Appendix A

WSDOT's Unstable Slope Management System

Guidelines for the P3 Unstable Slope inventory and prioritization process

To inventory and prioritize unstable slopes for the P3 Unstable Slope Program requires involvement of many partners in a multi-step process. Those partners include Regional Maintenance, Regional Materials Engineers, Regional Program Managers, OSC Office of Program Management, and the FOSSC Geotechnical Branch. The specific responsibilities of each partner are as follows:

- **Regional Maintenance Superintendents:** Identification of known unstable slopes. (See Step No. 1)
- **Regional Materials Engineers:** Numerically rate each known unstable slope within their Region. (See Step No. 2 for description of the eleven rating categories used to rate unstable slopes.)
- **FOSSC Geotechnical Branch:** Manages the unstable slope management system (USMS) that is part of the P3 Preservation Program. Conducts field reviews of unstable slopes. Develops conceptual designs, performs cost-benefit analyses, and generates prioritized lists of unstable slopes statewide for programming purposes.
- **Regional Program Managers:** Develop Project Definition cost estimates using the information contained in the conceptual designs developed by the Geotechnical Branch. Other required project costs such as mobilization, traffic control, surfacing and paving, preliminary engineering, construction engineering are considered.
- **OSC Office of Program Management:** Manages the P3 Preservation Unstable Slope Program identified with the Washington's Transportation Plan element titled the Highway System Plan. Works with Executive Management in taking statewide deficiencies in all action strategies and making decisions on where to commit funds based on available revenues.

The following STEPS identify the sequence and type of information that is required for the P3 unstable slope inventory and prioritization process:

Step No. 1: This step requires that the Maintenance Superintendents within each region develop a detailed and accurate list of known unstable slopes. This step was largely completed during the initial development of the Unstable Slope Management System. As new unstable slopes develop or existing unstable slopes worsen the Regional Materials Engineer should be supplied with updated information concerning those unstable slopes.

The important information that is required is as follows:

- State Route (SR) Number
- The beginning and ending mileposts for each unstable area. It is very important that the milepost limits be as accurate as possible. Also determine whether the unstable area is left, right (or both) of centerline in the increasing milepost direction.

- Make a preliminary determination of the cause of instability. For the purposes of this initial determination we prefer to limit the choices to the following categories of problem types, defined as follows:

Slope Erosion - The wearing away of a soil mass by the actions of running water. On slopes this process can result in the overland flow of water in an unconcentrated sheetwash, or the development of rills (e.g., small soil grooves or channels). Along streams or rivers the process can entail the near vertical undercutting of the adjacent stream/river banks.

Settlement - The vertical displacement of a soil mass not associated with a horizontal movement within a slope or embankment. Generally movement is slow. Piping occurs when erosion of subsurface soil, associated with groundwater flow, causes failure of the soil.

Landslide - The vertical and horizontal displacement of a soil mass, under the influence of gravity, within a slope or embankment. Generally landslides can be divided into two categories based on failure geometry. Those landslide categories are circular and sliding block failures. The rate of movement of landslides can vary from very slow moving to very rapid.

Debris Flow - A rapidly moving fluid mass of rock fragments, soil, water, and organic material with more than half of the particles being larger than sand size. Generally debris flows occur on steep slopes or in gullies and can travel long distances. Typically, debris flows result from unusually high intensity rainfall, or rain on snow events.

Rockfall - The fall of newly detached segments of bedrock of any size from a cliff or steep slope. The rockfall descends mostly through the air by free fall, bounding, or rolling. Movements are very rapid to extremely rapid, and may not be preceded by minor movements.

- Estimate the failure frequency for each unstable area. This category is based on the following criteria:

  - Failure occurs at a frequency greater than once in five years.
  - Failure occurs at a frequency of once in five years.
  - Failure occurs at a frequency of once a year.
  - Failure occurs at a frequency of more than once a year.

- Determine the annual maintenance costs that are incurred at each unstable area. These maintenance costs do not have to be exact, but should reflect reasonable estimates based on the knowledge of the Maintenance Superintendents. These maintenance costs include such items as ditch maintenance, roadway debris cleanup, roadway repair and patching, drainage, etc. that are associated with an area of instability. If these cost estimates cannot be obtained, then we would recommend that the costs be bracketed based on the following ranges:

  - Less than $5,000 per year
  - $5,000 to $10,000 per year
  - $10,000 to $50,000 per year
  - Greater than $50,000 per year

This information should be transmitted to the Regional Materials Engineer so that Step No. 2 of the process can be completed.

