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Task 3 Report

Rock Slope Asset Management Program

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Prepared for:

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ROCKFALL HAZARD PROCESS ASSESSMENT

TASK 3 REPORT
ROCKFALL RATING CRITERIA

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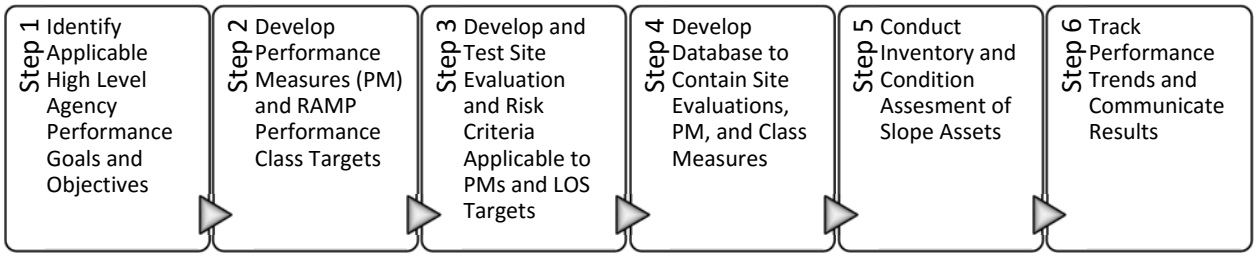
Executive Summary

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.

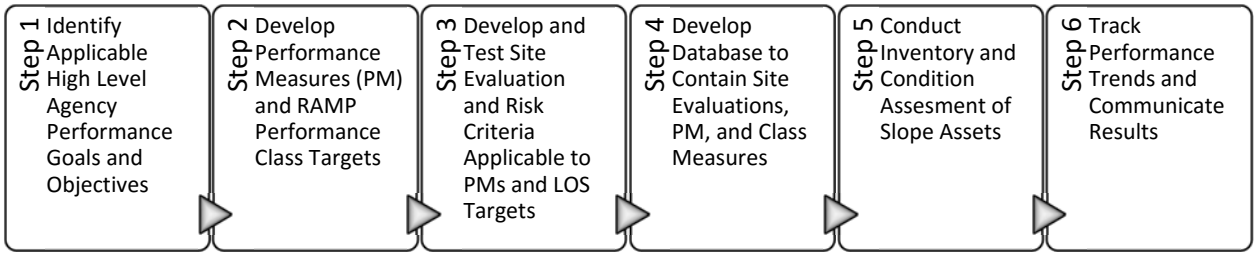


Figure 1-1: Flow Chart for RAMP Process.

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

[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

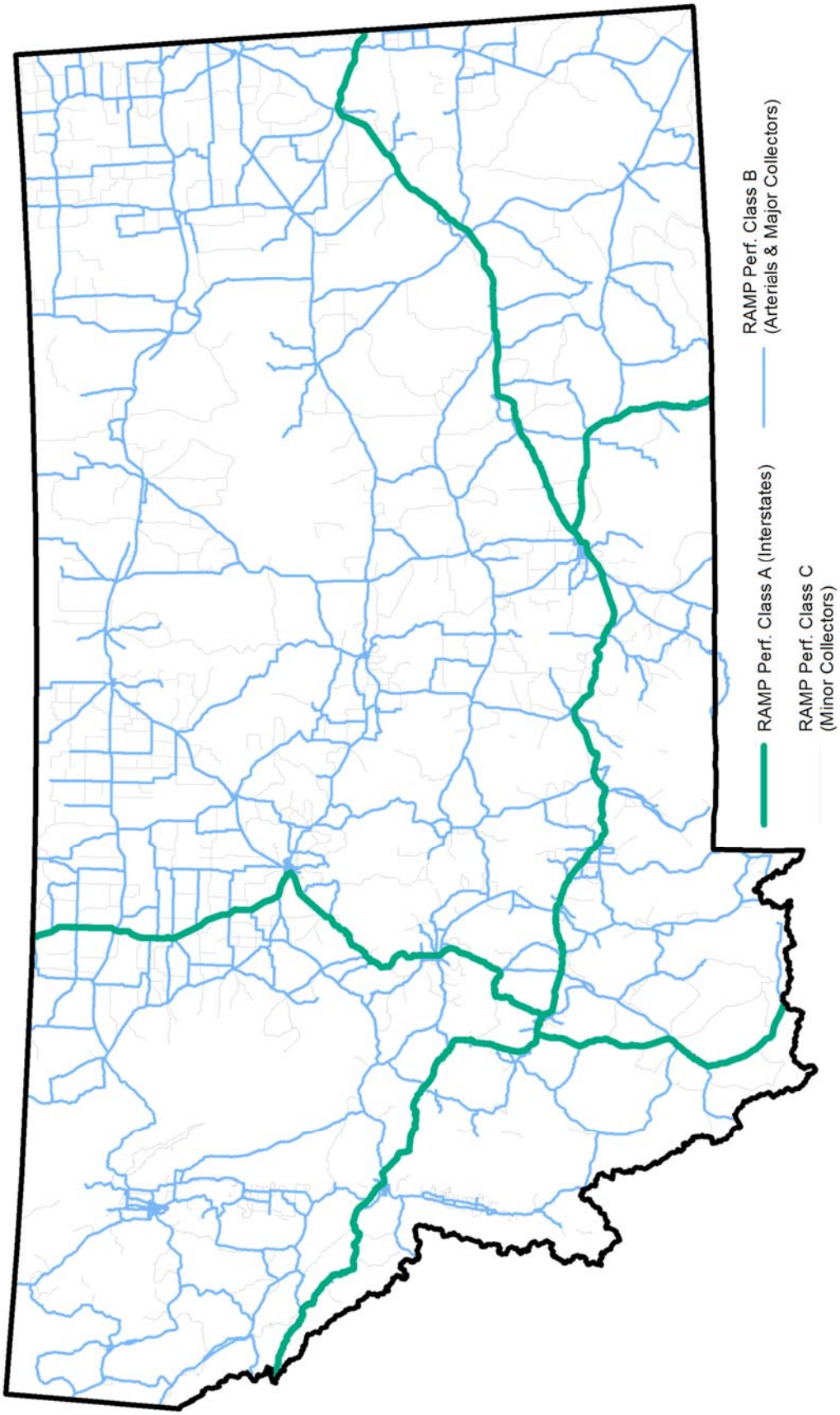


Figure 3-1: RAMP Performance Classes based on Functional Classification. Off system routes (Class C) not shown for clarity.

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 **Error! Reference source not found.**. 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.

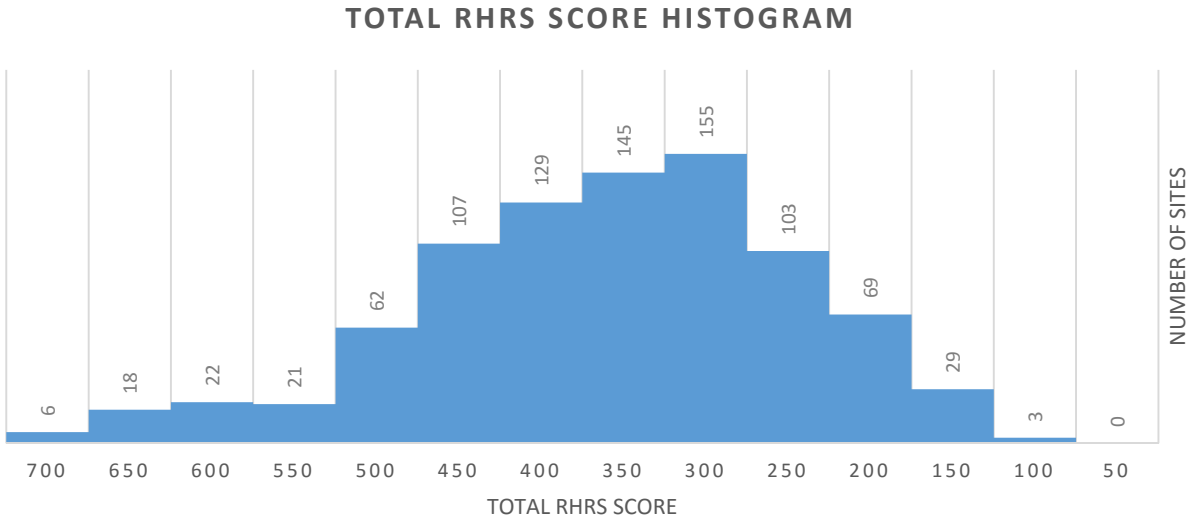


Figure 4-1: Histogram distribution of total RHRS scores for the 869 sites evaluated in 2004.

