157.24	4	6.3	14.2	7	1	0.14	0.31	5	1
79	155.70	4	6.2	8.2	8	11	0.14	0.18	6	7
83	156.26	3	6.2	14.2	9	2	0.08	0.15	11	8
85	156.60	4	5.9	5.1	10	13	0.14	0.11	7	12
77	155.50	4	4.5	10.4	11	7	0.10	0.23	9	3
75	154.66	3	3.5	11.4	12	6	0.04	0.12	12	11
92	158.16	3	3.4	7.3	13	12	0.04	0.07	13	13

Table 8-2: Conceptually mitigated rock slopes on US 2, ranked by incremental benefit/cost to improve to Condition State 1. Calculated Benefit/Cost ratios factored by 1,000. Highlights are the top 5 for each method. Sites on I-90 had benefit/cost ratios up to 5.7.

9 Task 6 Conclusions and Recommendations

The work conducted as part of this task helps ensure that the RAMP program incorporates current best practices for asset management. Because TAM Plans are now mandatory for certain department assets, rock slopes assets will be better cared for, pose less systemic risk to the Department and road users, and reduce expenditures in the long run if they can be incorporated into mandated Performance Management programs for other assets. With that in mind, the researchers developed the following list of recommendations for actions at the Agency level that will help incorporate the RAMP into MDT's TAM program the extent desired by the department:

- Develop written policies promoting mature asset management practices for rock slopes and other geotechnical assets. The covered topics include:
    - Creation and management of the inventory
    - Procedures and standards for inspection
    - Tracking of work accomplishments
    - Performance assessment and communication
    - Decision support
- Incorporate rock slopes, and eventually other geotechnical assets, in the Department's Transportation Asset Management Plan. Begin reporting condition trends over time with comparison to targets.
- Maintain a STIP line item for geotechnical asset preservation activities, with the intention of using federal funding where appropriate.
- Improve slope work reporting in MDT systems for maintenance and contract management, including reliable gathering of location, type of work, quantity, and cost so that data can be efficiently mined for future life-cycle and cost-benefit analyses for various department assets, including rock slopes.
- Promote and participate in national or pooled-fund research to improve deterioration modeling, cost, effectiveness, and risk models.

Applying these recommendations, particularly in the life cycle cost and project selection areas, will help the Department derive maximum benefit from limited budget dollars. The current models developed in this research project are heavily reliant on quantitative estimates and expert judgement. By collecting and incorporating additional, uniformly collected data, MDT will improve its decision support tools and budget forecasting capabilities. Ongoing research recommendations that can be undertaken at either the Agency or Geotechnical Group level to support TAM-compatibility include:

- Develop routine annual budget for geotechnical asset inspection, commensurate with the inspection intervals specified in the inspection policy.
- Enhance the inventory database to support the inspection process, including inspection crew and equipment scheduling, quality assurance review, storage of historical data, issuance of work requests, and management reports.
- Improve prototype asset-level analysis of risk and life cycle cost described in Section 8 for use in project planning and programming with continued data collection and event tracking. This might take the form of a spreadsheet model using the methods documented here.
- Publish annual reports of geotechnical asset condition to management and on a public-facing performance dashboard on the Department's web site.
- Improve accident reporting procedures to indicate when rockfall or geotechnical asset limitations or failures are contributing factors, ideally by encouraging use of the AGOL-based Event Tracker developed as part of the RAMP research project.
- Improve the statistical model of asset deterioration discussed in Section 4.2 with data obtained in future inspection cycles so that models of deterioration, cost, and mitigation effectiveness can be improved over time.

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Appendix A

Task 5 Conceptually Mitigated Sites Ranked Using Project Prioritization Tool

			Incremental Benefit/Cost Method				Improved Benefit/Cost Method			
RHRS Section	Corridor	Current Condition State	Mitigated to CS 1 (Factored by 1,000)	Improved by 1 CS (Factored by 1,000)	Rank - Mitigated to CS 1	Rank - Improved by 1 CS	Mitigated to CS 1	Improved by 1 CS	Rank - Mitigated to CS 1	Rank - Improved by 1 CS
1146	C000090	3	120.3	164.4	1	4	2.4	3.2	1	5
1147	C000090	2	114.2	114.2	2	12	0.8	0.8	14	25
1144	C000090	2	112.7	112.7	3	13	0.8	0.8	15	26
1150	C000090	3	106.7	137.3	4	7	2.1	2.7	2	8
1148	C000090	3	70.7	80.4	5	19	1.4	1.6	3	16
1157	C000090	3	67.5	292.3	6	1	1.4	5.7	4	1
1181	C000090	3	66.6	186.6	7	2	1.3	3.6	5	2
1174	C000090	2	63.9	63.9	8	22	0.5	0.5	22	28
1156	C000090	2	62.0	62.0	9	23	0.5	0.5	23	29
1138	C000090	3	57.5	85.2	10	17	1.1	1.6	6	15
1154	C000090	2	56.9	56.9	11	24	0.4	0.4	24	30
1152	C000090	3	55.9	73.9	12	21	1.1	1.4	7	18
1165	C000090	3	51.9	56.1	13	25	1.0	1.1	8	21
1180	C000090	3	48.2	44.2	14	31	1.0	0.9	9	24
1178	C000090	2	45.5	45.5	15	30	0.3	0.3	29	34
1158	C000090	3	45.4	169.1	16	3	0.9	3.3	10	4
1153	C000090	3	41.7	117.0	17	11	0.8	2.3	13	12
1151	C000090	2	40.4	40.4	18	33	0.3	0.3	30	37
1159	C000090	3	39.5	121.7	19	10	0.8	2.4	16	11
946	C000050	5	38.8	111.6	20	14	0.9	2.5	11	9
949	C000050	4	38.8	48.2	21	28	0.9	1.1	12	22
1179	C000090	2	38.4	38.4	22	35	0.3	0.3	31	38
1166	C000090	2	33.2	33.2	23	36	0.2	0.2	34	40
948	C000050	4	32.6	121.9	24	9	0.7	2.7	17	7
1170	C000090	2	31.6	31.6	25	37	0.2	0.2	35	41
1160	C000090	3	30.6	123.9	26	8	0.6	2.4	18	10
1140	C000090	2	30.3	30.3	27	38	0.2	0.2	36	44
935	C000050	3	28.3	101.9	28	15	0.4	1.3	25	19
1167	C000090	2	26.4	26.4	29	39	0.2	0.2	37	47
1161	C000090	3	25.3	154.3	30	5	0.5	3.0	19	6
1163	C000090	3	25.1	75.6	31	20	0.5	1.5	21	17
1176	C000090	2	24.8	24.8	32	41	0.2	0.2	38	49
933	C000050	4	22.3	54.6	33	26	0.5	1.2	20	20
1171	C000090	2	21.0	21.0	34	42	0.2	0.2	41	51
1260	C000090	3	18.8	44.0	35	32	0.4	0.8	26	27
1141	C000090	2	18.1	18.1	36	43	0.1	0.1	48	54
1137	C000090	2	18.0	46.2	37	29	0.1	0.3	49	33
1142	C000090	2	17.4	17.4	38	45	0.1	0.1	50	55
1183	C000090	2	15.9	48.6	39	27	0.1	0.3	52	32
945	C000050	4	15.4	14.5	40	46	0.4	0.3	27	35
1261	C000090	4	15.3	39.1	41	34	0.3	0.9	28	23
1143	C000090	2	13.8	13.8	42	49	0.1	0.1	56	60
936	C000050	4	11.7	150.4	43	6	0.3	3.3	32	3
947	C000050	4	10.8	81.7	44	18	0.2	1.8	33	14
1162	C000090	2	9.5	9.5	45	57	0.1	0.1	59	62
87	C000001	3	8.7	12.1	46	50	0.1	0.1	53	56
1182	C000090	2	8.4	25.6	47	40	0.1	0.2	60	48
1169	C000090	2	7.5	7.5	48	61	0.1	0.1	61	63
950	C000050	3	7.3	11.8	49	52	0.1	0.1	54	52