Step No. 2: WSDOT uses a numerical system to rate unstable slopes. The numerical rating system is a matrix evaluation system, which objectively evaluates the potential hazard of an existing unstable slope. Within each of the eleven rating categories are four columns that correspond to logical breaks in the rating categories, with exponentially increasing point values from left to right. The point values for each rating category increase from 3 to 81 to distinguish increasing importance or hazard potential. The total points for this rating system range from a low of 33 to a high of 891. Unstable slopes with a higher number will generally represent a greater risk.

It is important to note that the numerical rating system does not predict which slope will fail first, only its' relative hazard based on the risk factors that are evaluated.

Before an unstable slope rater can determine how to score an unstable slope using the numerical rating system, the criteria for each rating category must be thoroughly understood. Some of rating categories will require a subjective evaluation, while others can be measured directly and then scored. The following Table 1 identifies the unstable slope numerical rating system categories and the rating criteria for each of the categories.

Table A.1: Unstable Slope Numerical Rating System

Rating Criteria

CATEGORY	Points = 3	Points = 9	Points = 27	Points = 81
Problem Type: SOIL	Cut or Fill Slope Erosion	Settlement or Piping	Slow Moving Landslide	Rapid Landslide or Debris Flow
Problem Type: ROCK	Minor Rockfall Good Catchment	Moderate Rockfall Fair Catchment	Major Rockfall Limited Catchment	Major Rockfall No Catchment
Average Daily Traffic	<5,000	5,000 - 20,000	20,000 - 40,000	>40,000
Decision Sight Distance	Adequate	Moderate	Limited	Very Limited
Impact of Failure on Roadway	<50 Feet	50 - 200 Feet	200 - 500 Feet	>500 Feet
Roadway Impedance	Shoulder Only	1/2 Roadway	3/4 Roadway	Full Roadway
Average Vehicle Risk	<25% of the Time	25% to 50% of the Time	50% to 75% of the Time	>75 % of the Time
Pavement Damage	Minor - Not Noticeable	Moderate - Driver Must Slow	Severe - Driver Must Stop	Extreme - Not Traversable
Failure Frequency	No Failures in Last 5 Years	One Failure in Last 5 Years	One Failure Each Year	More Than One Failure Per Year
Annual Maintenance Costs	< $5000 Per Year	$5000 to $10000 Per Year	$10000 to $50000 Per Year	>$50000 Per Year
Economic Factor	No Detours Required	Short Detour < 3 Miles	Long Detours > 3 Miles	Sole Access No Detour
Accidents in Last 10 Years	0 to 1	2 to 3	4 to 5	>5

The following is a description of each of the eleven rating categories of the unstable slope rating system:

Rating Category No. 1: Problem Type

Problem Type: **SOIL**	Cut or Fill Slope Erosion	Settlement or Piping	Slow Moving Landslide	Rapid Landslide or Debris Flow
Problem Type: **ROCK**	Minor Rockfall Good Catchment	Moderate Rockfall Fair Catchment	Major Rockfall Limited Catchment	Major Rockfall No Catchment

The nature of unstable slope conditions is evaluated in this category. Since most slope instabilities can be classified into two general types (i.e., unstable slopes involving primarily soils, and unstable slopes that are predominately rockfall related), we have developed rating criteria for both. When rating an unstable slope only one of the problem types should be used. In the event that both problem types are present at the site, the worst-case problem type should be rated.

Problem Type: SOIL - These unstable slope conditions deal exclusively with soil or soil like instabilities. The categories are based on the definitions found in Step No. 1 (i.e., slope erosion, settlement, landslide, and debris flow), and are rated based on the potential speed of failure. Although the rates are somewhat subjective, we would offer a guide to the two end conditions. Slow would be defined as a progressive ongoing movement of small magnitude over a period of years. Rapid would be defined as sudden movement of large magnitude over a very short period of time, generally less than a day.

Problem Type: ROCK - These unstable slope conditions deal exclusively with rockfall, based on the definition found in Step No. 1. The category evaluates the amount of rockfall catchment that is presently available to contain and prevent the rockfall from entering the roadway. The rockfall ditch criteria in the WSDOT Design Manual (Figure 640-4a) can be used as a guideline for evaluating effective rockfall catchment criteria. This category also subjectively evaluates the size of the events in terms of minor, moderate, and major rockfall. For purposes of consistency the following definitions should apply:

Minor Rockfall - Rockfall that is less than one foot in diameter and less that three cubic yards in volume.