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

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

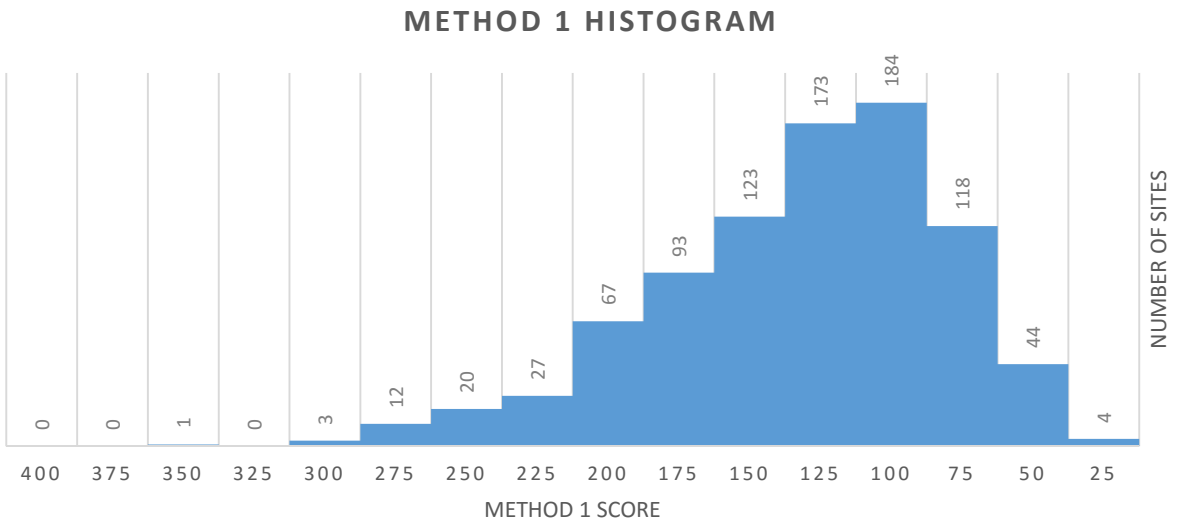


Figure 4-2: Histogram distribution of Method 1 scores for the 869 sites evaluated in 2004.

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

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

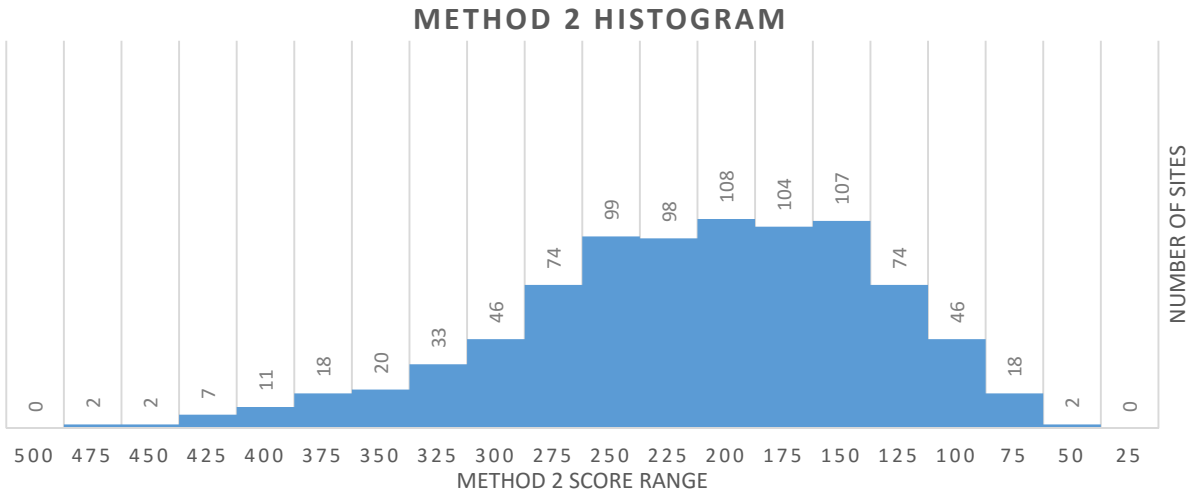


Figure 4-3: Histogram distribution of Method 2 scores for the 869 sites evaluated in 2004.

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

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

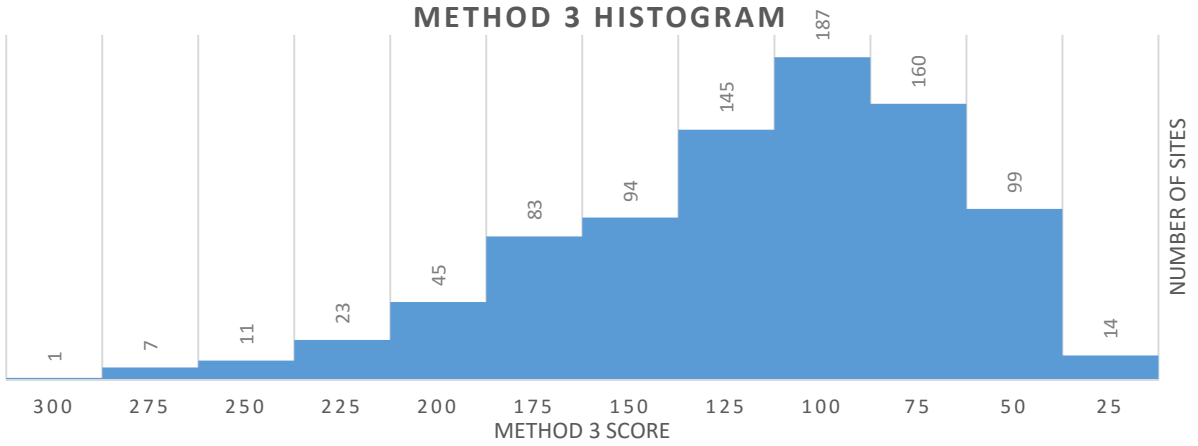


Figure 4-4: Histogram distribution of Method 3 Slope Rating scores for the 869 sites evaluated in 2004.

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.

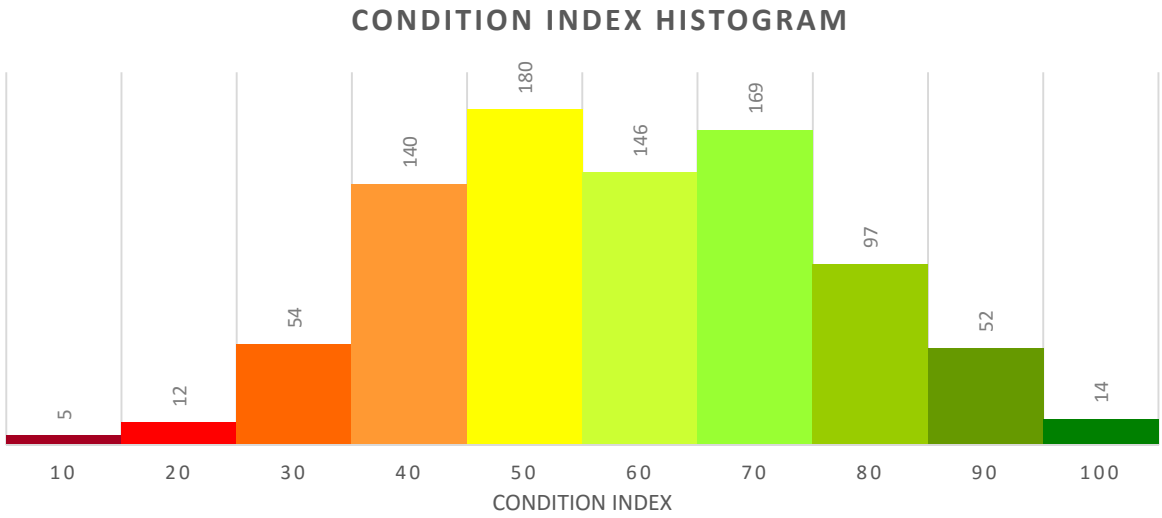


Figure 4-5: Histogram distribution of Condition Indexes for the 869 sites evaluated in 2004. Color gradient signifies the transition through Good/Fair/Poor conditions.

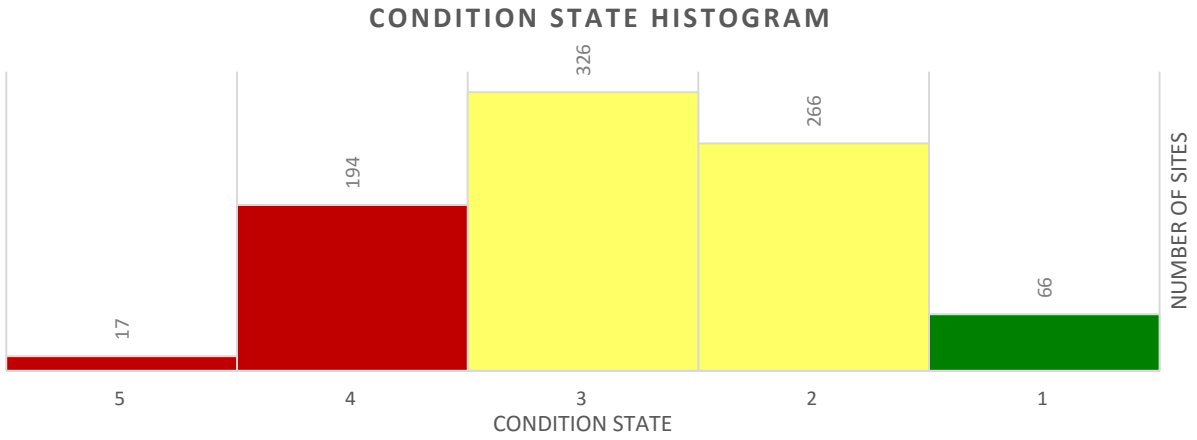


Figure 4-6: Histogram distribution of Condition States for the 869 sites evaluated in 2004. Green/yellow/red color scheme indicates Good/Fair/Poor condition.