			Incremental Benefit/Cost Method				Improved Benefit/Cost Method			
RHRS Section	Corridor	Current Condition State	Mitigated to CS 1 (Factored by 1,000)	Improved by 1 CS (Factored by 1,000)	Rank - Mitigated to CS 1	Rank - Improved by 1 CS	Mitigated to CS 1	Improved by 1 CS	Rank - Mitigated to CS 1	Rank - Improved by 1 CS
80	C000001	4	7.3	9.4	50	58	0.2	0.2	39	45
94	C000001	4	7.2	11.9	51	51	0.2	0.3	40	39
937	C000050	4	6.8	17.5	52	44	0.2	0.4	42	31
84	C000001	3	6.7	11.4	53	53	0.1	0.1	57	57
90	C000001	4	6.5	9.0	54	59	0.1	0.2	43	46
76	C000001	4	6.4	10.4	55	56	0.1	0.2	44	43
88	C000001	4	6.3	14.2	56	47	0.1	0.3	45	36
79	C000001	4	6.2	8.2	57	60	0.1	0.2	46	50
83	C000001	3	6.2	14.2	58	48	0.1	0.1	58	53
85	C000001	4	5.9	5.1	59	63	0.1	0.1	47	59
934	C000050	4	5.5	90.8	60	16	0.1	2.0	51	13
77	C000001	4	4.5	10.4	61	55	0.1	0.2	55	42
75	C000001	3	3.5	11.4	62	54	0.0	0.1	62	58
92	C000001	3	3.4	7.3	63	62	0.0	0.1	63	61
1136	C000090	1	0.0	0.0	64	64	0.0	0.0	67	67
1139	C000090	1	0.0	0.0	64	64	0.0	0.0	64	65
1145	C000090	1	0.0	0.0	64	64	0.0	0.0	67	67
1149	C000090	1	0.0	0.0	64	64	0.0	0.0	67	67
1155	C000090	1	0.0	0.0	64	64	0.0	0.0	67	67
1164	C000090	1	0.0	0.0	64	64	0.0	0.0	65	66
1168	C000090	1	0.0	0.0	64	64	0.0	0.0	67	67
1172	C000090	2	0.0	0.0	64	64	0.0	0.0	67	67
1173	C000090	1	0.0	0.0	64	64	0.0	0.0	67	67
1175	C000090	2	0.0	0.0	64	64	0.0	0.0	67	67
1177	C000090	1	0.0	0.0	64	64	0.0	0.0	66	64
1184	C000090	1	0.0	0.0	64	64	0.0	0.0	75	75

Appendix G

TASK 7 REPORT – EVALUATE TAM COMPATIBILITY

Montana Department
or Transporation

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

Task 7 Report
Evaluate TAM Compatibility

LANDSLIDE
TECHNOLOGY
A DIVISION OF CORNFORTH CONSULTANTS

Prepared for:

Montana Department of Transportation
Helena, Montana

ROCKFALL HAZARD PROCESS ASSESSMENT

TASK 7 REPORT
EVALUATE TAM COMPATIBILITY

August 30, 2017

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Executive Summary

This document is the deliverable for Task 7 of the Montana Department of Transportation (MDT) research project "Rockfall Hazard Rating Process Assessment" (Project No. 15-3059V). The goal of this task is to evaluate the compatibility of the new RAMP with MDT's TAM plan, and provide recommendations for continued integration of the RAMP into MDT's IT and enterprise GIS environment.

The researchers reviewed the work completed under the previous six tasks, identifying which components of a functioning asset management program have been addressed by those tasks, and which areas would require additional study when developing an asset management plan. The results are summarized in Table ES-1 below. Many of the components not addressed in the RAMP, such as incorporating geotechnical-specific activities to the integrated maintenance management system, will require additional support and input as they arise. Others, such as data presentation formats, are best addressed when rock slope assets are added to the TAM program, to achieve a uniform look across all asset types.

Table ES-1: Summary of policy components for a geotechnical asset management plan, and the components that have been addressed by the current RAMP research project.

Future GAM Plan Policy Components	Included in RAMP	Report
Geotechnical Inventory Policy		
Criteria for asset inclusion	✓	RHRS (2005)
Detailed inventory reference manual	✓	RHRS (2005)
Prototype Maintenance tracking procedures	✓	Maint. Tracker
Contract Close-Out procedures to update sites	✗	--
Geotechnical Inspection Policy		
Criteria for asset inclusion	✓	RHRS (2005)
Set inspection interval	✓	Task 4
Procedures for updating site information	✓	Task 4
Procedures for tracking site activity	✓	Event Tracker
Ensure data accessibility to systems and processes that need it	✓	Task 4
Formalize data retention policy	✗	--
Work Accomplishment Tracking Policy		
Criteria for Inclusion of Individual Work Items	✗	--
Develop data QA/QC standards for work-related updates	✗	--
Integrate into existing data management	✗	--
Performance Assessment/Communication Policy		
Define performance measures (condition states, indices, etc.)	✓	Task 3
Determine internal and public formats for data presentation	Prototype	AGOL apps, maps, & dashboard
Develop means of presenting performance/trends graphically (past, present, and future)	✗	--
Set updating interval for the various data presentation forms	✗	--
Decision Support Policy		
Life-cycle cost analysis	✓	Task 6
Deterioration models	✓	Task 6
Risk assessment and monetization	✓	Task 6
Performance measures (based on prioritization, performance classes, etc.)	✓	Task 3

1 MDT's Current Technology Infrastructure

As part of Task 1, the Research Team reviewed MDT's IT infrastructure for the RHRS. As part of the RHRS program, MDT used an Oracle instance in MDT's enterprise database system to store and review information. This database provided basic abilities: query existing data, view existing records, or add new data. It was not possible to update an existing record, or save multiple versions of a record for an existing site. The search functions were limited, photos and reports were not linked to site entries, and any geospatial work (i.e. GIS integration) had to be performed by advanced users on an ad-hoc basis. In essence, the system did not meet user expectations for a "modern" IT system, making it difficult to achieve widespread use of the RHRS data within the Department.

1.1 Current RAMP Infrastructure

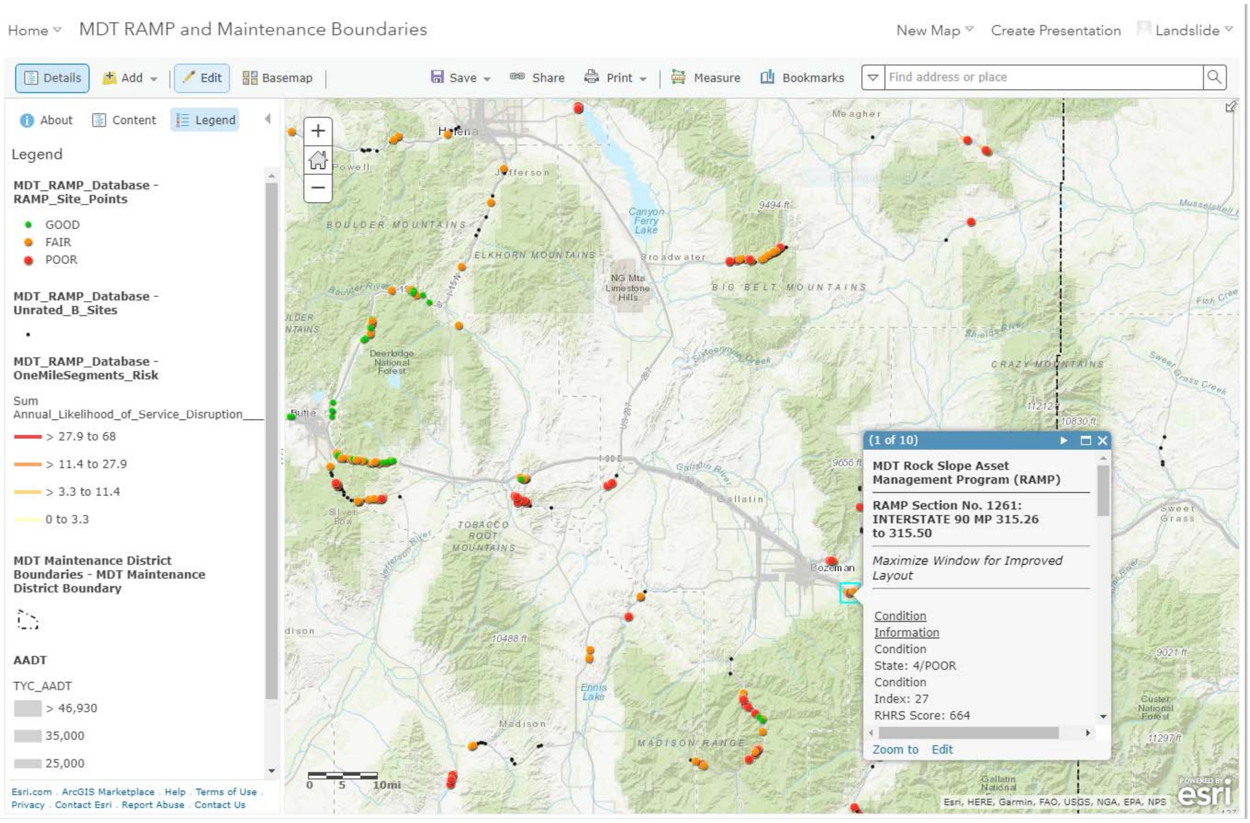
In order to make the RAMP's infrastructure more modern and user-friendly, LT combined existing vendor platforms, commercial-off-the-shelf (COTS) sub-products, and revised data collection tools. Existing data was extracted from the RHRS Oracle database, and incorporated into an ArcGIS geodatabase. This database is hosted on ESRI's ArcGIS Online (AGOL) platform, for which MDT already maintains a license. Since AGOL is accessible from any internet-enabled computer, and is also designed to work offline with various ESRI-developed COTS products, this makes rock slopes data much easier to access and maintain. Over the course this project, LT made the following improvements to RAMP's technology infrastructure:

- Creation of an ArcGIS geodatabase that can be updated in the AGOL platform or accessed for use in the ArcGIS Desktop environment;
- Utilization of ESRI's Collector App to gather new site information in the field using inexpensive Android or iOS tablets;
- Replacement of the RHRS Access database with an Excel spreadsheet, which can be installed on a tablet and used to compile field rating data;
- Enabling easy access to site photos or reports through a hyperlink in the geodatabase that points to both internal and external server locations.