Moderate Rockfall - Rockfall that is between one to two feet in diameter, and three to six cubic yards in volume.

Major Rockfall - Rockfall that is greater than two feet in diameter, and greater than six cubic yards in volume.

Rating Category No 2: Average Daily Traffic

Average Daily Traffic	< 5000	5000 to 20000	20000 to 40000	> 40000

This category rates the current Average Daily Traffic along the section of highway where the unstable slope is located.

Rating Category No. 3: Decision Sight Distance

Decision Sight Distance	Adequate Sight Distance	Moderate Sight Distance	Limited Sight Distance	Very Limited Sight Distance

The decision sight distance is a measure of the minimum distance (in feet) required for a driver to detect a hazard, make an instantaneous decision, and take a corrective action. For the purposes of the unstable slope inventory the Decision Sight Distance criteria found in AASHTO "Policy on Geometric Design of Highways and Streets," Table III-3 (McGee, H. W. et al, 1978) has been simplified. The Decision Sight Distance criteria in Table 2 represent the minimum values from AASHTO Table III-3. The posted speed limit is used.

Posted Speed Limit (mph)	Decision Sight Distance (ft)
30	450
40	600
50	750
60	1000
70	1100

Table 2: Decision Sight Distance

The actual sight distance at the unstable slope site is defined as the measured horizontal distance at which a six-inch high object disappears when the eye height is at 3.5 feet. This distance needs to be measured when the detailed rating is being conducted at the unstable slope. Both the horizontal and vertical sight distance should be evaluated.

The criteria in the Decision Sight Distance category are based on a ratio (expressed as a percentage) of the Actual Sight Distance and the Decision Sight Distance. This ratio is called the Percent of the Decision Sight Distance (PDSD). To determine the PDSD the following formula is used:

The four rating criteria for the Decision Sight Distance category are defined as follows:

- **Adequate Sight Distance** - The PDSD is 100% or greater.
- **Moderate Sight Distance** - The PDSD ranges between 80% and 99%.
- **Limited Sight Distance** - The PDSD ranges between 60% and 79%.
- **Very Limited Sight Distance** - The PDSD is less than 60%.

Rating Category No. 4: Impact of Failure on Roadway

Impact of Failure on Roadway	< 50 Feet	50 to 200 Feet	200 to 500 Feet	> 500 Feet

This category measures the actual failure length (as measured in the field) of the unstable area along the roadway. This length is also used in the calculation of the Average Vehicle Risk in Rating Category No. 6.

Rating Category No. 5: Roadway Impedance

Roadway Impedance	Shoulder Only	1⁄2 Roadway	3⁄4 Roadway	Full Roadway

This category rates the impedance to traffic in the event of a failure of an unstable slope. It is based on the width of the roadway that is impacted.

Rating Category No. 6: Average Vehicle Risk (AVR)

Average Vehicle Risk	< 25% of the Time	25% to 50% of the Time	50% to 75% of the Time	> 100% of the Time

This category measures the percentage of time that a vehicle will be present in the unstable slope area. This AVR percentage is obtained by using the following formula:

A rating of 100% means that on average a vehicle will be present within the unstable area 100% of the time. The AVR number can be greater than 100%, where longer areas of instability exist in combination with high Average Daily Traffic. This means that there is more than one vehicle present within the unstable area at any given time.

Rating Category No. 7: Pavement Damage

Pavement Damage	Minor - Not Noticeable	Moderate - Driver Must Slow	Severe - Driver Must Stop	Extreme - Not Traversable

This category evaluates the severity of the potential damage to the roadway surface due to the failure of an unstable slope. The rating is based on the traversability of the unstable area by a motorist traveling at the posted speed limit. The degradation to the roadway surface must occur from the failure process, and not be due to normal wearing.

Rating Category No. 8: Failure Frequency

Failure Frequency	No Failures In The Last Five Years	One Failure In The Last Five Years	One Failure Each Year	More Than One Failure Per Year

This category prioritizes the failure frequency of the unstable slope. The information generated by the Maintenance Superintendents in Step No. 1 of the unstable slope inventory process is used in this category.

Rating Category No. 9: Annual Maintenance Cost

Annual Maintenance Cost	< $5000 Per Year	$5000 to $10000 Per Year	$10000 to $50000 Per Year	> $50000 Per Year

This category measures the annual maintenance cost incurred for an unstable slope. The annual maintenance cost determined by the Maintenance Superintendents in Step No. 1 of the unstable slope inventory process is used in this category.