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.

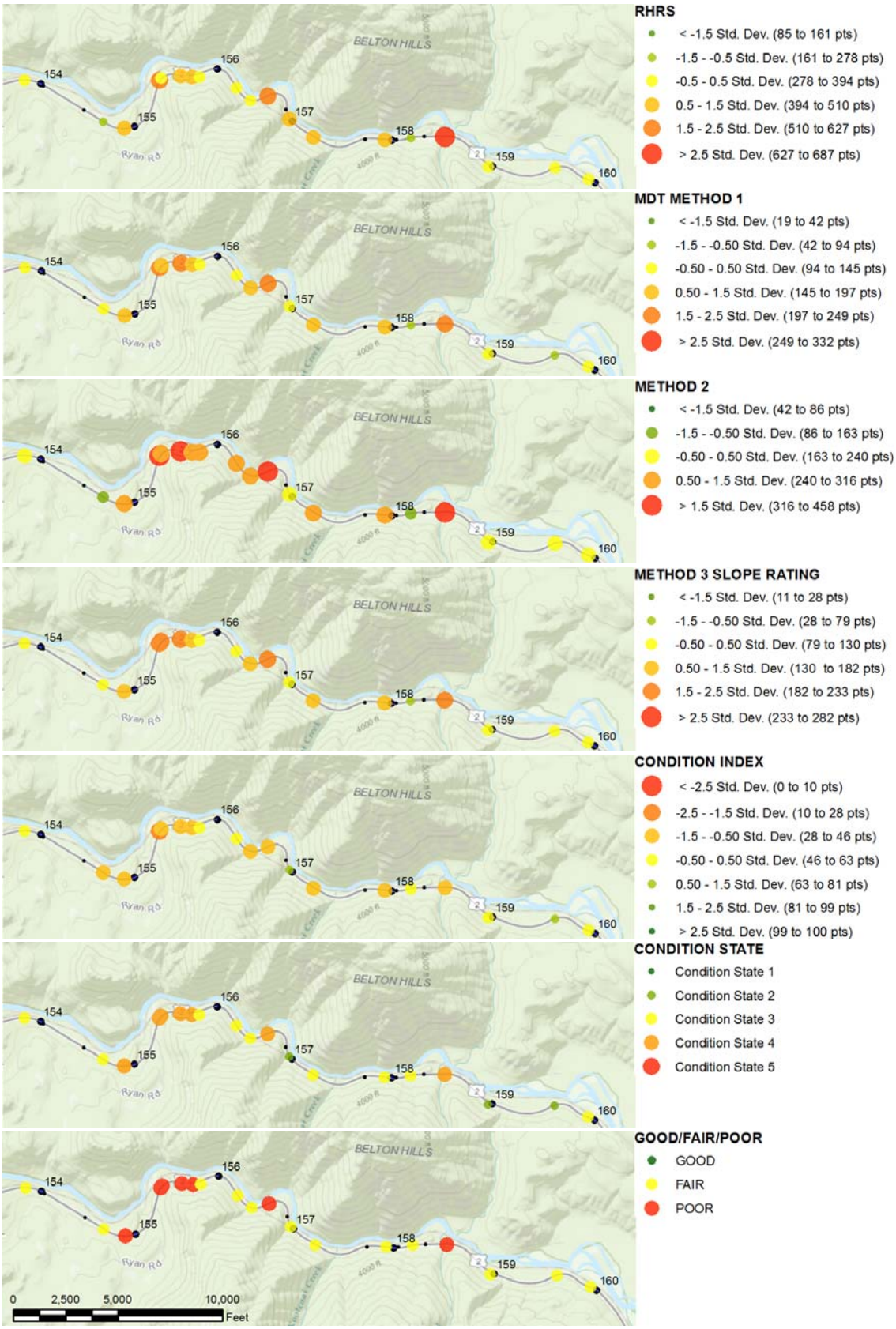


Figure 4-7: Comparison of rating methods for a six mile corridor immediately east of West Glacier on Highway 2, MP 154 to 160.

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.

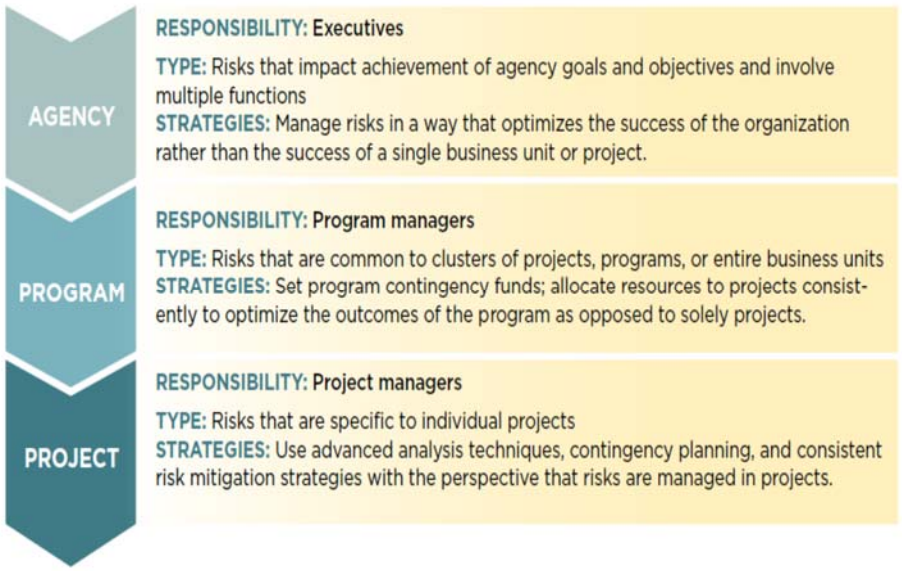


Figure 5-1: Transportation Agency Levels of Risk. (Federal Highway Administration 2012)

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.

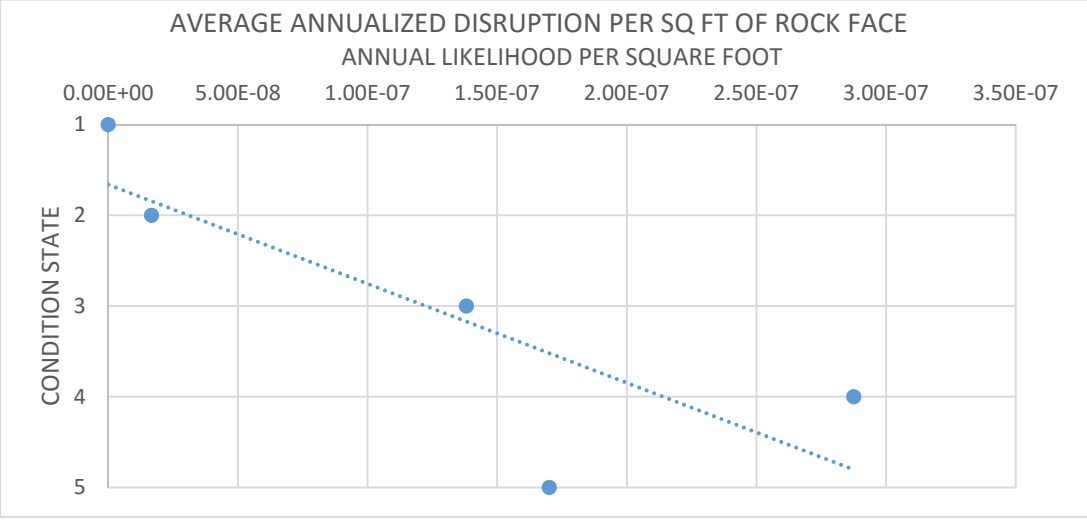


Figure 5-5: Average annual likelihood of service disruption per square foot of rock slope face, based on 2016 MDT survey responses.