The ArcGIS geodatabase contains both location and detailed rating information for all inventoried sites. Because it is geospatially referenced, it allows users to easily search for sites by simply scanning the map. Within a desktop or AGOL workspace, users can further identify specific sites by filtering based on any number of criteria, extending far beyond asset location to things like condition, estimated risk, detour length, etc. Because MDT already uses the AGOL platform, it is also easy to incorporate other data, like AADT or proposed STIP projects. Likewise, the RAMP geodatabase can be accessed by users from other units within the Department and filtered to meet their decision support needs.

Likewise, using AGOL to host the geodatabase also enables MDT to save money through the use of off-the-shelf programs, such as ESRI's Collector App to collect data off-line, and sync it with the database upon returning from the field. This app runs on both iOS and Android operating systems, and can be installed on both phones and tablets. It is generally user-friendly, and likely to be maintained by ESRI in the future. In fact, the most recent version of the Collector App is also compatible with the Windows 10 desktop environment, making data editing in the office even easier. The main limitation of the Collector App platform is that calculations cannot be performed in the program during the detailed rating process. Instead, an Excel spreadsheet is used to meet this need, and data is transferred to the Collector App or directly into the geodatabase.

Using the GIS map services hosted by MDT (https://mdt.maps.arcgis.com), LT developed several maps to present RAMP data for various purposes. The map shown in Figure 1-1 below contains all inventoried rock slopes, and has a "click-to-access" functionality for accessing data, with integrated hyperlinks to photos and is available to select personnel (those belonging to the 'Rockfall Management' AGOL group within MDT) at http://arcg.is/1uvb0O. With an adjustment in the map permissions, this map can be shared with the public via embedment in a website.



(1 of 10)

MDT Rock Slope Asset Management Program (RAMP)

RAMP Section No. 1261: INTERSTATE 90 MP 315.26 to 315.50

Maximize Window for Improved Layout

Condition Information

Condition State: 4/POOR

Condition Index: 27

RHRS Score: 664

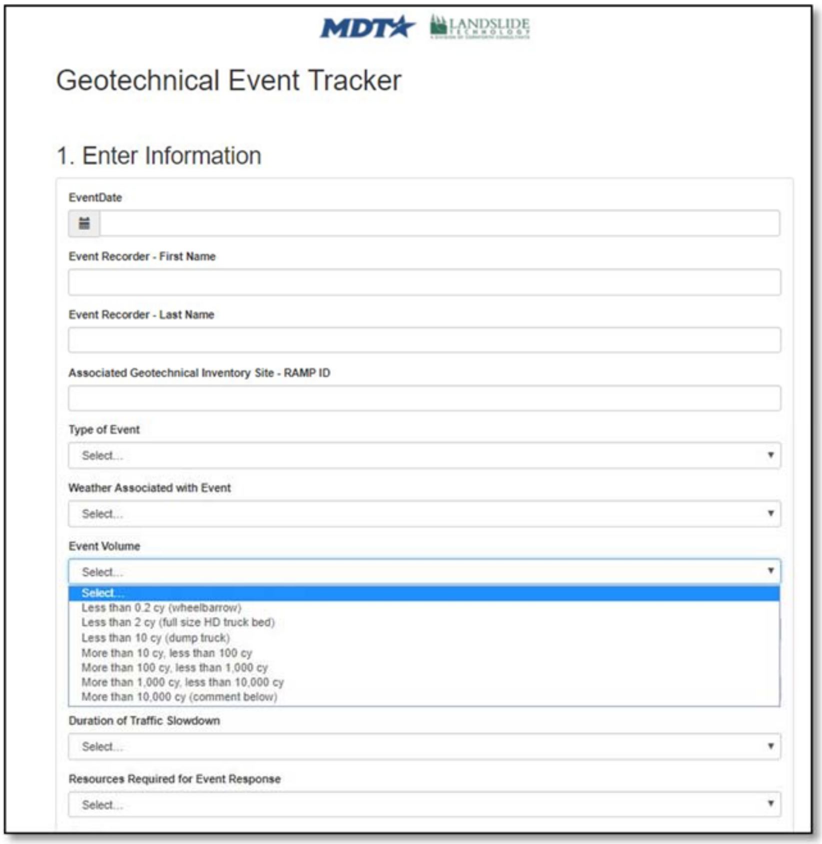
Zoom to Edit

Figure 1-1: Screenshot of current MDT RAMP map showing MDT rockfall sites in the web-based GIS interface.

1.2 Integrating Event Information

Based on additional data needs identified during project research, particularly for improved event likelihood and maintenance cost data, LT took advantage of additional AGOL capabilities to develop a platform to facilitate future data collection. Using AGOL's Geoform templates, LT created a pair of forms: the Geotechnical Event Tracker, and the Geotechnical Maintenance Tracker.

As shown in Figure 1-2, reporters are prompted to answer a series of questions, largely from drop-down menus that populate an AGOL-hosted database. The database also supports attachments, so that reports can add event photos or other files, such as pdfs of press releases or news reports. Before submitting, the event is marked on a map, as shown in Figure 1-3. RAMP section data is also included in the basemap as a useful reference.



Geotechnical Event Tracker

1. Enter Information

EventDate

Event Recorder - First Name

Event Recorder - Last Name

Associated Geotechnical Inventory Site - RAMP ID

Type of Event

Select...

Weather Associated with Event

Select...

Event Volume

Select...

- Select...
- Less than 0.2 cy (wheelbarrow)
- Less than 2 cy (full size HD truck bed)
- Less than 10 cy (dump truck)
- More than 10 cy, less than 100 cy
- More than 100 cy, less than 1,000 cy
- More than 1,000 cy, less than 10,000 cy
- More than 10,000 cy (comment below)

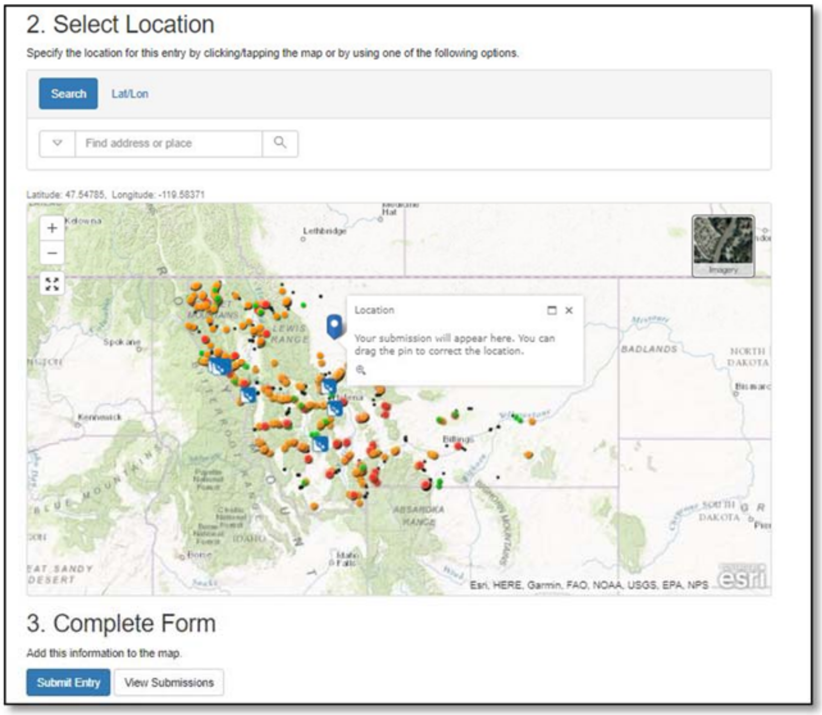
Duration of Traffic Slowdown

Select...

Resources Required for Event Response

Select...

Figure 1-2: Screenshot of current MDT Geotechnical Event Tracker showing some of the queries used to populate the database.



2. Select Location

Specify the location for this entry by clicking/tapping the map or by using one of the following options.

Latitude: 47.54785, Longitude: -119.58371

Location

Your submission will appear here. You can drag the pin to correct the location.