Rating Category No 10: Accidents in the Last 10 Years

This category rates the number of accidents that have occurred in the vicinity that may be associated with the unstable slope.

Rating Category No. 11: Economic Factor

Economic Factor	No Detour Required	Short Detour < 3 Miles	Long Detour > 3 Miles	Sole Access No Detour Available

This category rates the potential economic impact of a roadway closure as a result of a failure of an unstable slope. It is based on the availability and length of a detour around the failure area. When determining the suitability of a detour route several factors such as detour conditions, traffic volume, potential traffic flow, etc. must be evaluated. If a number of these factors could result in a major negative impact, even though a detour route is available, then a sole access rating should be given to the unstable slope.

Step No. 3: To develop rating consistency, the Geotechnical Branch Staff works in the field with the Regional Materials Engineers in rating and reviewing unstable slopes. The specific location and dimensions of each unstable slope can be determined by Geotechnical Branch staff using GPS and a laser range finder. Digital photos of the unstable slopes are maintained by the Geotechnical Branch and many can be viewed through the USMS intranet website.

Step No. 4: Within each highway functional class the slopes are ranked in descending numerical rating order, so the highest risk slopes within the functional class are considered first. After a ranked list of unstable slopes is developed, a first-cut list of slopes for the next biennium construction program is made based on anticipated funding level. A field review of these selected slopes is conducted to verify the numerical ratings and to describe the unstable slope problem in detail. A conceptual design for mitigation of the unstable slope is developed by the geotechnical staff with estimating factors. It is forwarded to the Regional Program Managers.

Step No. 5: The Regional Program Managers develop Project Definition cost estimates. They use the information from the conceptual mitigation recommendations and other required project items such as mobilization, traffic control, surfacing and paving, preliminary engineering, construction engineering, sales tax, and contingencies. Once these cost estimates are completed the Geotechnical Branch performs a cost-benefit analysis.

Step No. 6: A cost-benefit analysis is conducted by the Geotechnical Branch. A cost benefit for an unstable slope is determined by comparing the traffic delay cost and maintenance cost factored over the 20-year life of the program to the cost of mitigating the unstable slope. The two most reliable indicators of economic impact caused by a slope failure on a highway facility are the costs associated with traffic delays and the annual maintenance cost factored over the 20-year life of the program. Based on experience, in most cases traffic is disrupted for at least 24 hours after a slope failure. The life cycle maintenance cost is based on the estimated annual cost that has been generated by Regional Maintenance and multiplied by a 20-year program life. The maintenance cost and the traffic delay cost is compared with the cost of mitigation to determine the cost benefit ratio.

Step No. 7: Based on the analysis, unstable slopes are ranked by descending cost benefit ratio, forming a prioritized list of unstable slopes statewide for programming purposes. The unstable slope must have a cost benefit ratio greater than one to be on the prioritized list.

Step No. 8: The Office of Program Management, in concert with Executive Management, takes statewide deficiencies in all action strategies and makes decisions on where to commit funds based on available revenues. The funds are allocated to these action strategies based on performance outcomes and benefit. It should be noted that when a slope fails that is not on the priority list for the current biennium it is moved to the top of the priority list; emergency relief funding is sought, and state emergency bond money is used.

Appendix B

Review of WSDOT's Unstable Slope Program by Golder Associates

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December 9, 2005 — Our Ref.: 053-1687.100

Washington State Department of Transportation
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Attention: Mr. Steve Lowell, L.G., L.E.G.

RE: REVIEW OF WASHINGTON STATE DEPARTMENT OF TRANSPORTATION P-3 UNSTABLE SLOPE INVENTORY AND PRIORITIZATION PROCESS

Dear Steve:

Golder Associates Inc. (Golder) and Wyllie & Norrish Rock Engineers Inc. (W&N) are pleased to present this letter report containing our comments relative to our review of the WSDOT's P-3 Unstable Slope Inventory and Prioritization Process. The proposed scope of work was presented to the WSDOT and approved on November 10, 2005.

INTRODUCTION AND SCOPE OF WORK

This review of the P-3 Unstable Slopes Management System (USMS) program was requested by the WSDOT with the objective of providing a critical review of the P-3 process. In particular, we were requested to review the relative merits of the system and to provide opinions regarding the effectiveness of the current system and whether the system is providing the desired hazard evaluation of the slopes along the 7,048 miles of the WSDOT highway system.