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	

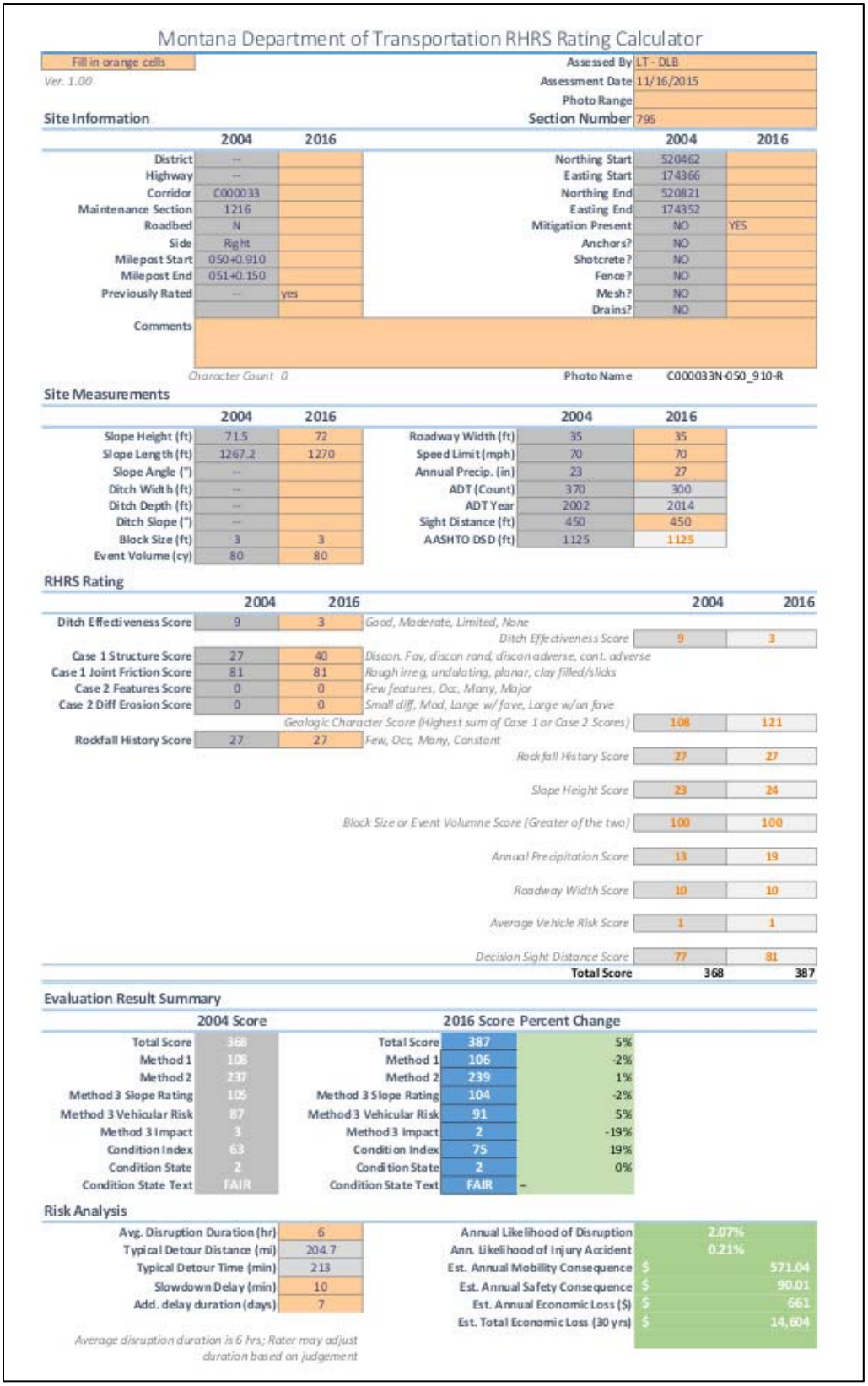
6 Steps 4 and 5: Database and Conducting Assessments

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		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 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.

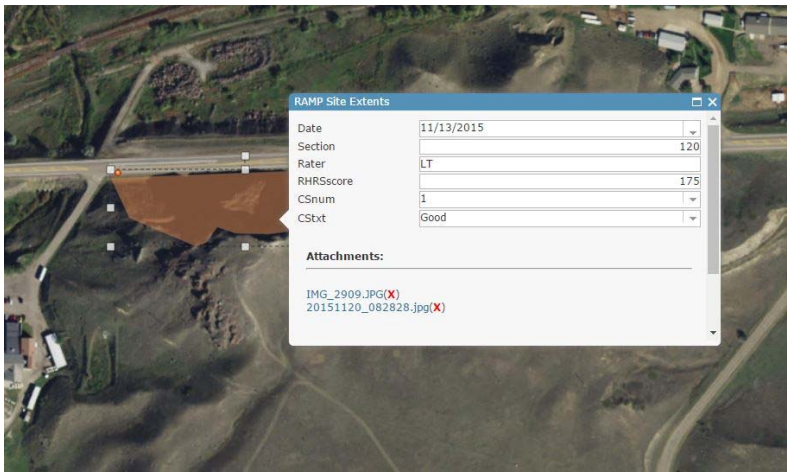


Figure 6-2: Data entry for RHRS section 120 (MT 2 near Havre) using the AGOL Collector Application. Note uploaded photos and dropdown entry options.

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:).

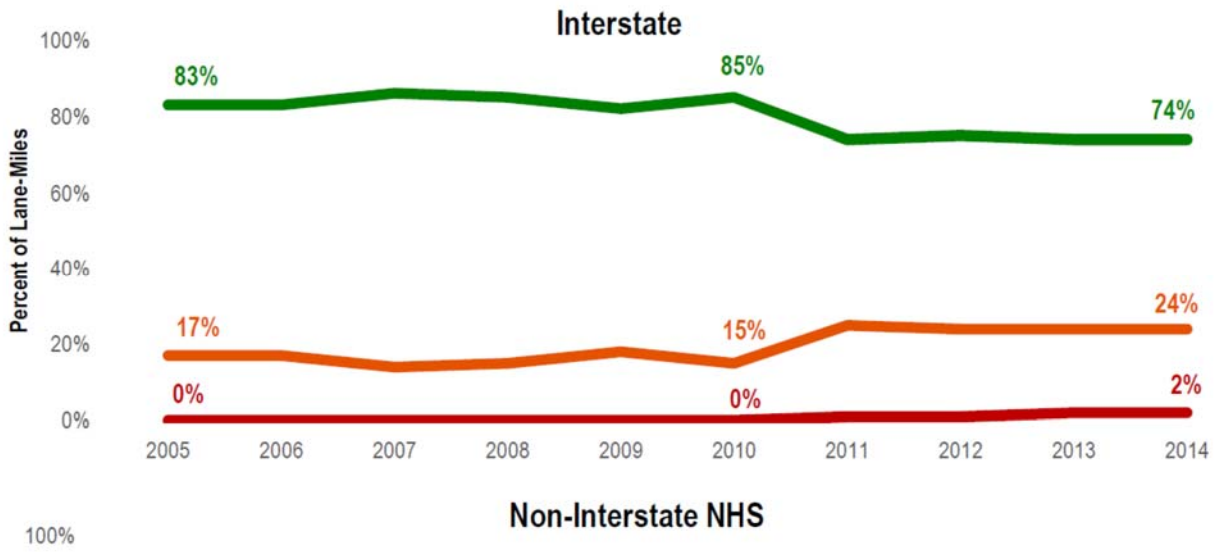


Figure 7-1: Example of Pavement Performance over the time.

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)

[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.

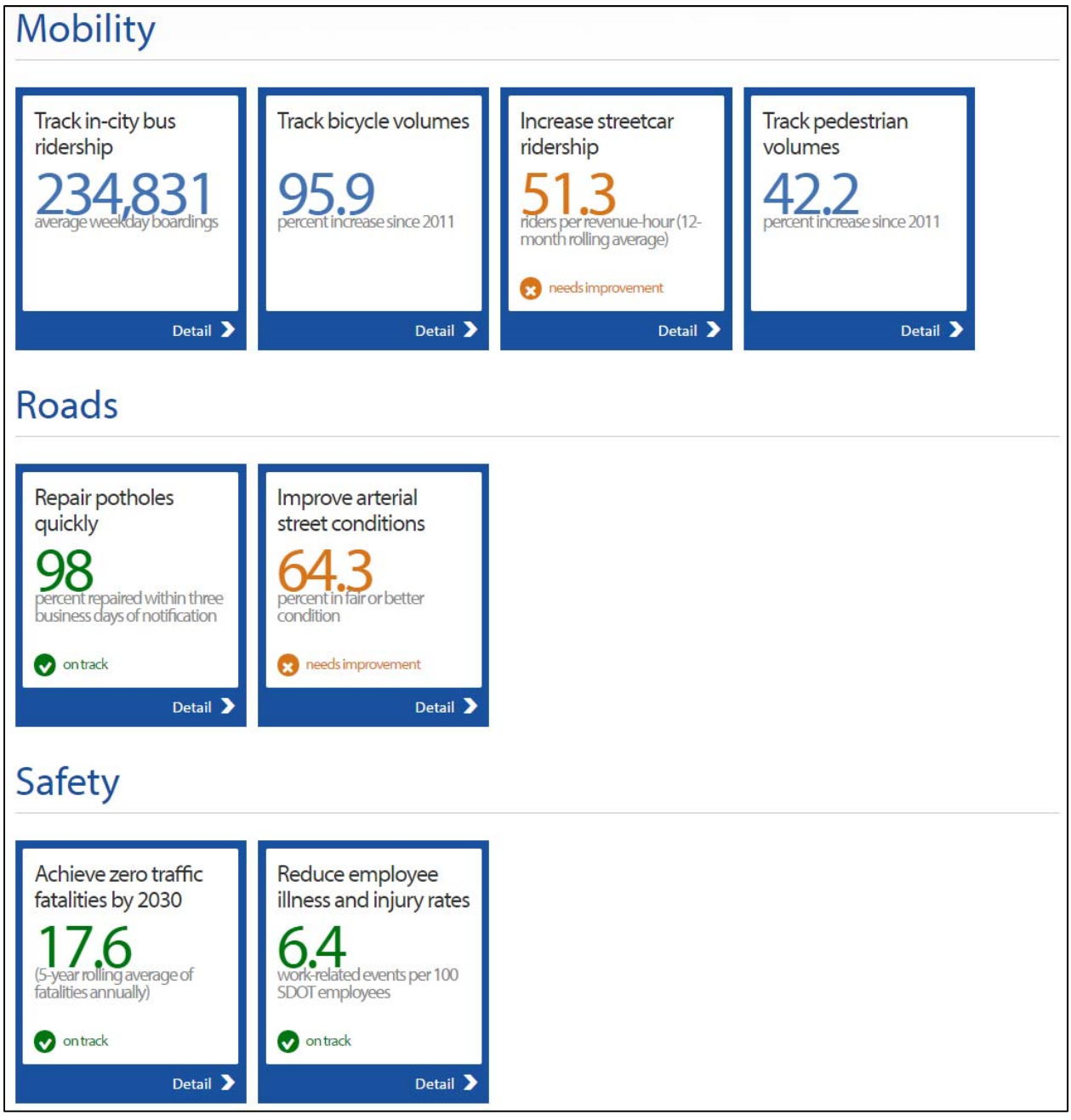


Figure 7-2: City of Seattle's Performance Dashboard.

