RISK ASSESSMENT TECHNIQUES FOR OPTIMISING SLOPE-FAILURE PREVENTIVE MAINTENANCE PROGRAMMES

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AN IMPORTANT NOTE FOR THE READER

The research detailed in this report was commissioned by Transfund New Zealand.

Transfund New Zealand is a Crown entity established under the Transit New Zealand Act 1989. Its principal objective is to allocate resources to achieve a safe and efficient roading system. Each year, Transfund New Zealand invests a portion of its funds on research that contributes to this objective.

The material contained in this report is the output of research and should not be construed in any way as policy adopted by Transfund New Zealand but may form the basis of future policy.

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Mr Brian Paterson of Paterson Coates & Associates (consulting geologists) contributed technical information towards the research.

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Introduction

This report reviews the use of slope-failure preventive maintenance programmes along highway corridors, and selects one programme for detailed study with respect to its suitability for New Zealand roads. A North American method for risk assessment was chosen because of its use of commercially available spreadsheet software and its potential general application across a wide range of geotechnical characteristics. The method offers the potential for rigorous decision-making by incorporating probabilistic techniques to take account of factor uncertainty, and by allowing a range of maintenance programmes to be compared on the basis of cost and effectiveness. The method can be carried out using Transfund New Zealand's 1998 procedures for the treatment of costs, benefits and discounting.

As there will be uncertainty in all of the input parameters, the method allows these to be treated in terms of joint probability distributions using Monte Carlo simulation and commercial spreadsheet software incorporating @RISK. Based on a comparison of the cost of implementation and the accident reduction effectiveness of each preventive slope failure maintenance programme, the most cost-effective maintenance programme in terms of the present value total equivalent costs can be identified. This can be found in one of two ways, either using the maintenance programme with the lowest present value total equivalent cost, or using that with the greatest probability of being the cheapest.

Verifying the Method using a Case Study

A case study was carried out in 1997-98 on a length of State Highway 73 (Christchurch to Arthur's Pass; SH73 RP 121/4.975 - 6.380) to verify the suitability of the method for New Zealand roads. The existing slope-failure maintenance programme at the study area, involving detritus clearing and call outs to remove rockfall material from the road, appears not to be the optimum when considered in terms of present value costs over a 25-year term. Significant cost savings would appear to be available if alternative maintenance programmes were to be implemented.

To verify the suitability of the method, a 1405 m-long section of SH73 in the Waimakariri Valley near Arthur's Pass has been selected for study. The highway is narrow and winding, with short sections that are being continuously affected by rockfall and rock slide instability. These hazards have caused many non-injury accidents (about 35 per year) but to date no injury (fatal, serious, minor) accidents have occurred in the 18 years that accident records have been kept. However, given the high frequency of rockfall instability and the poor road geometry, this low accident number can only be attributable to the very low traffic volume (AADT[1] 900) on the road.

The highway section is currently (1998) visited by road contractors, under a Network Maintenance Contract, about 550 times per year for detritus clearing and rockfall call outs. Based on an accepted rating system known as the Rockfall Hazard Rating System (RHRS), used by a number of North American roading agencies, at least three sections of highway in the study area would be classified as requiring urgent remedial treatment because of the high risk of adverse slope instability effects.

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[1] A Glossary to the report explains symbols, abbreviations and definitions of technical terms.

Detailed investigations for two specific sites were carried out within the study area in 1997-98. At each site, a number of preventive slope-failure maintenance programmes have been considered that range in terms of their accident reduction effectiveness and cost of implementation. The present value total equivalent costs for each maintenance programme (being the sum of the implementation costs and accident mitigation costs, in NZ$1998 values) have been determined using Monte Carlo simulation. This simulation allows parameter uncertainty, such as frequency of rockfall occurrence and the cost consequences if instability occurs, to be modelled. The optimum slope-failure maintenance programme has been identified on the basis of being either the lowest expected present value total equivalent cost or the greatest probability of being the cheapest.

For both sites, the existing programme of detritus clearing and rockfall call outs is not the optimum, and significant net benefits in terms of present value costs can be affected by implementing more rigorous maintenance programmes. By implication, additional net benefits are likely to be available for other sections of the study area.