DISTINCTION BETWEEN HAZARD AND RISK

It is useful to clarify the terms "*hazard*" and "*risk*" that will be used through the balance of this letter report. A rock fall or soil slope failure is one of a number of geologic processes categorized as natural hazards. These natural processes include landslides, debris avalanches, slope creep movement, soil piping, snow avalanches and so on. These events occur in nature and have done so since the geologic evolution of landforms began. In some cases, the activities of humans can influence the occurrence of natural hazard events. When there is a reference to a high hazard, the meaning is that there is a high likelihood an event will occur.

Risk refers to the consequences of a natural hazard event if it occurs. It is easy to envision an event that has absolutely no consequence in terms of humans, for example a snow avalanche in the remote mountains. The same natural hazard perched above a ski resort would represent a significant risk.

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The hazards that engineers are most interested in are those that have both a high likelihood of occurrence and a high likelihood of causing damage, injuries, death or severe economic impacts. Applied to highway slopes, it is necessary to assess both the degree of **hazard** in terms of the rock or soil becoming dislodged from the slope and the potential damage **(risk)** it could inflict based on its energy, probable trajectory and the likelihood of something being in its path.

BACKGROUND

The WSDOT implemented the USMS in 1995 in an attempt to develop a proactive methodology to systematically and rationally mitigate known unstable slopes within the WSDOT system. Prior to implementation of the P-3 program, slope stabilization was reactive to individual slope failure events. The slope management system developed by the WSDOT was precedent setting for highway agencies, as no comparable program existed at the time from which to model a system.

Processes Leading To Slope Instability

Slope instability is a category of natural hazard that refers to the movement of a soil or rock mass under the influence of gravity. Rock falls occur on both natural and excavated slopes. Causes of rock falls include a combination of natural processes and man-made influences, acting singly or in combination, to dislodge discrete blocks of rock. Usually planes of weakness termed "discontinuities" physically divide the rock mass into an assemblage of blocks. The predominant mechanisms that can dislodge these blocks and result in a rock fall include:

- Progressive loosening through the action of freeze-thaw cycles acting on water-filled discontinuities;
- Weathering and degradation of less resistant layers creating unstable overhangs and ledges;
- Erosion of the rock slope caused by water or wind;
- High intensity rainfall events that can increase groundwater pore pressures within discontinuities;
- Dynamic events such as earthquakes that apply a non-vertical acceleration force to the rock block;
- Blasting, both as a mechanism to induce acceleration forces and also to create additional fractures or loosen existing fractures in the rock mass, or
- Wedging effect of tree roots particularly under the cyclic action of wind loading.

Landslides are a category of natural hazards that involve the downslope movement of soil materials under the influence of gravity. Soil slope failures generally fall into two categories: 1) deep seated rotational failures or translational slides and 2) shallower debris flows and slides. Generally, rotational type slope failures occur more slowly than debris flows and slides which can occur quite rapidly. Landslide mechanisms involve either an increase in driving forces or a reduction of resisting forces (i.e. loss of shear strength of the soil).

Typical causes of landslides include:

- Intense short term rain fall events, prolonged sustained rainfall, or rain on snow events causing an increase in pore water pressures;
- Oversteepening of a slope through erosion or grading activities;
- Removal of the toe of a slope either through natural means (erosion) or human efforts (cuts);
- Presence of adversely dipping stratigraphy and/or weak bedding;
- Placement of surcharge, such as an earth fill, near the top of a slope causing an imbalance in the slope equilibrium;
- Volcanic eruptions causing debris flow avalanches and mud flows like those that occurred during the Mt. St. Helens eruption in 1980, and
- Seismic accelerations.

The important characteristic of most of these rockfall and landslide mechanisms is that they result from long term, progressive deterioration of slopes that is often imperceptible to even the trained observer. The complexities of geological conditions and the temporal effects also highlight the inability of geotechnical professionals to determine absolute stability of a given slope solely on the basis of visual examination.

The Unstable Slope Management System (USMS)

The USMS was initiated by compiling a baseline inventory of all **known unstable** slopes within the WSDOT system. This identification process was completed largely by personnel from the various WSDOT regions who were most familiar with slope performance within their region and resulted in a statewide baseline inventory of over 2,500 sites.