3. Complete Form

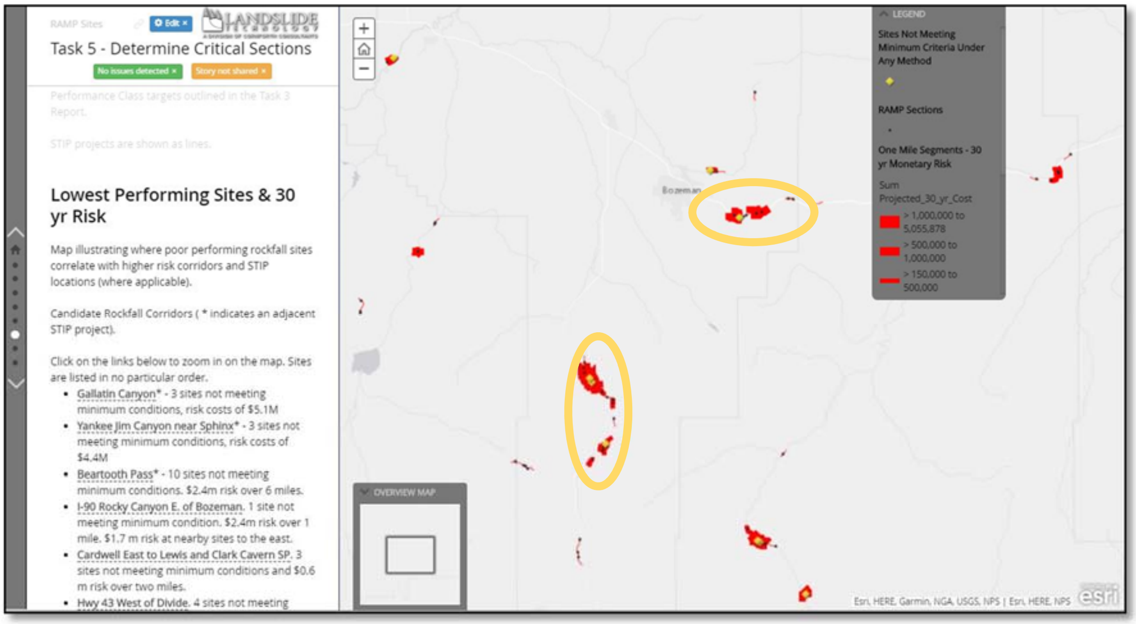
Add this information to the map.

Figure 1-3: Screenshot of current MDT Geotechnical Event Tracker showing the map used to locate the event.

Department budget forecasting and refinement of models described in Task 6 can be improved with data mined from these tools. They can also be added to maps with the RAMP geodatabase, and, within AGOL, used to create animations showing activity over time. Also of importance: the ease of use of these trackers will help keep Department personnel engaged in updating and maintaining the RAMP system.

1.3 Developing Visualizations for Decision Support

Using the improved infrastructure in the AGOL environment, MDT can also easily create engaging data visualizations for planning purposes and related meetings. For example, at a meeting in Helena for Task 5/6 work, LT used an existing AGOL template, MapJournal, to compile multiple maps showing the RAMP dataset filtered using various decision support tools. One of the goals of this meeting was to select a set of sites, either individually or on a corridor basis, for conceptual mitigation design work. LT created different maps to help guide discussion, identifying individual sites based on asset condition and corridor segments based on estimated risk. The frame in Figure 1-4 shows high-risk corridor segments and individual sites that do not meet minimum performance criteria under any scoring method. By incorporating this reference tool into the meeting discussion, the attendees were able to select four corridors around the state for mitigation work. The original plan was to target only three corridors, but this map helped researchers identify a small but high risk corridor segment on I-90 east of Bozeman (Rocky Canyon) to incorporate into more extensive conceptual cost work in the Gallatin Canyon corridor. This type of tool is easy to develop within the RAMP's current technology infrastructure using tools and programs already available to MDT.



Performance Class targets outlined in the Task 3 Report.

STIP projects are shown as lines.

Lowest Performing Sites & 30 yr Risk

Map illustrating where poor performing rockfall sites correlate with higher risk corridors and STIP locations (where applicable).

Candidate Rockfall Corridors (* indicates an adjacent STIP project).

Click on the links below to zoom in on the map. Sites are listed in no particular order.

- Gallatin Canyon* - 3 sites not meeting minimum conditions, risk costs of $5.1M
- Yankee Jim Canyon near Sphinx* - 3 sites not meeting minimum conditions, risk costs of $4.4M
- Beartooth Pass* - 10 sites not meeting minimum conditions. $2.4m risk over 6 miles.
- I-90 Rocky Canyon E. of Bozeman. 1 site not meeting minimum condition. $2.4m risk over 1 mile. $1.7 m risk at nearby sites to the east.
- Cardwell East to Lewis and Clark Cavern SP. 3 sites not meeting minimum conditions and $0.6 m risk over two miles.
- Hwy 43 West of Divide. 4 sites not meeting

Figure 1-4: Screenshot of the Critical Section WebApp developed for use as a reference tool during the Task 5 meeting. The map is zoomed in on the Bozeman area, with two of the four corridors ultimately selected for conceptual mitigation work are circled.

2 Additional Requirements for Future TAM Plan Implementation

Transportation Asset Management (TAM) is a strategic and systematic process of maintaining and managing infrastructure assets throughout their life cycle, focusing on business and engineering practices for resource allocation and utilization. It uses data and analysis to improve decision making, with the objective of providing the required level of service in the most cost-effective manner (Gordon et al 2011).The RAMP program was designed to incorporate modern asset management principles to the extent possible. All of the data collection and technical analysis performed in previous tasks of this study were structured to provide support for what is envisioned as a long-term ongoing asset management process for rock slopes, extendable in the future to other geotechnical assets such as embankments, soil slopes, retaining walls, and even drainage assets. The technical tools are meant to provide decision support to officials who are implementing asset management policies and working toward achievement of transportation system performance goals. The following sections discuss the bigger picture of asset management implementation, and further steps that can be taken to ensure that MDT is able to fully implement the tools and engage in a process of continuous improvement of its capabilities in the asset management area. The additional requirements for incorporating the RAMP into a TAM plan will likely require input and cooperation between multiple Department stakeholders, and it would therefore be ideal if rock slope assets were discussed during the early stages of implementing MDT's TAM 2015 Plan.

2.1 Transportation asset management plan

MDT has long recognized the principles of asset management as a matter of industry best practice, embodied in its Performance Programming Process, known as "P3" and discussed in the next section (MDT 2015). In the 2012 federal highway bill, known as MAP-21 or the Moving Ahead for Progress in the 21st Century Act, the Congress recognized the same ideas and took steps to make these principles common practice nationally.

The keystone of the MAP-21 performance management philosophy is the Transportation Asset Management Plan. This document has been in common use in other countries for two decades, and was introduced in the United States in Chapter 4 of the AASHTO Guide for Transportation Asset Management, Volume 2 (Gordon et al 2011). Subsequent federal legislation and FHWA rule-making have strengthened the concept (FHWA 2016 and 2017).

TAM Plan requirements in 23 CFR 515 specify that the TAM Plan shall cover at least a 10-year period, shall be made easily accessible to the public, and shall establish a set of investment strategies that improve or preserve condition and performance in support of the national goals enumerated in 23 USC 150(b). The regulation explicitly links the TAM Plan to the Statewide Transportation Improvement Program (STIP), which is the primary vehicle for programming of transportation projects.

Section 515.9(d) lists the minimum content of the TAM Plan:

1. TAM objectives, aligned with agency mission;
2. Performance measures and targets;
3. Summary of asset inventory and condition;
4. Performance gap identification;
5. Life cycle planning;
6. Risk management analysis;
7. Financial plan;
8. Investment strategies.

MAP-21 specifies that the TAM Plan shall be risk-based. The Final Rule, Section 515.7(c) elaborates that the TAM Plan must establish a process to identify the hazards affecting the movement of people and goods, assess the likelihood and consequences of adverse events, and evaluate and prioritize mitigation actions. Section 505.7(b) specifies that life cycle planning is a quantitative network-level analysis that considers current and desired condition levels, asset deterioration, effects of adverse events, and treatment options over the whole life of assets.

Although only National Highway System (NHS) pavements and bridges are required to be covered by the TAM Plan, 23 USC 119(e)(3) encourages States to include all infrastructure assets within the right-of-way corridor. Coverage of non-NHS roads is also encouraged. The regulations promulgated under MAP-21 and the FAST Act provide for reduced TAM Plan requirements for assets other than NHS pavements and bridges "at whatever level of effort is consistent with the State DOT's needs and resources." (FHWA 2016, pg. 73197; Stanley & Anderson, 2017). While agencies that decide to go beyond the minimum TAM Plan requirements by including assets other than NHS pavements and bridges (such as rock slopes) are allowed to relax the level of quantitative rigor used for those optional asset classes, it remains the case that asset management is a discipline of using data and analysis to improve decision-making, applicable to all types of transportation infrastructure (Gordon et al 2011). There also remain appropriate goals to "achieve and sustain a desired state of good repair" and to "improve or preserve the condition of the assets" over their life cycle. (FHWA 2016, pg. 73197)

Rock slope assets affect the safety, mobility, and efficiency of Department operations and processes due to both risk of rockfall (e.g. road patrols looking for rock on the road, programming rockfall risk reduction projects) and actual rockfall (e.g. blocked roads, cleaning up debris, emergency response call-outs and repair). Like rockfall events themselves, the risk of rockfall requires a response from the Department in its planning and design processes and in funding decision-making. When rockfall occurs, DOTs routinely expend scarce resources to clear fallen rocks from roads, to recover from rock-vehicle collisions, to scale loose rock before it falls, and to install and maintain mitigation measures such as catchment ditches, barriers, and fences. The ultimate purpose of these activities is to satisfy Department goals for safety, mobility, and efficiency. Application of asset management principles to rock slopes will help MDT allocate limited funding more efficiently over time.