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.

9 References

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Appendices

2004 Rockfall Sites - Total RHRS Score

Rated Sites

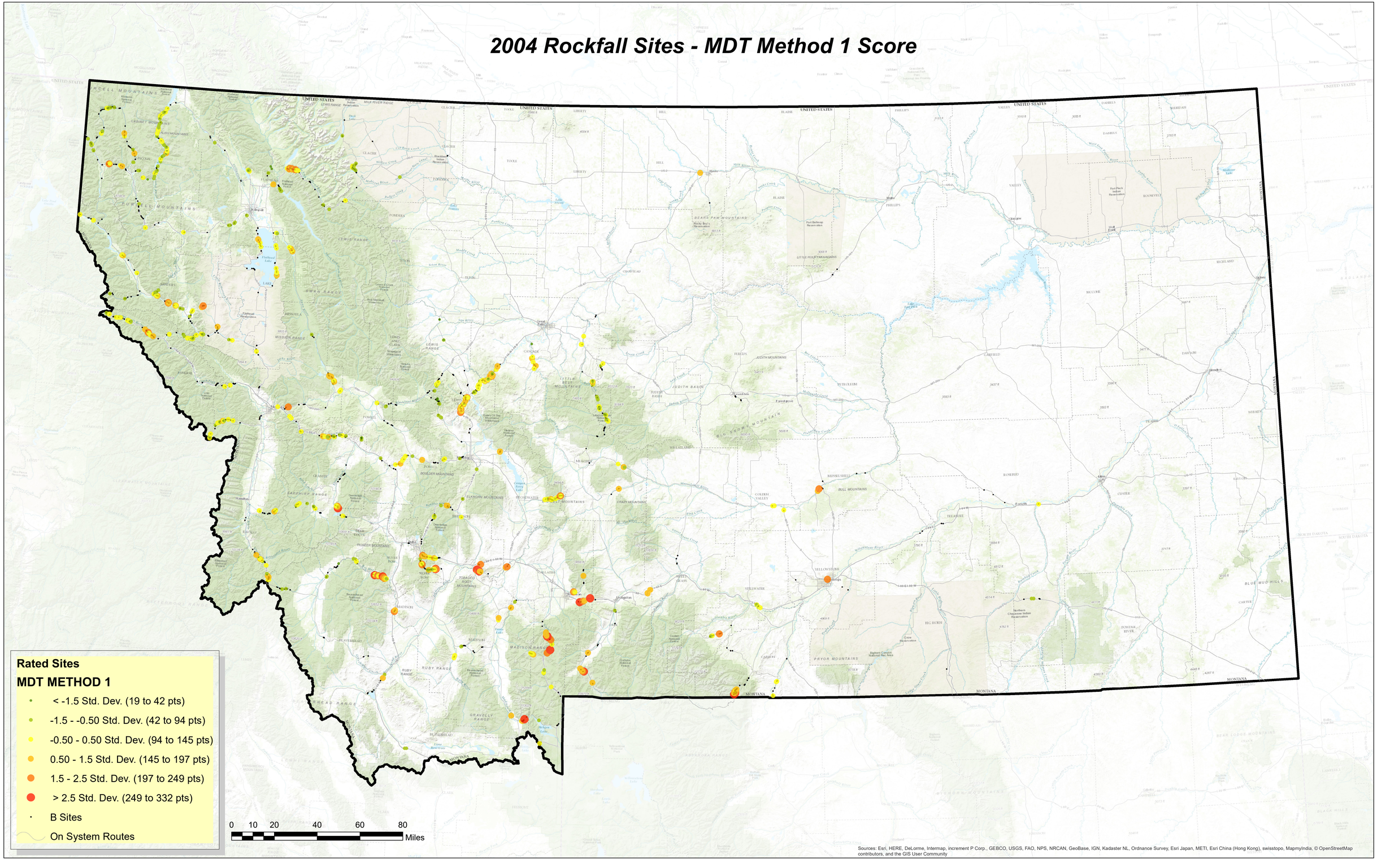
RHRS Score

- < -1.5 Std. Dev. (85 to 161 pts)
- -1.5 - -0.5 Std. Dev. (161 to 278 pts)
- -0.5 - 0.5 Std. Dev. (278 to 394 pts)
- 0.5 - 1.5 Std. Dev. (394 to 510 pts)
- 1.5 - 2.5 Std. Dev. (510 to 627 pts)
- > 2.5 Std. Dev. (627 to 687 pts)
- B Sites
- On System Routes

0 10 20 40 60 80 Miles

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

2004 Rockfall Sites - MDT Method 1 Score



2004 Rockfall Sites - MDT Method 2 Score

Rated Sites

METHOD 2

- < -1.5 Std. Dev. (42 to 86 pts)
- -1.5 - -0.50 Std. Dev. (86 to 163 pts)
- -0.50 - 0.50 Std. Dev. (163 to 240 pts)
- 0.50 - 1.5 Std. Dev. (240 to 316 pts)
- > 1.5 Std. Dev. (316 to 458 pts)
- B Sites
- On System Routes