These 2,500 sites were scored with a numerical rating system based on eleven criteria that measure the potential impacts and risk factors to the highway facility if a slope were to fail. The eleven criteria are:

- Problem type: soil or rock - self explanatory;
- Average Daily Traffic (ADT): self explanatory;
- Decision Sight Distance: measures the distance in feet a driver has to recognize road hazard, react, and take corrective action;
- Impact of Failure on Roadway: Measures the length of unstable area along the roadway;
- Roadway Impedance: Measures the width of roadway that is impacted;
- Average Vehicle Risk: Measures the exposure time a vehicle is located within the unstable slope area;
- Pavement Damage: Measures the severity of potential landslide damage on the roadway surface that could impact the ability of a vehicle to traverse the site while traveling at the posted speed limit;
- Failure Frequency: self explanatory;
- Annual Maintenance Costs: self explanatory;

- Economic Factor: Rates the potential economic impact from roadway closure resulting from the unstable slope. Considers the availability, length and suitability of detour routes;
- Accidents in last 10 years: self explanatory

Based on the numerical rating system, a site may have a score ranging from 33 to 891, the higher number representing the greater potential impact and risk to the highway. It should also be noted that the statewide inventory is dynamic and additional sites are added to it as new slope performance information becomes available. Since inception, the statewide inventory has grown from 2500 to approximately 2700 sites to incorporate virtually every conceivable unstable slope in the state.

A filtering technique to screen the sites with highest needs based on highway functional class is applied to candidate sites with scores of 250 or greater. The priority functional classes include interstates, principal arterials, and other routes with average daily traffic volumes of 5,000 or greater. The unstable slopes on these priority functional classes are ranked based on the scores derived from the above criteria. A field review of these ranked slopes is completed by geotechnical specialists with expertise in rockfall and landslide hazards to verify the numerical rating, determine and define the geologic context of the slope stability problem (hazard), and develop conceptual design(s) and corresponding cost estimate(s).

A benefit/cost (BC) analysis is completed by the Geotechnical Branch based on the conceptual designs. The BC analysis compares the costs of a 24-hour traffic delay plus the expected maintenance costs over a period of twenty years to the estimated mitigation cost for the slope. Based on the BC analysis, sites with a BC ratio of 1 or greater and with numerical ratings of 350 or greater currently are placed on a prioritized list of slopes to be programmed for remediation. In the future, the 350 point numerical ranking threshold will be lowered, as slopes on the prioritized list are remediated. The intent of this approach is to ensure that sites are prioritized on both risk and BC ratio, or stated another way, to avoid prioritizing sites with low risk but a high BC ratio.

Currently, the WSDOT funding level for the P-3 program is $300 million over 10 bienniums (20 years). We understand that to-date more than 100 sites have been remediated for an expenditure of $130 million dollars and that the rating checks, problem definitions, conceptual designs, and cost estimating process of candidate sites has been completed on 433 slopes and is on-going. In addition, geotechnical specialists have reviewed 400 slopes with numerical rankings down to a point rating of 250.

SLOPE MANAGEMENT SYSTEMS

Geotechnical engineering and in particular its application to slope stability is an imperfect science. In many cases limited information is available and of necessity decisions are based on a combination of observational input, past experience, professional judgment, analyses, and inference. The objective is to provide practical recommendations with the available information and resources. These precepts apply to a slope management systems as well as general slope engineering.

Slope ratings are intended to be relative in order to enable comparison of the slopes within a common transportation network. Thus, it is important that procedures be implemented to make sure that the ratings are internally consistent, for example through training of the personnel doing the fieldwork. The absolute rating of a slope does not, of itself, indicate the need or the urgency to carry out remedial measures. Rather, the rating in comparison to all other ratings for the network is a filtering mechanism through which the highest priority sites can be identified for follow up investigation, design and stabilization. It should also be noted that a low rated slope is not a "zero hazard" slope in terms of the occurrence of instability events.