2.2 Performance Programming Process

Montana's version of the same ideas promoted by both TAM and the Federal regulations is rooted in TranPlan21, the Department's statewide Long-Range Transportation Plan (Cambridge 2008). TranPlan21 is currently under revision as TranPlanMT. The vision promoted in the 2008 document describes the use of asset inventory, condition, and performance data, tracked over time in an information system, to describe and visualize performance trends and forecast future needs for preservation, rehabilitation, and reconstruction. These would be used "to optimize system service life, safety, and mobility."

This vision was reinforced in a separate brochure about the P3 process (MDT 2015, Figure 2-1). The programming process is driven by a set of performance goals, which are measured and tracked using technology. These goals drive investment decisions at the network level and project level, feeding into the Statewide Transportation Improvement Program (STIP).

In comparing the federal TAM Plan vision with P3, it can be seen that both start with statements of objectives, tied to the agency mission; both feature quantitative measurement and tracking of performance; both use performance objectives as a framework for prioritizing investments; and both promote accountability for improving performance. Some important differences can also be seen:

- The federal vision focuses on a tangible product, the Transportation Asset Management Plan, which must be prepared and updated periodically, and made available to the public. This is intended to facilitate standardization and transparency, as well as supporting a federal review process.

- In addition to the P3 objectives of asset condition, mobility (travel delay reduction), and safety, the federal vision places a stronger emphasis on long-term economics of preservation, requiring life cycle cost analysis and a process geared toward minimizing long term cost.
- Similarly, the federal vision places more emphasis on risk as an essential consideration to be managed as a part of asset management and the TAM Plan.
- The federal TAM Plan concept is more explicit about integrating a financial plan with the investment plan. Performance targets in the TAM Plan are required to be fiscally constrained, just as the STIP is fiscally constrained. This also promotes transparency and accountability by helping ensure that performance goals are achievable and encouraging decision makers to closely observe the linkage between funding and performance, as well as performance tradeoffs.

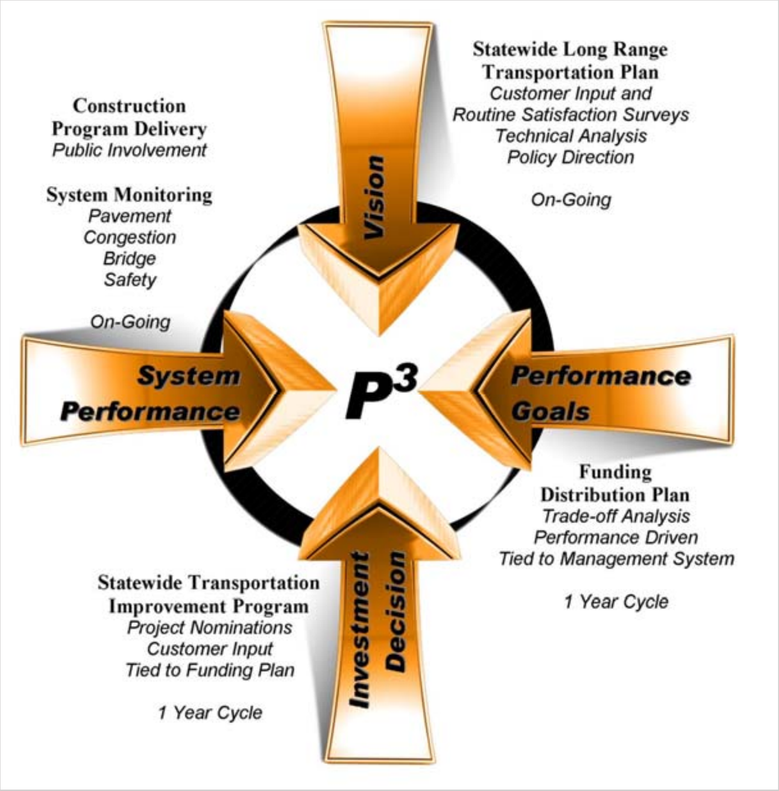


Figure 2-1: Performance Programming Process (MDT 2015).

Although the federal TAM Plan includes ingredients not currently addressed or emphasized in P3, the new elements are viewed as non-controversial: there is broad agreement that the agency should attempt to minimize costs in the long term, manage risks, and set realistic accountable objectives. Within fiscal constraints, the STIP focuses on agency output, while the TAM Plan focuses on outcomes. P3 also focuses on outcomes, so the additional federal requirements affect P3 largely by requiring a more explicit consideration of financial limitations.

Federal and P3 requirements are both currently limited to pavements and bridges, but both are intended to be extensible to other classes of infrastructure assets. The federal emphasis on risk makes it more desirable to consider rock slopes and other geotechnical assets, because it is through the risk of service disruption that these assets impact safety, mobility, and long-term cost. Preservation and risk mitigation work on rock slopes consumes some of the limited fiscal resources, but contributes to the achievement of performance goals, and is therefore an integral part of the asset management process.

2.3 Montana 2015 TAM Plan

The December 2015 MDT Transportation Asset Management Plan (MDT 2015) closely follows the P3 framework. For both pavements and bridges, the TAM Plan explicitly recognizes that the federal emphasis on long-term cost and fiscal constraints is intentional and valuable. For example:

> *MDT's 2015 TAMP provides a starting point for developing a robust bridge management framework. However, there are gaps in MDT's current analytical capabilities, data systems, and evaluation processes. Over the near-term, these gaps must be closed.*

> - *To explore options for a fully functional statewide Bridge Management System.*
> - *To establish realistic and attainable statewide bridge condition performance measures, MDT is working to perform cross-asset performance evaluations.*
>
> *Additional activities and resources may be required to fully implement an enhanced bridge management system. An action plan is being developed to address the gaps identified here. (MDT 2015, page 19)*

Above this text passage on the same page is an excellent example of the network level performance vs funding tradeoff that is at the heart of the federal philosophy for TAM Plans (Figure 2-2).

The federal rules make a clear distinction between network level and project level analysis, which is reflected in the above quote from Montana's plan. The TAM Plan is meant to describe life cycle management, risk management, and the investment plan at the network level. However, implementation of the TAM Plan requires corresponding capabilities at the asset and project level, which are embodied in pavement and bridge management systems.

A similar observation can be made for risk management. The MDT TAM Plan has an excellent risk register on page 22, which includes extreme weather events and catastrophic infrastructure failure. A corresponding asset-level risk analysis would not be complete without considering rockfall and other geotechnical asset failures having similar effects on the transportation network.

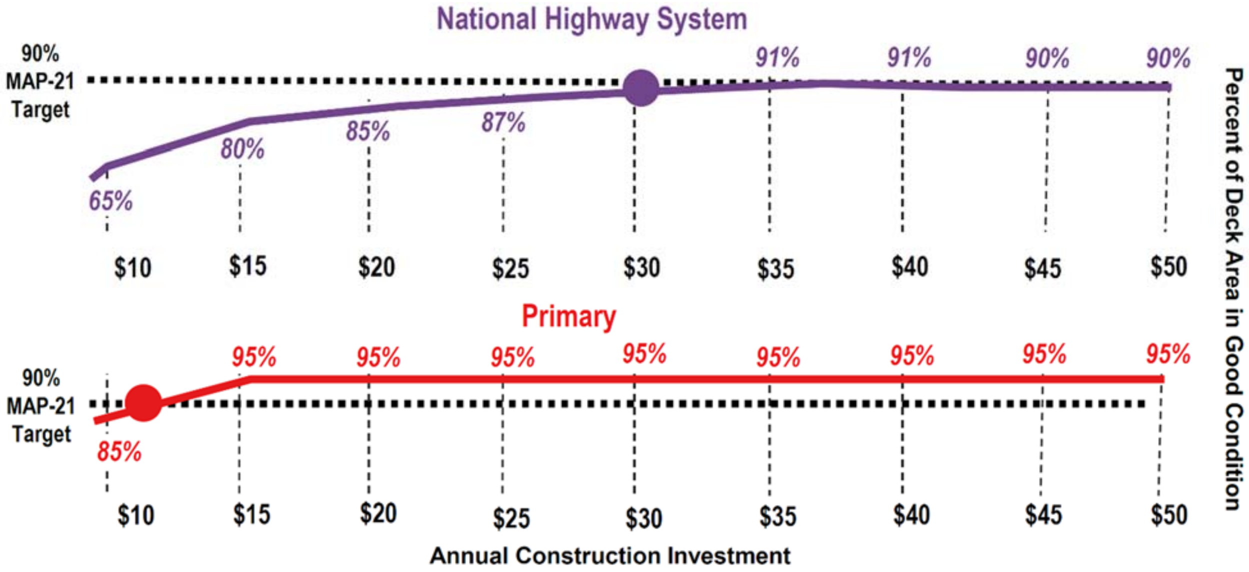


Figure 2-2: Tradeoff of funding vs performance (MDT TAM Plan 2015).