0 10 20 40 60 80 Miles

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

2004 Rockfall Sites - MDT Method 3 Slope Rating Score

Rated Sites

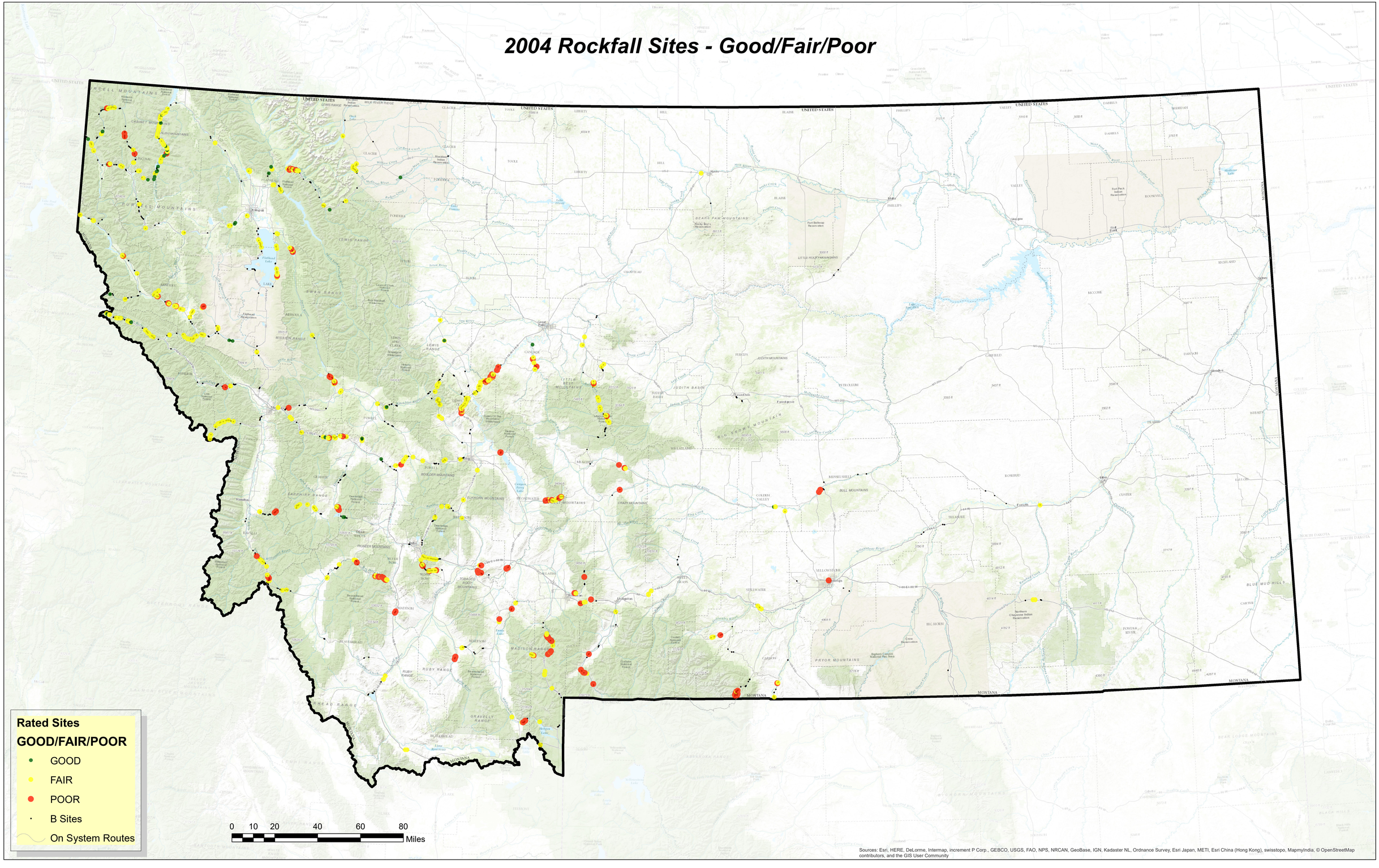
MEHOTD 3 SLOPE RATING

- < -1.5 Std. Dev. (11 to 28 pts)
- -1.5 - -0.50 Std. Dev. (28 to 79 pts)
- -0.50 - 0.50 Std. Dev. (79 to 130 pts)
- 0.50 - 1.5 Std. Dev. (130 to 182 pts)
- 1.5 - 2.5 Std. Dev. (182 to 233 pts)
- > 2.5 Std. Dev. (233 to 282 pts)
- B Sites
- On System Routes

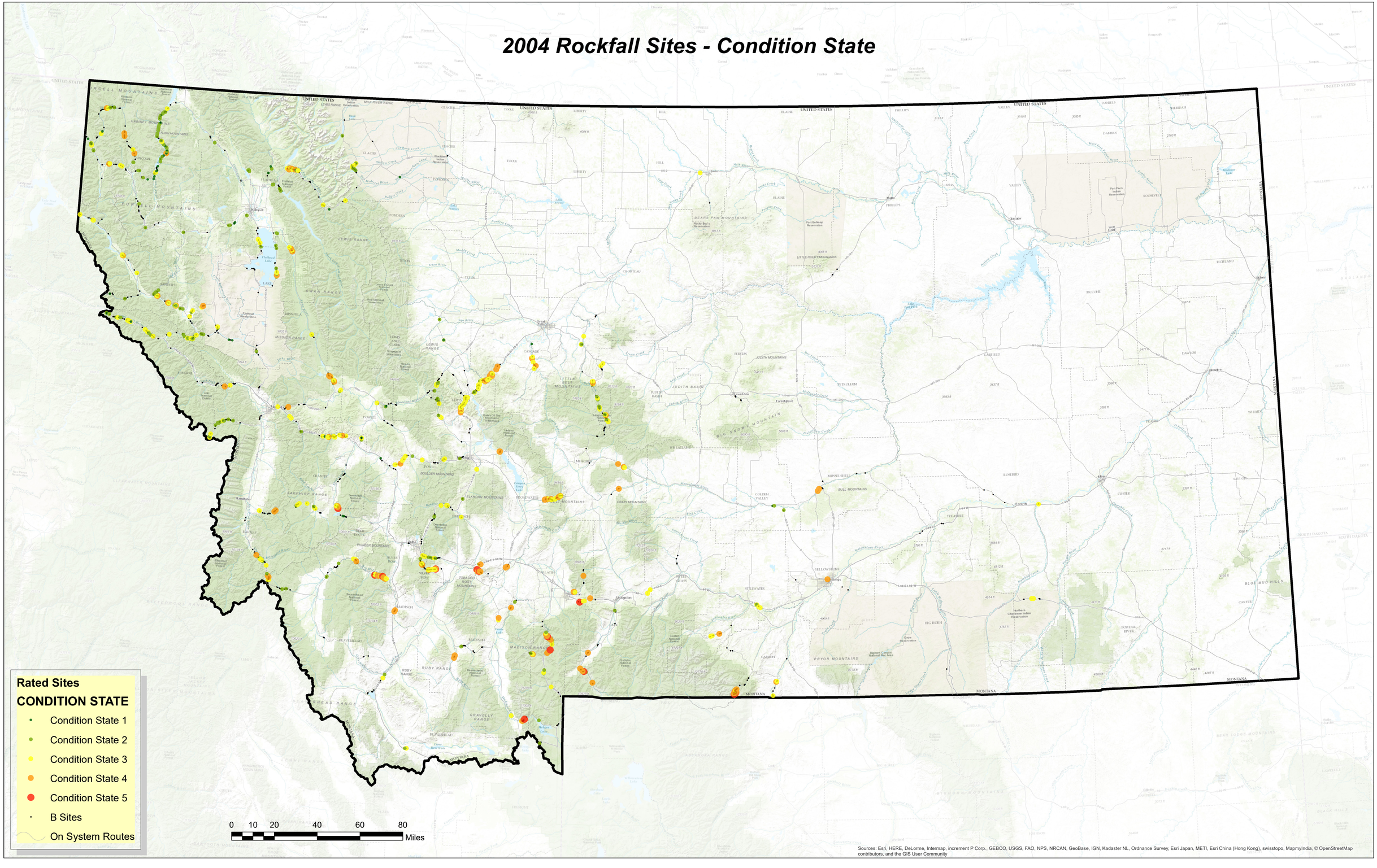
0 10 20 40 60 80 Miles

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

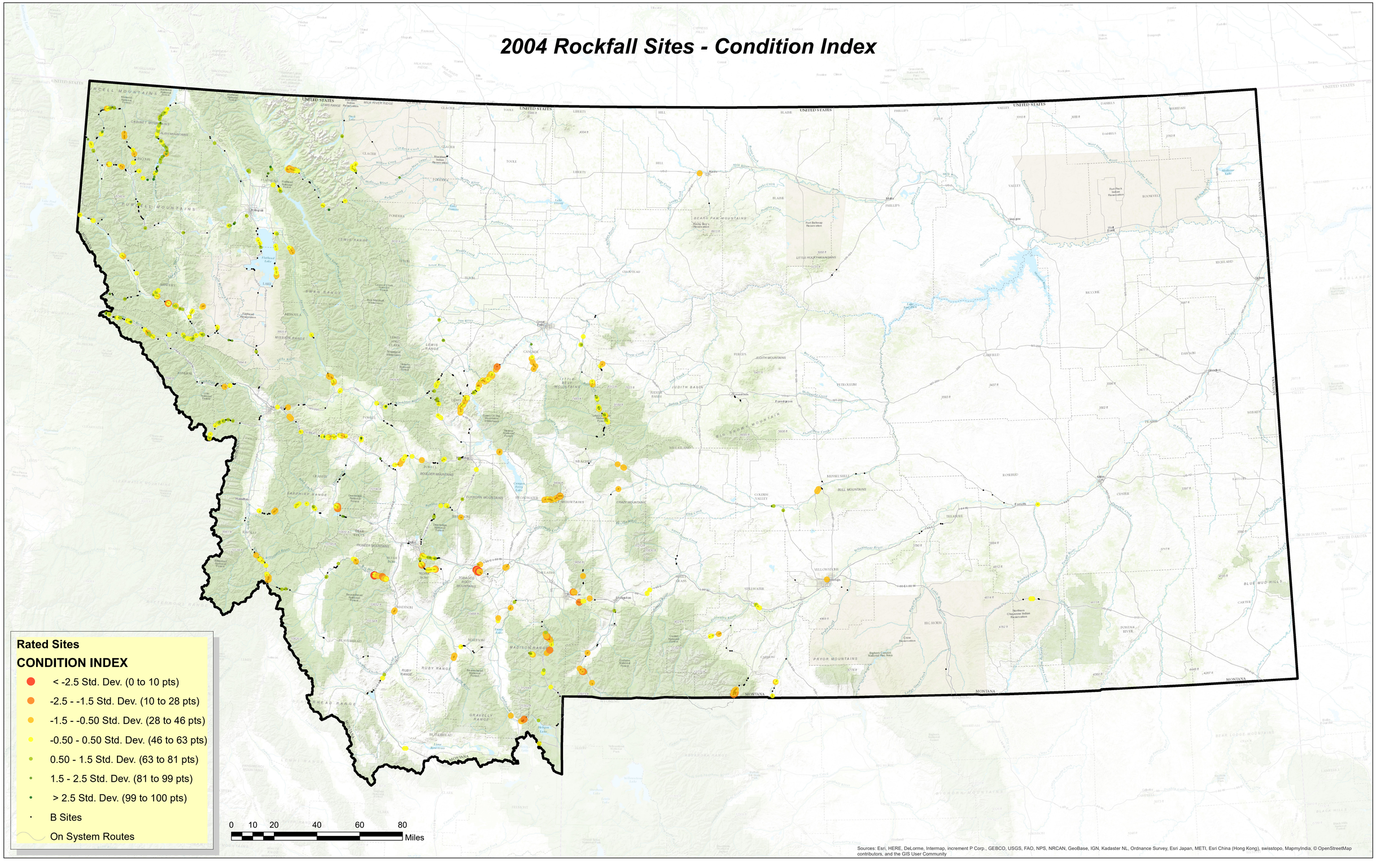
2004 Rockfall Sites - Good/Fair/Poor



2004 Rockfall Sites - Condition State



2004 Rockfall Sites - Condition Index



APPENDIX B

LIKELIHOOD ANALYSIS DATA SET

Road Closing Rockfall Events

District 1 Survey Responses

Please list all the events you can remember. Use a '?' if there is uncertainty in location or other event details.
Please also estimate how many additional events may occur each year that are not listed individually.