Elements of an Unstable Slope Management Program

The Transportation Research Board (TRB, 1996) has published guidance for the requirements of an effective management system for rock slopes. Although more restrictive than the USMS, the TRB criteria are an appropriate framework on which to evaluate the USMS. According to TRB, an effective unstable slope management program should include the following six essential elements:

Element		Activity
1.	***Inventory of Stability Conditions***	Assign point scores to parameters describing slope and hazard conditions (slope hazard rating).
2.	***Analyze Unstable Slope Hazards***	Analyze inventory database to determine locations and causes of the unstable slope.
3.	***Plan Stabilization Work***	Plan work according to hazard rating, site location and type of work.
4.	***Decision Analysis To Determine Optimum Stabilization Methods***	Compare effectiveness of stabilization measures in reducing unstable slope hazards.
5.	***Design Stabilization Measures and Preparation of Contract Document***	Categorize stabilization measures according to reinforcement, removal, and protection methods.
6.	***Construction Services***	Perform construction under flexible unit price contracts wherein modifications to stabilization measures can be implemented to suit actual conditions

In our opinion a seventh element should be added to the TRB (1996) listing above. This additional factor is an explicit consideration of the risk to the highway system in the selection process of candidate sites for prioritized slope remediation.

USMS Compared to Other Slope Management Systems

The USMS is one system among several that attempts to proactively manage slope stability issues. A commonly used system endorsed by the FHWA is known as the Rockfall Hazard Rating System (RHRS) (Ref: Federal Highway Administration, 1993). This system has been introduced by a number of State DOTs usually with modifications to suit the conditions and objectives of the particular state. It was most recently implemented by the Montana Department of Transportation. The RHRS system, like the USMS, is intended to provide agencies a means to actively manage slopes. Both systems rate slopes with a numerical system and provide a rational methodology for an agency to make informed decisions. A fundamental difference between the two systems is that the RHRS system addresses only rock slopes while the USMS is more comprehensive, to include both rock and soil slopes. Furthermore, through differences in implementation, the RHS system is based on a combination of geologic hazard and highway risk, while the USMS system places a greater emphasis on risk.

It is reiterated that little risk does not equate to "no risk". There will always be some risk that must be balanced against hazard exposure, potential consequences and available funding.

CRITIQUE OF WSDOT's USMS

In the following discussion the USMS is assessed using the six program elements recommended by TRB (1996) with the addition of a seventh element that incorporates risk to the highway.

Element #1 – Inventory of Stability Conditions

The USMS implementation of the slope rating system has evolved with time to more closely match the needs of the WSDOT network. In concert with the progressive development of slope rating systems in the overall transportation industry, the WSDOT adapted the ODOT RHRS methodology to include both unstable rock and soil slopes. Specific changes or deletions were made to the ODOT categories to recognize and/or simplify climatic, geometric and geologic factors important in Washington. For example, the USMS slope ratings are designed to be developable by Regional Materials Engineers who may not have a geotechnical background.

In our opinion these modifications are a reasonable adaptation to the conditions in the State and do not compromise the intrinsic comparative characteristics of the slope rating system. Thus the USMS meets the requirements for Element #1 – Inventory of Stability Conditions.

Element #2 – Analyze Slope Hazards

The WSDOT regularly analyzes the slope inventory to identify statewide sites with a rating greater than 250 that are then subject to rating verification, problem definition, conceptual design and BC analysis. Such analysis demonstrates that the USMS meets the requirements for Element #2 – Analyze Unstable Slope Hazards.

Element #3 – Plan Stabilization Work

Starting with the highest functional class highways, the USMS prioritizes the sites for stabilization in order of descending BC ratio, conditional on a minimum slope rating of at least 350. This process avoids mitigating sites with low hazard and/or low risk but with a high BC ratio. The above methodology demonstrates that the USMS meets the requirements for Element #3 – Plan Stabilization Work.

Element #4 – Decision Analysis to Determine Optimum Stabilization Methods

During the conceptual design stage, the USMS regularly considers various remediation techniques as alternatives in its stabilization designs. Where several alternatives exist for a given site, input is often solicited from maintenance personnel as to their preferences. In addition, opportunities are evaluated for collateral benefits such as capacity improvement and avalanche protection. Also, it is standard practice to design and cost a slope regrade option as a base case against which reinforcement and protection options are compared.

These practices demonstrate that the USMS meets the requirements for Element #4 – Decision Analysis to Determine Optimum Stabilization Methods.

Element #5 – Design Stabilization Measures and Preparation of Contract Document

With the same background as for Element #4, the USMS has successfully carried out landslide stabilization and debris flow mitigation measures as well as stabilization programs using a variety of rock reinforcement, rock removal, and rock fall protection measures at over 100 sites since the inception of the program. The WSDOT commonly uses the latest available design and construction practices and often is at the forefront of developing new slope stabilization procedures, for example through the pooled research programs with other state DOT's. Thus, the USMS meets the requirements for Element #5 - Design Stabilization Measures and Preparation of Contract Document.