2.4 Incorporating rock slopes and other geotechnical assets in the TAM Plan

In the present study for rock slopes, the Task 6 report covers all of the analysis topics envisioned in the federal rules in a similar way to how other TAM systems began, particularly the development of performance targets, a life cycle management plan, a risk management plan, and investment strategies. Earlier tasks of the present study provide the basic ingredients for the asset inventory, conditions, and performance gap identification. Task 6 notes the data, analysis, and procedural issues requiring further work in order to perpetuate an asset management process for rock slopes. Most importantly, it is essential to ensure consistent resources and policies supporting an ongoing slope inspection process.

The National Highway Performance Program (NHPP) was established in MAP-21 and subsequent legislation as the primary federal means of paying for infrastructure replacement and preservation. Funding can be used for "a project or part of a program of projects supporting progress toward the achievement of national performance goals for improving infrastructure condition, safety, mobility, or freight movement on the National Highway System" (23 USC 119(d)(1)(A)). Inclusion of geotechnical assets within the Transportation Asset Management Plan ties the construction and preservation of these assets to the national goals and ensures the eligible use of these funds under 23 USC 119(d)(2)(A), "Construction, reconstruction, resurfacing, restoration, rehabilitation, preservation, or operational improvement of segments of the National Highway System."

In addition, 23 USC 119(d)(2)(K) allows the use of NHPP funds for "Development and implementation of a State asset management plan for the National Highway System in accordance with this section, including data collection, maintenance, and integration and the cost associated with obtaining, updating, and licensing software and equipment required for risk-based asset management and performance-based management."

It is clear from the MAP-21 legislation and subsequent rules that the TAM Plan is intended to become a strategic document that guides and justifies a large portion of the STIP. By providing an objective, data-driven justification for the funding and selection of geotechnical investments, and by including these investments in the STIP process, incorporation of geotechnical assets within the TAM Plan gives this asset class a seat at the table in preservation strategy, funding allocation, and investment programming decisions (Stanley 2011).

A geotechnical asset management plan (GAM Plan), whether integral with or separate from the TAM Plan, serves a very similar purpose. Therefore, it would promote the eventual usefulness and understandability of a GAM Plan if it is written to be consistent with the requirements of a TAM Plan, even if they are not fully integrated. It is also important that the GAM Plan satisfy a set of Department objectives which may or may not be the same as the federal objectives. These may include the following:

For stakeholders and customers (the public perspective):

- Define the types of geotechnical assets and explain how they contribute to cost-effective, safe, and reliable transportation service.
- Describe why preservation and risk mitigation are necessary for geotechnical assets, because of foreseeable impacts on mobility, safety, condition, and other performance concerns.
- Explain how the Department recognizes problems and measures success.
- Show the Department's 10-year objectives and the progress it is making toward them.
- Show that the public's investment is being used as efficiently as possible to achieve success.
- Be consistent and credible in how the Department grades itself.

For agency decision-makers (the technical perspective):

- Develop and apply a consistent, objective basis for selecting actions.
- Estimate costs and 10-year needs using available data.
- Invest at the right times to keep assets in service for as long as possible.
- Prioritize for long-term success (as explained to stakeholders).
- Determine 10-year network performance targets that are feasible with expected funding.
- Allocate limited funding toward the greatest reduction in risk and life cycle cost.

For both stakeholders and decision-makers:

- Improve the reliability of cost and performance forecasts.

- Provide a migration path so future research can improve the measures without re-defining them.
- Be compatible with pavement and bridge asset management, to facilitate long-term implementation.

This GAM Plan will be useful for multiple audiences. For outside stakeholders, the general public, and senior leaders an Executive Summary can communicate performance and decisions in a meaningful but non-technical manner. For management staff and professionals within the Department, a more extensive presentation can provide the necessary support for performance targets, budgets, and capital programs, showing how these investments relate to the Department's mission, goals, and objectives. For geotechnical and maintenance personnel, the GAM Plan provides the rationale and methods to guide routine decision-making regarding geotechnical assets, in pursuit of better transportation system performance. It also identifies additional or modified data collection practices to support the plan.

2.5 Self-assessment process

The incremental process of advancement in asset management necessarily occurs in phases spread over many years. During that time, much can change in an agency's institutional and economic environment, in the needs of stakeholders, in the agency's delivery capability, and in technology. Implementation may start and stop, even run backward at times. At any given time it is possible to sketch a roadmap to improved asset management, but only its initial steps are near enough in time to plan implementation.

A useful general approach to commence or resume the implementation of improved asset management is self-assessment. Agencies typically start with a relatively quick analysis at the strategic level, which helps in deciding which parts of the organization are ahead or behind, identifying barriers, and setting some initial priorities. Table 2-1 summarizes a strategic self-assessment presented in Volume 1 of the AASHTO Asset Management Guide (Cambridge 2002).

Table 2-1:.Outline of AASHTO TAM strategic self-assessment

Part A. Policy Guidance. *How does policy guidance benefit from improved asset management practice?*
Policy guidance benefitting from good asset management practice Strong framework for performance-based resource allocation Proactive role in policy formulation
Part B. Planning and Programming *Do Resource allocation decisions reflect good practice in asset management?*
Consideration of alternatives in planning and programming Performance-based planning and a clear linkage among policy, planning, and programming Performance-based programming processes
Part C. Program Delivery *Are appropriate program delivery processes that reflect industry good practices being implemented?*
Consideration of alternative project delivery mechanisms Effective program management Cost tracking and estimating
Part D. Information and Analysis *Do information resources effectively support asset management policies and decisions?*
Effective and efficient data collection Information integration and access Use of decision-support tools System monitoring and feedback

The Strategic Self-Assessment is couched in very general terms in order to be applicable to all transportation agencies and all types of assets. Volume 2 of the AASHTO Asset Management Guide provides more detail (Gordon et al 2011). In the specific domain of geotechnical assets, it is useful to think about how information about these assets enters into each of the business processes addressed in the strategic assessment. For example:

- Does the agency have written internal policies and procedures that govern how geotechnical asset needs are identified and prioritized? Are there quantitative criteria defined in the policies and procedures, which can be computed and used with inventory and inspection data about these assets? Do policies and procedures support reliable updating of quality inventory and inspection data?
- Do projects focused on geotechnical assets make it into the Statewide Transportation Improvement Program (STIP), and what barriers exist in making sure needed projects are programmed? Is it certain that all needs are identified? Do corridor-based projects focused on other asset types (e.g. pavements and bridges) also routinely and reliably consider geotechnical needs in project scoping? Are there reliable processes to include routine slope maintenance in the operating budget?
- Does the agency know how much it spends today on preservation, reconstruction, risk mitigation, and incident recovery on rock slopes and other geotechnical assets? Does the agency know the value of its geotechnical assets (replacement, depreciated or other) and how that value compares with other agency assets?
- Does the agency have the necessary delivery capability to inspect, maintain, and preserve geotechnical assets in the places where it may be needed? Is agency capability kept up-to-date with the worldwide state of the practice? Are both internal and external resources fully developed and leveraged to support the program? Are work accomplishments reliably recorded from planning to construction to performance monitoring? Are appropriate cost factors captured and used to update forecasting models?
- Is there a complete inventory database of geotechnical assets? Can conditions be plotted on a map along with other asset types? Can future deterioration be reliably forecast? Is there a process that can forecast future preservation needs?
- Do project planners and designers have readily-accessible data, which they can understand and rely upon, to include geotechnical needs when planning new work?
- When new routes are constructed or existing routes are improved, does the agency consider geotechnical risk and life cycle cost as part of the evaluation of alternatives, and does it provide for appropriate expenditures to maintain new assets after they are opened?

Clearly many of these questions apply to all types of assets, so in many agencies it may be more cost-effective to consider geotechnical assets along with other infrastructure assets in the same self-assessment. This would be a prelude to developing a coordinated multi-year program that can fill all the gaps.

2.6 Strategic goals and policy support for asset management

The MDT Strategic Business Plan (MDT 2004) summarizes the Department's major goals, which are resolved into policies and actions in TranPlan21, the Department's Long-Range Transportation Plan (Cambridge 2008). Among the major goals in the Strategic Business Plan are:

> *Ensure investment decisions consider policy directions, customer input, available resources, system performance, and funding levels.*
>
> *Enhance traveler mobility by providing a safe and efficient multimodal transportation system that supports Montana's economy and is sensitive to the environment.*
>
> *Reduce fatal and injury crash rates.*

> *Continuously strive to improve the effectiveness and efficiency of operations and processes.*
>
> *Consistently communicate standards, guidelines, policies, and expectations throughout MDT.*

At the federal level, similar goals are expressed in the Moving Ahead for Progress in the 21st Century (MAP-21) act in 23 USC 150(b):

> *(1) SAFETY.—To achieve a significant reduction in traffic fatalities and serious injuries on all public roads.*
>
> *(2) INFRASTRUCTURE CONDITION.—To maintain the highway infrastructure asset system in a state of good repair.*
>
> *(3) CONGESTION REDUCTION.—To achieve a significant reduction in congestion on the National Highway System.*
>
> *(4) SYSTEM RELIABILITY.—To improve the efficiency of the surface transportation system.*
>
> *(5) FREIGHT MOVEMENT AND ECONOMIC VITALITY.—To improve the national freight network, strengthen the ability of rural communities to access national and international trade markets, and support regional economic development.*
>
> *(6) ENVIRONMENTAL SUSTAINABILITY.—To enhance the performance of the transportation system while protecting and enhancing the natural environment.*
>
> *(7) REDUCED PROJECT DELIVERY DELAYS.—To reduce project costs, promote jobs and the economy, and expedite the movement of people and goods by accelerating project completion through eliminating delays in the project development and delivery process, including reducing regulatory burdens and improving agencies' work practices.*

State Departments of Transportation are required to describe and quantify their strategies, targets, and progress in pursuing these goals by means of performance measures and the Risk-Based Transportation Asset Management Plan (TAM Plan).