Limitations and Advantages of the Method

The methodology for establishing the optimum slope-failure maintenance programme has a number of limitations and advantages. Where accurate information is lacking on slope stability, accident and maintenance data, the need is to allow for uncertainty in the modelling on the basis of subjective judgement. Further, the method is time-consuming because of the large number of inputs, and can therefore probably only be justified where there are significant cost consequences. However, the method does provide a rigorous technique for assessing the trade-offs between the accident reduction effectiveness with costs for each maintenance programme, at any slope and, on this basis the method can be used for identifying the optimum maintenance programme. While the research has been concerned primarily with rockfall hazards, the method could be applied to any type of slope stability hazard.

When priorities have been established for funding under Transit New Zealand's preventive maintenance budget, the methodology detailed in this research could be used as the basis for determining the optimum maintenance programme for mitigating slope failure effects. The method could be used either at individual sites or for entire highway corridors.

Applications of Method to New Zealand

The method also has an application to road safety. To date, litigation arising out of injury and/or death to road users attributable to slope instability has not occurred in New Zealand. However, the review of the literature indicates that litigation overseas is not uncommon. For example, in 1989, the Supreme Court of Canada found against the Ministry of Transportation and Highways (MOTH) in a case involving a rockfall failure on British Columbia Highway 99, at a location known as the Argillite Cut. The rockfall had resulted in the death of a road user. The victim's family successfully sued the road authority, which set a significant Canadian legal precedent in terms of the level of risk at which the road user is required to be protected. The Court found that, even though there had been a relatively few number of rockfalls (4 in 24 years), and that the roading authority had carried out remedial work following two of the events, MOTH was deficient in meeting a reasonable standard of care.

The British Columbia Highway 99 (Argillite Cut) case has possible implications for New Zealand roading authorities and, given that the New Zealand legal climate is becoming increasingly litigious, similar trends can be expected to occur here.

Recommendations

The methods detailed in this research provide New Zealand roading authorities with an approach for demonstrating an appropriate "duty of care" to road users with respect to slope stability hazards. For sites where slope stability hazards are a problem, the methodology will allow meaningful quantitative risk assessments to be carried out, and appropriate engineering responses to be implemented when risks are above acceptable limits.

Developing optimisation procedures for slope-failure maintenance would have merit as it would allow New Zealand roading authorities to implement optimised preventive maintenance programmes within their own jurisdiction or territory.

So that meaningful quantitative risk assessments can be made, and appropriate engineering responses can be implemented when risks are above acceptable limits, New Zealand roading authorities should implement procedures to record slope stability hazard information. As such procedures are currently lacking, recording slope stability hazard data on existing computer databases such as the Transit New Zealand RAMM (Road Assessment & Maintenance Management) system would be the simplest procedure.

The method also has scope for use in other roading applications such as the optimisation of road batter construction. For this, the optimum batter angle can be identified in terms of the trade-off between cost and the risk of slope failure. As a result of this, an appropriate contingency sum can be allowed in the costing of physical works contract estimates that are commensurate with the risk.

ABSTRACT

A North American method for establishing an optimised slope-failure preventive maintenance programme for use by roading authorities has been identified and trialed by way of a case study, to determine its application to New Zealand roads. The method requires a knowledge of the slope instability, and accident and maintenance history affecting the site. This information can be used to quantify the risk to road users from adverse slope instability affects, and to identify and cost a range of preventive maintenance programmes which could be implemented to mitigate the risk.

A study was carried out in 1997-98 on a length of State Highway 73 (Christchurch to Arthur's Pass) to verify the suitability of the method for New Zealand roads. The existing slope-failure maintenance programme at the study area, involving detritus clearing and call outs to remove rockfall material from the road, appears not to be the optimum when considered in terms of present value costs (NZ$1998), over a 25-year term. Alternative maintenance programmes would provide significant cost savings. The methodology detailed in the research study could be used by Transit New Zealand in conjunction with its present preventive maintenance strategies to identify optimum slope failure maintenance programmes. It could also be used to provide New Zealand roading authorities with procedures for implementing an appropriate "standard of care" for those sites where slope stability hazards pose a safety problem.

1. INTRODUCTION

1.1 Background

This report summarises a study, carried out in 1997-98, of the use of probabilistic risk assessment techniques in optimising slope-failure preventive maintenance programmes along highway corridors. The study reviews current international practices and examines the applicability of a selected methodology to New Zealand roads.