Element #6 – Construction Services

Both in-house geotechnical specialists and consultants are employed to monitor construction. Typically specialty contractors are procured through a competitive procedure to carry out the construction work for slope stabilization. Contractors that have been employed include Wilder, Scarcella, Goodfellow and Pacific Blasting. This practice demonstrates that the USMS meets the requirements for Element #6 – Construction Services.

Element#7 – Risk Analysis

Ratings within the USMS that are directly or indirectly related to risk to the highway system include average daily traffic (ADT), accident frequency, frequency of slope failures, decision sight distance, impact of failure on roadway, roadway impedance, average vehicle risk, pavement damage, annual maintenance costs, and an economic factor related to available detour routes. These rating factors combined with the BC analysis demonstrate that the USMS incorporates risk into the site prioritization and stabilization planning process. The risk and BC analysis portion of the WSDOT process is a defining parameter of the USMS.

In summary, the USMS implemented by the WSDOT in 1995 exhibits all the elements of a responsible program appropriate to a highway network with more than 2700 unstable slopes to maintain.

CONCLUSIONS & RECOMMENDATIONS

In order to reach our conclusions we reviewed the USMS against the six essential elements of a similar but more narrowly focussed management program for rockfalls as outlined by the Transportation Research Board (TRB, 1996) and against the Rockfall Hazard Rating System (RHRS) sponsored by the Federal Highway Administration (FHWA, 1993). Based on these comparisons, our opinions with respect to the overall USMS program are:

1. The WSDOT demonstrated an appropriate standard of engineering care in the implementation of its slope management program. In our opinion the USMS program was probably amongst the most advanced in the country in the mid 1990's timeframe.

2. The USMS contains the six essential elements for the management of natural hazards as defined in reference publications (TRB, 1996)

3. The USMS is more inclusive than comparable management systems (e.g. RHRS) in that it includes both soil and rock slopes into a common system. To emphasize this point, it is our understanding that the current WSDOT inventory of approximately 2700 slopes is comprised equally of soil and rock slopes.

4. The individual slope ratings are performed with an adequate level of technical care. The accuracy of the ratings is sufficient to enable valid comparisons of *risk* between slopes throughout the state network.

5. The USMS numerical rating system meets its objectives of screening the inventory of slope sites for more detailed assessment and conceptual design followed by a prioritization of sites for remedial stabilization based on benefit/cost analysis.

6. Upon identification of critical sites, the WSDOT responds appropriately by committing funds for each biennium for remedial stabilization that can be carried out in a timely fashion during favorable construction weather.

7. An appropriate feedback mechanism is built in to the program wherein the individual regions routinely report new slope activity or changes in slopes to the Geotechnical Branch so that slope ratings can be reassessed in a timely fashion. A good example of this continuous feedback loop between the regions and the Geotechnical Branch is the recent events that occurred on Chuckanut Drive in the Northwest Region when slope displacements were noted by regional maintenance personnel. This dynamic capability of the USMS is facilitated through deployment on the WSDOT intranet.

8. It is our understanding that 100 out of a total of some 2700 unstable sites (less than 4 per cent) have been remediated in the first 10 years of the USMS program. Overseers of the program must appreciate that several decades will be required to fully realize the demonstrable benefits of the program. To illustrate this point, an active rock slope maintenance program for an inventory of 750 sites has been in place for CP Rail in British Columbia since 1974. After three decades of stabilization work the opinion of the geotechnical specialist involved since inception is that only now are the benefits clearly recognizable.

Based on our review of the USMS and on familiarity with similar programs, the following recommendation is offered for consideration:

Under the USMS procedures a slope that qualifies for stabilization receives a comprehensive (i.e. ±20-year design life) treatment. In other words, stabilization is all or nothing at a given site. In many cases a minimal slope treatment can remediate a large component of the risk at a given site, for example, hand scaling or ditch widening. A methodology should be explored for implementing a risk reduction program that is complimentary to the USMS. One approach could be to make a pool of discretionary slope maintenance funds available each biennium in addition to that earmarked for programmed sites through the USMS. On an annual basis WSDOT Materials and regional personnel would jointly determine the sites and methodology to implement the risk reduction approach.

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We trust the foregoing is satisfactory for your current needs. If you should have any questions or comments, please feel free to contact us. We appreciate the opportunity to be of service to the Washington State Department of Transportation.

Sincerely,

GOLDER ASSOCIATES INC. **WYLLIE & NORRISH ROCK ENGINEERS INC.**

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