With this motivation, MDT can support long-term implementation of improved asset management business processes by adopting a set of written internal policies, describing the desired business processes that direct routine agency actions toward the stated goals in a measurable way. The following is a list of examples of potential topics for policy documents. It is clear that these types of policy and procedure documents, itemized below, would not necessarily have to be specific to rock slopes or geotechnical assets, but might cover all asset classes participating in transportation asset management. Many of the topics in these proposed policies have been addressed in the RAMP. The development and adoption of official policy documents by the Department would involve review and finalization of these initial procedures and models, as well as cooperation with other MDT groups allowing uniform data collection, data management, and data presentation for the Department's various asset types.

Geotechnical inventory policy

Purpose: To establish and maintain an electronic inventory of Department-owned geotechnical assets, to support transportation asset management and for other management needs.

Topics addressed: Criteria for inclusion of individual assets in the inventory; types of data to be maintained; maintenance crew procedures to keep the data up-to-date after maintenance actions; contract close-out procedures to update the inventory after asset modifications; reference to a manual for detailed instructions.

Geotechnical inspection policy

Purpose: To maintain permanent electronic records of current and past conditions and levels of service of the elements in the Geotechnical Inventory.

Topics addressed: Criteria for inclusion of individual assets in the inspection process; types of data to be gathered; inspection interval, including risk-based criteria; project close-out procedures for updating the condition data; accessibility of data to the systems and processes that need it; data retention policy; reference to a manual for detailed instructions.

Work accomplishment tracking

Purpose: To ensure that identified needs for maintenance, preservation, and improvement are implemented, and to gather data required for accurate deterioration and cost models.

Topics addressed: Criteria for inclusion of individual work items in the database; types of data to be gathered; standards for data quality and timeliness; accessibility of data to the systems and processes that need it; data retention policy; reference to a manual for detailed instructions.

Performance assessment and communication

Purpose: To communicate current condition and performance, past trends, future predictions, and performance targets for geotechnical elements of the transportation network.

Topics addressed: Definitions of performance measures, including condition states, condition index, and other resilience measures if used; the form of presentation of performance data in public-facing and internal web pages and reports; means of presenting performance geographically and in trends over time (including past trends, current performance, and projected 10-year future performance targets); and updating interval for each form of presentation.

Decision support

Purpose: To accurately, objectively, and consistently consider costs and performance in geotechnical asset management decision making; and to consistently quantify the cost and benefit for geotechnical needs in the budgeting and programming process.

Topics addressed: Requirements of life cycle cost analysis; quantitative parameters including analysis period, discount rate, and inflation assumptions; consistent definitions of cost factors; requirements for deterioration models; requirements for risk assessment and monetization; performance measures for each business process including:

> Needs identification;
> Comparison of project scope and timing alternatives;
> Prioritization and resource allocation;
> Tracking of the performance of individual assets and groups of assets;
> Comparing investments across asset categories;
> Evaluating projects that affect multiple classes of assets in a corridor;
> Retirement or other disinvestment alternatives;
> Network target-setting and tracking;
> Establishment of level-of-service standards;
> Establishment of treatment selection policies;
> Negotiating funding levels;
> Public reporting of network performance.

The policy would state the form that these measures take, while more technical documentation would cover the means of calculating these measures for each purpose.

2.7 Management systems and equivalent analysis tools

Statewide rock slope inventory and assessment work was conducted for the initial RHRS Program in 2005. In 2016, researchers revisited a subset of these sites for reassessment work, as well as conducting detailed rating on Interstate 'B' slopes, which had been previously inventoried but not rated. The data collected from these two field assessment efforts was used to develop the analyses, models, decision support tools, event likelihood, and risk/mitigation cost correlations discussed in previous task reports. However, this work was only a starting point. Successful asset management requires regular inventory and assessment work to track how the agency is meeting goals, and improve the models underlying these goals. When incorporating rock slopes into a future TAM plan, MDT will need to determine an inventory/assessment interval and how the resulting information will be incorporated into analyses. With the aid of a comprehensive inventory and condition assessment of rock slopes, MDT will be able to perform the same types of analysis for these assets as it will be able to do for pavements and bridges:

- It will be able to use its condition and work history data to develop forecasting models for deterioration and costs, using methods such as those documented in NCHRP Report 713 (Thompson et al 2012), and as demonstrated in Task 6 of the present study. It will be able to use these models to forecast system-wide needs, to prioritize needs on individual sites, and to optimize the level of preservation and risk mitigation.
- It will be able to compute reasonable estimates of life cycle cost taking into account near-term and long-term forecasts of maintenance and capital costs, to promote efficiency by minimizing these costs, using methods such as those documented in NCHRP Report 483 (Hawk 2003).
- It will be able to quantify safety and mobility impacts of rockfall using research-based methods as was demonstrated in Task 6 of the present study, based on the standard AASHTO 'Red Book' (AASHTO 2010).
- It will be able to compute the return on investment of preservation work, and plan a program of work that optimizes return on investment. Task 6 of the present study showed that the potential system-wide return on investment of rock slope preservation activity is on the order of 114%.
- It will be able to perform a fiscally-constrained investment analysis for the TAM Plan, satisfying all the federal requirements by incorporating funding uncertainty, and enabling the development of reasonable performance targets and expectations to fit any given funding level.

All of these are appropriate, though not mandatory, for inclusion of rock slopes in the TAM Plan, according to the federal rule. They all are also needed for inclusion in MDT's Performance Programming Process (P3). These capabilities are all dependent on a consistent, objective assessment of rock slope condition as conducted in the present study.

By implementing and continuing to update the enhanced rock slope rating system, MDT will satisfy the immediate goals of identifying current needs, and will position itself to achieve the longer-range goals of the TAM Plan and the P3 process.

The data management procedures used in the present study and other studies of geotechnical asset management are generally much simpler than those in common use today for pavement and bridge management. It is appropriate to consider integration of geotechnical asset databases with other, existing systems such as geographic information systems, agency data warehouses, maintenance management systems, or even bridge and pavement management systems.

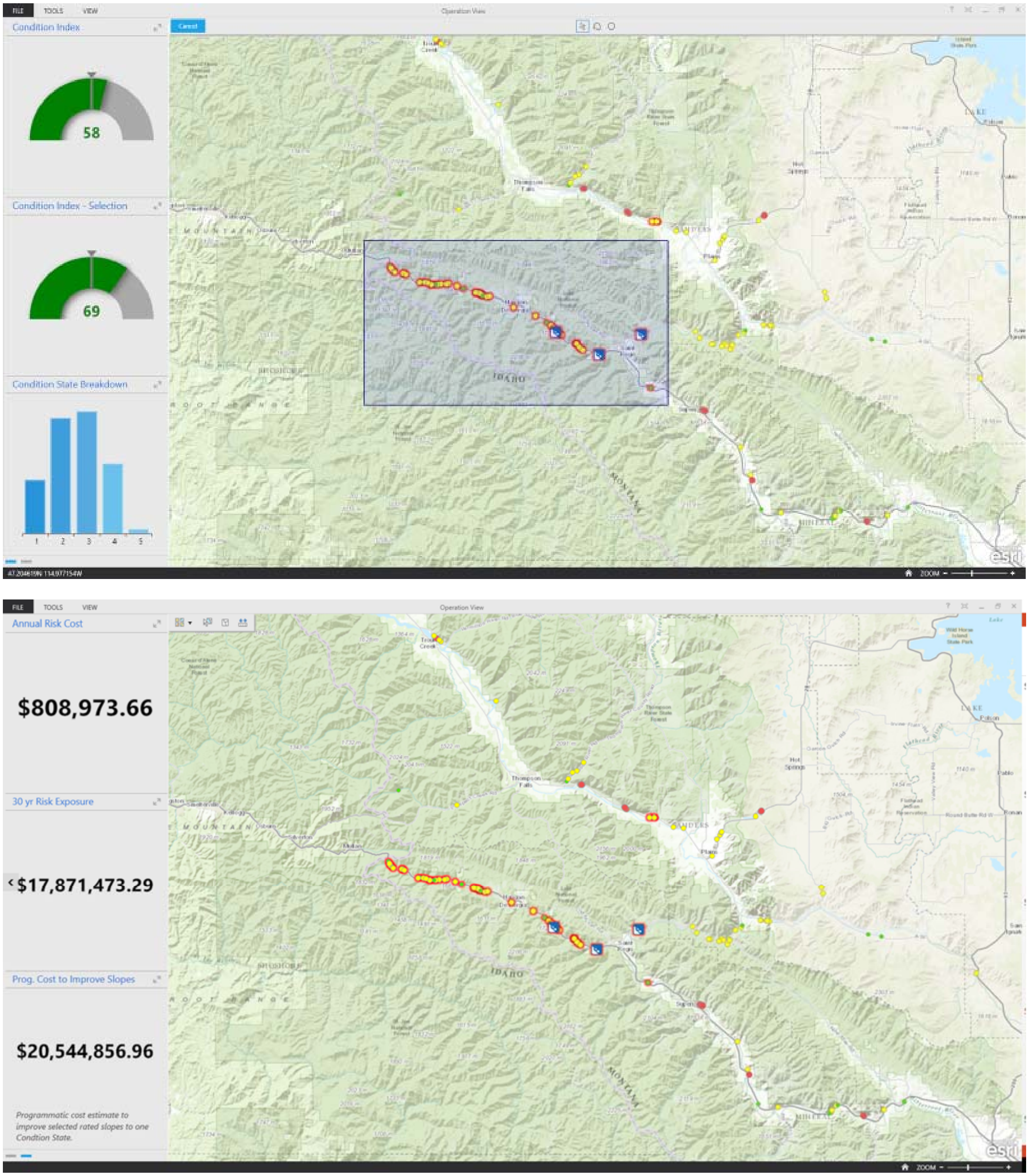
A decision support tool for geotechnical asset management would cover the same types of analysis addressed in Task 6 of the present study, but would be conducted at both the network level and the asset level. Modern spreadsheets are an appropriate class of tool to address the analytical and reporting needs, as was done in Task 6. Therefore the development of a fully-implementable analysis tool is feasible and might be a logical future step in MDT's asset management implementation for rock slopes and other geotechnical assets.