Few parts of New Zealand are free from slope instability effects because of the varied and dynamic geology and frequent heavy rainfall. Hazards from both natural and excavated (cut) slopes can pose serious problems to the roading network where steep terrain is in close proximity. Instability takes a number of forms including rockfall, shallow and deep seated slippage and associated processes such as debris flows and wash outs from flooding. Initiating causes include not only extreme events such as rainfall and earthquake, but also normal weathering processes. Such instability results in the expenditure of millions of dollars related to unplanned maintenance, disruption to services, and injury or death. To date costs associated with litigation arising out of injury and or death have not occurred to any significant extent in New Zealand, but are common overseas. However, given the increasing litigious climate within New Zealand, costs from this cause can be expected to occur in the future.

Various approaches can be used for the management of slope stability effects on road, as summarised in Table 1.1, each of which have different impacts in terms of their consequences on road user safety and maintenance costs.

Table 1.1 Possible risk management approaches and their impacts.

Approaches	Potential Adverse Consequences			
	Damage remediation	Service Disruption	Injury/death	Litigation
REACTIVE				
Remediate	Status quo	Status quo	Status quo	Status quo
Monitor/evacuate	Status quo	Status quo	Reduced	Reduced
PROACTIVE				
Preventive maintenance	Reduced	Reduced	Reduced	Reduced

Typically in the past, cut slopes along road corridors have been designed on the basis of either precedence (i.e. on slopes which exhibit good stability characteristics) or on the safety factor concept, after which their performance is largely ignored until such time that failure occurs and remediation is required. This approach neglects to consider that slope conditions change and may degrade with time. Failures, when they occur, are therefore unexpected and considered as random occurrences, resulting in additional costs caused by disruption of services and unplanned maintenance.

Instead of considering slope failures as random, unexpected and uncontrollable occurrences, an alternative approach is to monitor slope conditions to mitigate the consequences of failure, rather than simply remediate after the event. A proactive approach such as this offers the possibility of choosing the most cost-effective maintenance strategy, for either individual slopes or entire roading corridors, commensurate with the risk to road users. Increasingly this approach is being required by some road authorities to demonstrate an appropriate "standard of care" to reduce consequences of litigation in the event of injury/death to road users.

This study results from the identification of a risk assessment technique developed by a North American geotechnical consultant for use in optimising road maintenance programmes to deal with slope instability effects (Roberds 1991). It was chosen because it uses commercially available spreadsheet software, and has potential general application across a wide range of geotechnical characteristics. The method offers the potential for rigorous decision-making by incorporating probabilistic techniques to take account of factor uncertainty. Also it is quantitative in defining costs and benefits for the various maintenance options, and therefore offers scope for comparison with the Transfund New Zealand benefit/cost procedures and analyses.

1.2 Objectives

The specific objectives of this study are to:

- Review relevant international literature on optimising slope-stability maintenance systems
- Identify and develop a quantitative risk assessment technique suitable for a trial study in New Zealand
- Identify a suitable section of New Zealand highway to carry out a trial study
- Collect relevant data on the slope instability history of the study section, and road conditions including accident and maintenance history, through fieldwork, review of technical reports, records and personal interviews
- Quantitatively assess the risk posed by slope instability to road users at the selected site
- Identify potential preventive maintenance activities and prepare rough order costings, together with their respective effectiveness in reducing accident and repair costs
- Use the chosen risk assessment methodology to determine the optimum maintenance programme
- Review the applicability of the methodology to New Zealand roads.

2. METHODOLOGY

2.1 Literature Review

Transit New Zealand has recently completed a study of the security of the road network of New Zealand (Montgomery Watson 1997a) to determine the loss of business cost caused by disruption to the road network arising from unplanned events and incidents including slope instability effects. This involved consideration of the level of importance of each road network, the risk and expected duration of disruption, and the consequences of temporary road closure on the operation of the road network. These factors were used to rank individual road networks based on their assessed vulnerability. Those road networks judged to be most vulnerable included a mix of both urban and rural roads in both North and South Islands.

Hungr & Evans (1989) studied the economic significance of rockfall hazards on Canadian transportation routes and found that this can be measured in terms of millions of dollars of loss related to road user injury/death, traffic disruption, and repair costs per year. A total of 13 deaths on roads and railways have been recorded in Canada from rockfall, and a large number of traffic accidents are related to this form of slope instability annually.