District	Date (Event year, at a minimum)	Corridor	Milepoint (approx. ok)	RHRS Section No. (if avail.)	Duration of complete closure (approx. hours)	Duration of work zone slowdown (approx. days/weeks)	Vehicle/Property Damage?	Injury Accident?	Comments
1	Feb. 2012	I-90	24.1	1172	Crossover, Months		Yes	no	Design Build Project, Rockfall Mitigation W of Drexel. 14 C.Y Boulder reached driving lane. Resulting wreck of truck.
1	Spring 2013	I-90	6.5	1147	Crossover, Months	Months	No	no	Change order in rockfall mitigation W of Drexel corrected the slope back to pre fail condiitons mostly
1	February 10-12, 2015	Hwy 12	18	1304	39 hrs	3 days	no	no	total 3 days includes the 39 hour closure, approximately 5000 ton rock give or take a few hundred tons.
1	Feb. 2015	I-90	22.4	1168	Crossover, Months	Months	Possibly	no	800 CY of debris filled ditch, overwhelmed truck rail with some material spilling onto roadway.
1	yearly	MT 200	58?	179, 181, 182		2-4 hours	Possibly	no	lots of minor rocks on the road, mostly can be plowed off. Requires frequent ditch cleaning. Larger rocks have fallen in the
1	yearly	MT 200	64	54, 189, 190, 191		2-4 hours	Possibly	no	I'm not positive about section 54. doesn't seem to match the route and might be a mistake in the RHRS.
1	once to twice a year	MT 1	27-28	500-506	6-12 hrs		minimal	no	most closures are single lane, if at night full closure until morning. (flint creek hill)
1	Jan. 2015	S-210	5	1316	<8 hours		Yes	no	App. 10 yd event. Roadway closed overnight, opened after maintenance assessed slope was ok during daylight conditions
1	once a year	MT 83	5 to 10	1076-1087	4-10 hrs	n/a	yes	no	nightime closure extended. Includes trees falling due to erosion.
1	one or two in five years	MT 200	3	532	8-12 hrs	same	no	no	Snow slide with rock debris east of Bonner on P-24
1	once every two years	X-20011	13-16.9	Not in RHRS	24-48	4 to 8 hrs	yes, occasional	no	Bearmouth frontage road, mud and rock
1	once a year to once every two years	us-2	168.3	102 or 103		4-8 hrs	no	no	blue rock cut
1	once a year to once every two years	us-2	153-161	72-98		4-8 hrs	no	no	
1	10/22/2009	us-2	182	110 or 111	9 hours	3 days?	no	no	cleaned up on 22nd, slid again on 23rd, pushed debris into ditch, didn't clean the ditch till spring due to winter.
1	9-Mar-01	MT-1	27.5 + or -	500-506		96 week?	no	no	Large slide, spurred project to install rockfall mitigation, including fences, bolts, pinned mesh, and scaling
1	2006	MT 135	20	837	?	No closure?	yes	yes	Fatality, slope has since been mitigated with scaling and draped mesh.
1	1995	US 93	91.5 +/-	139?	1 month	1 month +	?	?	50,000 - 80,000 CY failure. Site of failure has been re-sloped. No RHRS Data at this site, but maybe there should be. Section 139 is oposite of slope in question it is a through cut area. Lat 47.932065, -114.183441

Road Closing Rockfall Events

District 2 Survey Responses

Please list all the events you can remember. Use a '?' if there is uncertainty in location or other event details.
Please also estimate how many additional events may occur each year that are not listed individually.

District	Date (Event year, at a minimum)	Corridor	Milepoint (approx. ok)	RHRS Section No. (if avail.)	Duration of complete closure (approx. hours)	Duration of work zone slowdown (approx. days/weeks)	Vehicle/Property Damage?	Injury Accident?	Comments
2	2012?	C000090E	233	1218		3 days?	???	No	
2	2008 to present	C34448E	4.9	1676		1 hour	???	???	Maintenance only provided rough data for last 8 years
2	2008 to present	C34448E	6.3	1678		1 hour	???	???	Maintenance only provided rough data for last 8 years
2	2008 to present	C000011N	49.3	NA		1 hour	???	???	Site not in RHRS
2	2008 to present	C000090E	350.8	1268		1-2 hours	???	???	Maintenance only provided rough data for last 8 years
2	2008 to present	C000013N	88-93	323		1 hour	???	???	Maintenance only provided rough data for last 8 years