3 Future Technology Needs

In order to derive maximum benefit from the RAMP, MDT should maintain its licenses for ESRI's ArcGIS Online (AGOL) system until an enterprise TAM system with geospatial capabilities that incorporates the RAMP is conceived of and implemented. Currently, the system is easily accessible from any computer, and data can also be shared publicly via embedment in a Department webpage or through a sand-alone application, if desired. AGOL's RESTful application program interface (REST API) points facilitates cross-platform sharing of geospatial RAMP data. The geospatial functionality also helps users quickly visualize proximity of an asset to a proposed construction project. If MDT begins using AGOL to present other asset inventories, they can also be added to maps or incorporated into geospatial analysis tools, potentially identifying areas where various assets interact in complex ways to undermine corridor function. Incorporating mitigation of a poorly performing rock slope, or any other poorly performing asset, into the early stages of a project will help MDT avoid costly surprises.

Using Feature Data Layers within MDT's AGOL service, users can map presence of slopes from within either desktop or online platforms, as well as utilize features of the online platform, such as specialty, cross-platform (desktop PC, Android, and iOS) Apps and Performance Dashboards. An example of such a Dashboard utilizing a desktop ESRI program accessing online RAMP data is shown in Figure 3-1. In this example, the condition of the both the entire network and a selected slope subset are illustrated in a gauge format. On the next screen, the risk factors of the selection are listed, including both the annual and 30-yr risk exposure and then the programmatic cost for improving the slopes one condition state. This demonstrates the potential incorporation of similar data presentations for future internal and public-facing TAM IT products.

MDT should identify a person, small group, or consultant to maintain the AGOL-hosted rock slope database. This entity would be responsible for tracking edits to the asset database and the geotechnical event and maintenance trackers, confirming the quality of those edits, collecting any missing information, and regularly ensuring database back up the on MDT's server to prevent accidental data loss. These tasks could all be conducted on an annual to 6-month basis. For large-scale rounds of inventory/assessment work, QA/QC should be part of the process, and not left for the database manager to deal with at some future date.



Condition Index
58

Condition Index - Selection
69

Condition State Breakdown

Annual Risk Cost
$808,973.66

30 yr Risk Exposure
$17,871,473.29

Prog. Cost to Improve Slopes
$20,544,856.96

Programmatic cost estimate to improve selected rated slopes to one Condtion State.

Figure 3-1: Prototype Performance and Decision Support Dashboard. Top exhibits a site selection process and bottom exhibits aggregated data for the selected RAMP sites.

4 Strategic Enterprise Architecture (EA) Alignment

MDT has recently begun implementing a Strategic Enterprise Architecture (EA) Plan for improving digital data systems for the next five to seven years (Cooney & Paxton, 2016). This roadmap recommends many separate programs, several of which are relevant to the RAMP: Transportation Project Delivery, Maintenance and Asset Management, and Civil Integrated Management (reported on in the 2017 report addendum). The RAMP fits into these three categories as follows:

- **Transportation Project Delivery**. Transportation Project Delivery is responsible for all aspects of the project delivery lifecycle from initial systems planning to detailed project scoping through environmental, preconstruction, construction and project closeout. Incorporating mitigations to rock slopes early in the planning and environmental assessment process allows preservation projects to be constructed as part of the standard project delivery process. Preservation actions such as ditch improvements with paving or guardrail replacements projects, shepherds along the preservation aspects of the RAMP to reduce life cycle costs as described in the Task 6 reports. Adding a figurative ‘checkbox’ to the planning process ‘checklist’ that the RAMP has been consulted for improvement opportunities is recommended as a first step in tying the RAMP to the planning process.

- **Maintenance and Asset Management.** Continuing success of the RAMP program will be, in part, through recording of rock slope-relevant maintenance activities as a measure of performance and integration of the RAMP with the rest of the Asset Management Framework currently being conceived. The new Maintenance Managment System (MMS) digital field tools are based on the ESRI Collector App. The RAMP AGOL geodatabase is compatible with the Collector App and maintenance items that relate to rock slopes should be integrated into the MMS workflow.

  For Asset Management, the RAMP geodatabase is compatible with geospatial databases of the remainder of the MDT’s assets. Future integration should be ensured by communications with MDT’s Information Services Division (ISD) and incorporation into the planning and asset management work flow.

- **Civil Integrated Management.** Civil Integrated Management (CIM) encompasses the technologies and processes that facilitate the transition from traditional construction project delivery and facility management (2-dimensional paper plans and specifications) to digital project delivery and asset management. Transitioning to CIM requires highly accurate advanced survey methods, intelligent model-based design, digital project delivery, and a digital database for asset management. Conceivably, CIM will require 3D scanning and/or photogrammetric surveys for existing and as-built information. Repeat, detailed surface surveys of rock slopes and other geotechnical assets will supplement detailed rockfall activity information from maintenance. By performing surface difference calculations between survey sets, a measure of rockfall activity and debris accumulation is available for incorporating into rock slope assessments. An example of this would be collecting a detailed scan of a newly excavated or existing slope and collecting a secondary survey sometime later. Comparing the surfaces with one another will both highlight where rock has fallen from the slope and the total quantity differences. Eventually, these types of calculations can be an objective measure of rockfall activity, supplementing the RAMP Performance Measures.

5 Recommendations

Based on our review, it is our opinion that the current RAMP program is compatible with a future TAM plan, but that some additional work would need to be done during the integration process. Currently, federal guidelines require only bridges and pavements be included in state's TAM plans (FHWA 2016 and 2017). However, the most recent federal rules provide incentives to include assets other than pavement and bridges, such as geotechnical assets by simplifying the requirements for inclusion into a state's TAM Plan. This gives MDT significant flexibility in how it incorporates the RAMP into its TAM plan.

To move forward with development and implementation of the RAMP, the Department should, at a minimum:

- Maintain existing IT licenses to host the RAMP data in an accessible online environment;
- Adopt the Geotechnical Event and Maintenance Trackers developed as part of this program, which will enable the Department to refine estimate event likelihoods, gauge consequences of rockfall events, and maintenance costs associated with rock slopes;
- Continue improvements in the Department's maintenance cost tracking program, including modification and addition of maintenance codes to include slope-related codes so that the amount of money spent on maintaining rock slopes, as well as other assets like landslides or settlement, can be more easily extracted for improved budget forecasting;
- Enter new rock slopes created by corridor realignment or reconstruction work into the ArcGIS/AGOL RAMP geodatabase;
- Update information and ratings for existing sites in the RAMP geodatabase following construction, mitigation, or significant failure events;
- Conduct another large-scale inventory and assessment program in 5 to 7 years incorporating additional data collected using tools developed as part of this program;
- Include slope assets and slope-related project concepts early in the planning and design process to improve overall project outcomes and avoid costly design changes and construction change orders;
- Develop a formal process for querying the RAMP database for opportunities to improve rock slope condition as part of other improvement projects;
- Integrate the RAMP into the three Strategic Enterprise Architecture (EA) fields above and provide feedback to MDT ISD on how RAMP is needed for a comprehensive approach;
- Develop and maintain a STIP-level project for maintaining and improving the RAMP; and
- Incorporate the RAMP into MDT's TAM plan.

These steps will help MDT maintain the quality of the current RAMP database so that it remains a valuable reference for Department personnel. Additionally, if MDT chooses to incorporate rock slope assets in a future TAM plan, having an up-to-date RAMP dataset and an established connection between geotechnical staff and the planning process will make it much easier to develop the forecasting tools and performance goals that are an essential part of an asset management plan.

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