Bunce et al. (1997) detailed the case of a rockfall failure on British Columbia Highway 99 at a location known as the Argillite Cut which had resulted in the death of a road user. The victim's family successfully sued the Ministry of Transportation and Highways after pursuing the claim to the Supreme Court of Canada. This case set a significant Canadian legal precedent in the level of risk at which the road user is required to be protected.

Numerous accidents resulting in injuries and/or deaths, and often followed by expensive litigation, have occurred on North American highways because of rockfall (McCauley et al. 1985, National Transportation Safety Board 1988, New York Department of Transport 1988). The State of Washington, USA, has experienced a "significant number of accidents and nearly a half dozen fatalities ... because of rockfalls in the last 30 years" (Badger & Lowell 1992). This state and other North American state and private sector road, rail and pipeline agencies have implemented preventive maintenance strategies to manage the effects of rockfalls by prioritising those sites where mitigation measures are required to be implemented (Badger & Lowell 1992, Keaton & Eckhoff 1990, McCauley et al. 1985, National Transportation Safety Board 1988, New York Department of Transport 1988, Pierson 1992, Pierson et al. 1990, Wyllie 1987). In addition to the Washington State Department of Highways, other agencies to introduce maintenance strategies include the British Columbia Ministry of Transport and Highways (MOTH[1]), the Oregon Department of Transportation (ODOT), and Capilano Highway Services Ltd (CHSL). These strategies are based mainly on the Rockfall Hazard Rating System (RHRS) developed

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[1] See Glossary for symbols, abbreviations and definitions of technical terms.

by the ODOT (Keaton & Eckhoff 1990, Pierson 1992, Pierson et al. 1990, Wyllie 1987). This system covers a range of factors including geotechnical controls, terrain characteristics, hazard history, vehicle and road conditions, and climatic conditions. The RHRS was developed over a 5-year period between 1984 to 1989, based on testing at over 3000 sites. A principal deficiency of the RHRS is that it does not include any recommendations on actions to be taken for different ratings.

Roberds (1991) considers that maintenance programmes based on rating systems such as the RHRS may not be optimum, having been developed on simplified, non-comprehensive analyses. He has proposed more rigorous techniques which allow uncertainty, in terms of the frequency of hazard occurrence, the cost, risk and consequence of hazard mitigation, to be modelled using probabilistic techniques to identify the optimum programme.

His method considers the possible slope-failure modes and their consequences on the road user, and the effectiveness of possible alternative maintenance programmes considering their cost and impact on risk reduction, from which an optimum maintenance programme can be identified.

This study has selected Roberd's method to determine its applicability to New Zealand roads, as the method offers the potential for rigorous decision-making by incorporating probabilistic techniques to take account of parameter uncertainty. Also it is quantitative in terms of the definition of costs and benefits for the various maintenance options, and therefore offers scope for comparison with Transfund New Zealand benefit/cost procedures and analyses.