Survey Responses Edited for Likelihood Analysis

RHRS Section No.	Rockfall Activity Score	Ditch Effectiveness Score	Slope Condition State (AKDOT-based CS)	Calculated CS	Slope Height	Slope Length (miles)	Slope Sq Footage	Number of Events 2001-2015	Road Closure?	No. Closures 2001-2015	Annualized Closure Rate	Annualized Closure Rate per sq footage of face	Road Slowdown?	No. Slowdowns 2001-2015	Annualized Slowdown Rate	Annualized Slowdown Rate per sq footage of face	Annualized Disruption Rate	Annualized Disruption Rate per sq footage of face	Vehicle/Property Damage?	No. Damages 2001-2015	Annualized Damage Rate	Annualized Damage Rate per sq footage of face	Injury Accident?	No. Injuries 2001-2015	Annualized Injury Rate	Annualized Injury Rate per sq footage of face
96	9	9	2	1.25	44	0.05	7550.4	0.5	No	0	0	0	Yes	0.5	0.03571429	4.7301E-06	0.03571429	4.7301E-06	no	0	0	0	no	0	0	0
95	27	9	2	1.88	118	0.09	36447.84	0.5	No	0	0	0	Yes	0.5	0.03571429	9.7987E-07	0.03571429	9.7987E-07	no	0	0	0	no	0	0	0
1148	9	15	2	1.54	119	0.11	44924.88	1	Yes	1	0.07142857	1.59E-06	Yes	1	0.07142857	1.59E-06	0.14285714	3.1799E-06	No	0	0	0	no	0	0	0
87	27	8	2	1.81	124	0.21	89369.28	0.5	No	0	0	0	Yes	0.5	0.03571429	3.9963E-07	0.03571429	3.9963E-07	no	0	0	0	no	0	0	0
1304	9	15	2	1.54	134	0.09	41389.92	1	Yes	1	0.07142857	1.7257E-06	Yes	1	0.07142857	1.7257E-06	0.14285714	3.4515E-06	no	0	0	0	no	0	0	0
313	9	6	2	1.02	307	0.18	189652.32	1	No	0	0	0	Yes	1	0.07142857	3.7663E-07	0.07142857	3.7663E-07	???	0.5	0.0357143	1.883E-07	???	0.1	0.007142857	3.76629E-08
501	7	60	3	2.19	35	0.02	2402.4	3	Yes	3	0.21428571	8.9197E-05	No	0	0	0	0.21428571	8.9197E-05	Yes	3	0.2142857	8.92E-05	no	0	0	0
503	15	35	3	2.31	39	0.05	6692.4	3	Yes	3	0.21428571	3.2019E-05	No	0	0	0	0.21428571	3.2019E-05	Yes	3	0.2142857	3.202E-05	no	0	0	0
1078	50	27	3	2.85	45	0.05	7722	2.3	Yes	2.3	0.16428571	2.1275E-05	No	0	0	0	0.16428571	2.1275E-05	yes	2.3	0.1642857	2.128E-05	no	0	0	0
92	20	20	3	2.16	52	0.08	14277.12	0.5	No	0	0	0	Yes	0.5	0.03571429	2.5015E-06	0.03571429	2.5015E-06	no	0	0	0	no	0	0	0
1081	27	40	3	2.72	52	0.15	26769.6	2.3	Yes	2.3	0.16428571	6.137E-06	No	0	0	0	0.16428571	6.137E-06	yes	2.3	0.1642857	6.137E-06	no	0	0	0
81	27	27	3	2.50	54	0.17	31505.76	0.5	No	0	0	0	Yes	0.5	0.03571429	1.1336E-06	0.03571429	1.1336E-06	no	0	0	0	no	0	0	0
75	50	27	3	2.85	55	0.12	22651.2	0.5	No	0	0	0	Yes	0.5	0.03571429	1.5767E-06	0.03571429	1.5767E-06	no	0	0	0	no	0	0	0
72	9	50	3	2.23	56	0.05	9609.6	0.5	No	0	0	0	Yes	0.5	0.03571429	3.7165E-06	0.03571429	3.7165E-06	no	0	0	0	no	0	0	0
97	27	15	3	2.17	56	0.06	11531.52	0.5	No	0	0	0	Yes	0.5	0.03571429	3.0971E-06	0.03571429	3.0971E-06	no	0	0	0	no	0	0	0
83	27	20	3	2.33	61	0.13	27215.76	0.5	No	0	0	0	Yes	0.5	0.03571429	1.3123E-06	0.03571429	1.3123E-06	no	0	0	0	no	0	0	0
84	81	15	3	2.79	61	0.09	18841.68	0.5	No	0	0	0	Yes	0.5	0.03571429	1.8955E-06	0.03571429	1.8955E-06	no	0	0	0	no	0	0	0
1676	40	40	3	2.95	62	0.05	10639.2	1	No	0	0	0	Yes	1	0.07142857	6.7137E-06	0.07142857	6.7137E-06	???	0.5	0.0357143	3.357E-06	???	0.1	0.007142857	6.71372E-07
109	27	25	3	2.46	69	0.15	35521.2	2	Yes	2	0.14285714	4.0217E-06	Yes	2	0.14285714	4.0217E-06	0.28571429	8.0435E-06	no	0	0	0	no	0	0	0
88	81	20	3	2.95	76	0.1	26083.2	0.5	No	0	0	0	Yes	0.5	0.03571429	1.3692E-06	0.03571429	1.3692E-06	no	0	0	0	no	0	0	0
1086	60	27	3	2.95	82	0.13	36585.12	2.3	Yes	2.3	0.16428571	4.4905E-06	No	0	0	0	0.16428571	4.4905E-06	yes	2.3	0.1642857	4.491E-06	no	0	0	0
1218	15	45	3	2.46	105	0.21	75675.6	1	No	0	0	0	Yes	1	0.07142857	9.4388E-07	0.07142857	9.4388E-07	???	0.5	0.0357143	4.719E-07	No	0	0	0
1316	40	40	3	2.95	130	0.17	75847.2	1	Yes	1	0.07142857	9.4174E-07	No	0	0	0	0.07142857	9.4174E-07	Yes	1	0.0714286	9.417E-07	no	0	0	0
1168	27	27	3	2.50	134	0.1	45988.8	1	Yes	1	0.07142857	1.5532E-06	Yes	1	0.07142857	1.5532E-06	0.14285714	3.1063E-06	Possibly	0.5	0.0357143	7.766E-07	no	0	0	0
90	81	20	3	2.95	146	0.12	60128.64	0.5	No	0	0	0	Yes	0.5	0.03571429	5.9396E-07	0.03571429	5.9396E-07	no	0	0	0	no	0	0	0
1172	27	20	3	2.33	155	0.15	79794	1	Yes	1	0.07142857	8.9516E-07		0	0	0	0.07142857	8.9516E-07	Yes	1	0.0714286	8.952E-07	no	0	0	0
191	81	9	3	2.50	159	0.11	60025.68	3.5	No	0	0	0	Yes	3.5	0.25	4.1649E-06	0.25	4.1649E-06	Possibly	1.75	0.125	2.082E-06	no	0	0	0
837	27	20	3	2.33	167	0.08	45851.52	1	Yes	1	0.07142857	1.5578E-06	No	0	0	0	0.07142857	1.5578E-06	yes	1	0.0714286	1.558E-06	yes	1	0.071428571	1.55782E-06
1268	22	20	3	2.21	199	0.2	136593.6	1	No	0	0	0	Yes	1	0.07142857	5.2293E-07	0.07142857	5.2293E-07	???	0.5	0.0357143	2.615E-07	???	0.1	0.007142857	5.22928E-08
500	27	90	4	3.42	30	0.09	9266.4	3	Yes	3	0.21428571	2.3125E-05	No	0	0	0	0.21428571	2.3125E-05	Yes	3	0.2142857	2.313E-05	no	0	0	0
500	27	90	4	3.42	30	0.09	9266.4	1	Yes	1	0.07142857	7.7083E-06	Yes	1	0.07142857	7.7083E-06	0.14285714	1.5417E-05	no	0	0	0	no	0	0	0
502	26	81	4	3.10	60	0.02	4118.4	3	Yes	3	0.21428571	5.2031E-05	No	0	0	0	0.21428571	5.2031E-05	Yes	3	0.2142857	5.203E-05	no	0	0	0
1079	50	60	4	3.30	64	0.21	46126.08	2.3	Yes	2.3	0.16428571	3.5617E-06	No	0	0	0	0.16428571	3.5617E-06	yes	2.3	0.1642857	3.562E-06	no	0	0	0
76	81	60	4	3.58	65	0.14	31231.2	0.5	No	0	0	0	Yes	0.5	0.03571429	1.1435E-06	0.03571429	1.1435E-06	no	0	0	0	no	0	0	0
79	81	40	4	3.35	73	0.1	25053.6	0.5	No	0	0	0	Yes	0.5	0.03571429	1.4255E-06	0.03571429	1.4255E-06	no	0	0	0	no	0	0	0
78	81	50	4	3.48	74	0.07	17777.76	0.5	No	0	0	0	Yes	0.5	0.03571429	2.0089E-06	0.03571429	2.0089E-06	no	0	0	0	no	0	0	0
504	81	40	4	3.35	87	0.06	17915.04	3	Yes	3	0.21428571	1.1961E-05	No	0	0	0	0.21428571	1.1961E-05	Yes	3	0.2142857	1.196E-05	no	0	0	0
1087	40	50	4	3.07	92	0.11	34731.84	2.3	Yes	2.3	0.16428571	4.7301E-06	No	0	0	0	0.16428571	4.7301E-06	yes	2.3	0.1642857	4.73E-06	no	0	0	0
1076	50	60	4	3.30	96	0.15	49420.8	2.3	Yes	2.3	0.16428571	3.3242E-06	No	0	0	0	0.16428571	3.3242E-06	yes	2.3	0.1642857	3.324E-06	no	0	0	0
80	81	40	4	3.35	101	0.07	24264.24	0.5	No	0	0	0	Yes	0.5	0.03571429	1.4719E-06	0.03571429	1.4719E-06	no	0	0	0	no	0	0	0
85	81	60	4	3.58	108	0.13	48185.28	0.5	No	0	0	0	Yes	0.5	0.03571429	7.4119E-07	0.03571429	7.4119E-07	no	0	0	0	no	0	0	0
77	81	75	4	3.71	124	0.12	51068.16	0.5	No	0	0	0	Yes	0.5	0.03571429	6.9935E-07	0.03571429	6.9935E-07	no	0	0	0	no	0	0	0
179	27	70	4	3.04	130	0.06	26769.6	4.6	No	0	0	0	Yes	4.6	0.32857143	1.2274E-05	0.32857143	1.2274E-05	Possibly	2.3	0.1642857	6.137E-06	no	0	0	0
189	81	50	4	3.48	167	0.12	68777.28	3.5	No	0	0	0	Yes	3.5	0.25	3.6349E-06	0.25	3.6349E-06	Possibly	1.75	0.125	1.817E-06	no	0	0	0
94	81	50	4	3.48	173	0.17	100935.12	0.5	No	0	0	0	Yes	0.5	0.03571429	3.5383E-07	0.03571429	3.5383E-07	no	0	0	0	no	0	0	0
190	81	81	4	3.75	179	0.11	67576.08	3.5	No	0	0	0	Yes	3.5	0.25	3.6995E-06	0.25	3.6995E-06	Possibly	1.75	0.125	1.85E-06	no	0	0	0
323	55	75	4	3.49	235	0.3	241956	1	No	0	0	0	Yes	1	0.07142857	2.9521E-07	0.07142857	2.9521E-07	???	0.5	0.0357143	1.476E-07	???	0.1	0.007142857	2.95213E-08
1678	55	50	4	3.26	276	0.26	246280.32	1	No	0	0	0	Yes	1	0.07142857	2.9003E-07	0.07142857	2.9003E-07	???	0.5	0.0357143	1.45E-07	???	0.1	0.007142857	2.9003E-08
181	81	27	4	3.13	364	0.06	74954.88	4.6	No	0	0	0	Yes	4.6	0.32857143	4.3836E-06	0.32857143	4.3836E-06	Possibly	2.3	0.1642857	2.192E-06	no	0	0	0
532	81	27	4	3.13	420	0.09	129729.6	4.2	Yes	4.2	0.3	2.3125E-06	yes	4.2	0.3	2.3125E-06	0.6	4.625E-06	no	0	0	0	no	0	0	0
54	81	27	4	3.13	629	0.15	323809.2	3.5	No	0	0	0	Yes	3.5	0.25	7.7206E-07	0.25	7.7206E-07	Possibly	1.75	0.125	3.86E-07	no	0	0	0
182	81	27	4	3.13	690	0.08	189446.4	4.6	No	0	0	0	Yes	4.6	0.32857143	1.7344E-06	0.32857143	1.7344E-06	Possibly	2.3	0.1642857	8.672E-07	no	0	0	0
505	90	81	5	4.05	110	0.05	18876	3	Yes	3	0.21428571	1.1352E-05	No	0	0	0	0.21428571	1.1352E-05	Yes	3	0.2142857	1.135E-05	no	0	0	0
506	95	81	5	4.21	171	0.45	264092.4	3	Yes	3	0.21428571	8.114E-07	No	0	0	0	0.21428571	8.114E-07	Yes	3	0.2142857	8.114E-07	no	0	0	0

site with only known fatality in dataset. Decision sight distance is 850ft (77% of decision sight distance), roadway width is 31ft, ADT is 1510