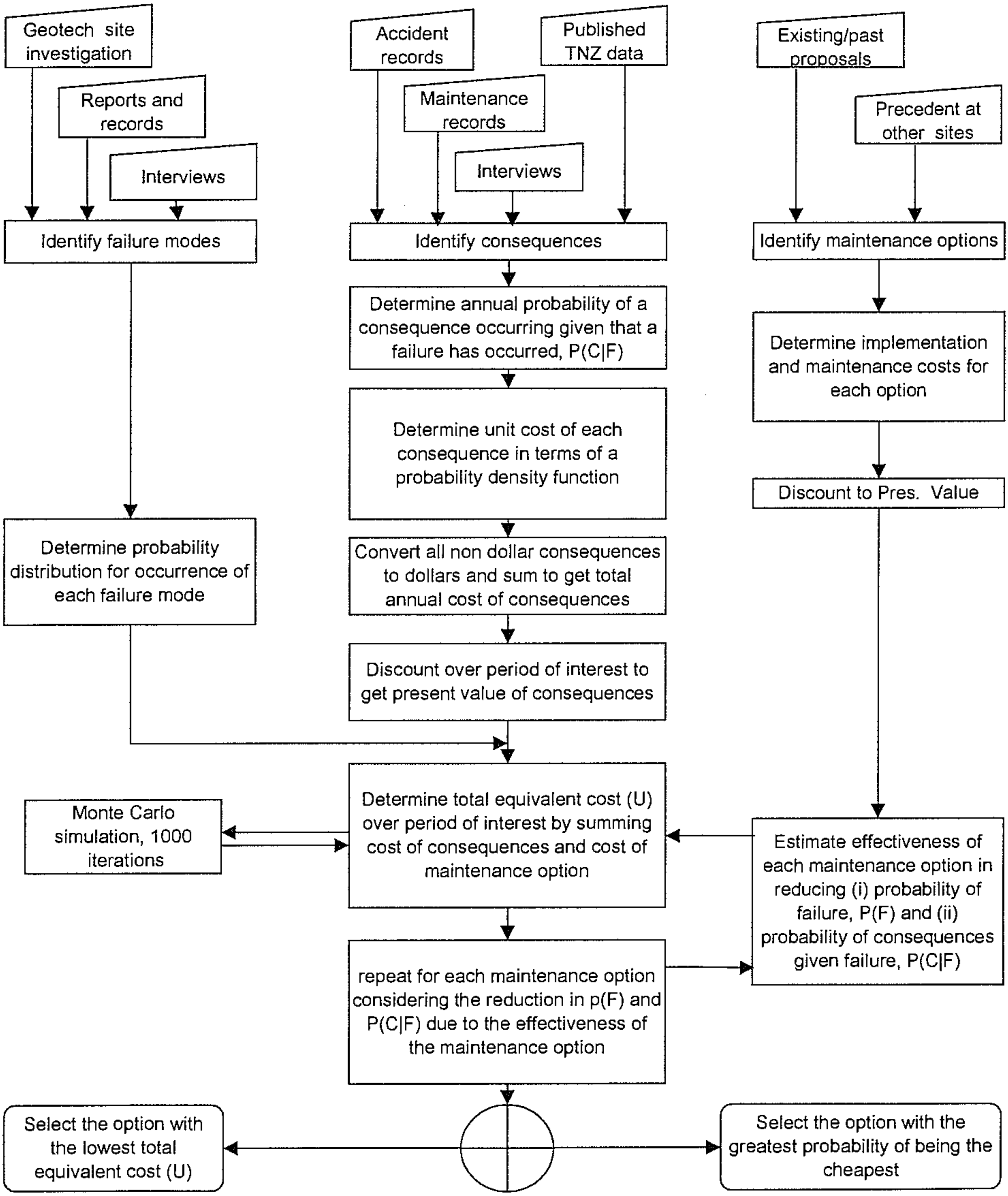
2.2 Procedure for Selecting an Optimum Highway Maintenance Programme

The methodology adopted in this study follows the approach of Roberds (1991), and is illustrated in the flow chart provided as Figure 2.1. Key elements of the methodology are explained more fully below.

2.2.1 Identify Slope Failure Modes

For each site under investigation, an understanding of the types (modes) of slope failure which occur and an estimate of their respective frequency of occurrence are required. Unless records are extremely accurate, there will be some uncertainty in the frequency of occurrence of each failure mode at each site, and therefore the frequency of occurrence is best represented by a probability distribution for a specific time period. The probability distributions are based on geotechnical site investigations to determine failure characteristics.

Figure 2.1 Detailed procedure for selection of optimum highway maintenance programme.



2.2.2 Identify Possible Slope Failure Consequences

For each failure mode, the consequences of failure also need to be estimated, given that failure has occurred. Typical consequences include the costs of road maintenance, service disruption caused by road closures, accident costs, and possible litigation costs in the event of injury/death to road users. These consequences will also be uncertain in terms of their costs, and can best be dealt with in terms of probability distributions.

Where roading authority records exist, consequences of failure may be estimated directly. Where records are deficient or are non-existent, alternative risk assessment techniques are required.

2.2.3 Identify Possible Maintenance Programmes

Based on the recognised slope-failure modes and on an assessment of the cost consequences of their failure on the road network, the other significant input element is the identification of a range of possible preventive maintenance programmes which could be implemented for each site to mitigate the hazard. These could range from basic programmes involving detritus clean ups, to monitoring the hazard, through to costly protection measures or realignment. Once the range of possible programmes has been identified, each programme is required to be costed. As the accuracy of cost will also be uncertain, this can best be dealt with in terms of a probability distribution.

The effectiveness of each maintenance programme in terms of reducing the frequency of occurrence and reducing the consequences given failure of each mode of slope instability is required to be estimated. This is also best represented by a probability distribution to take account of uncertainty.

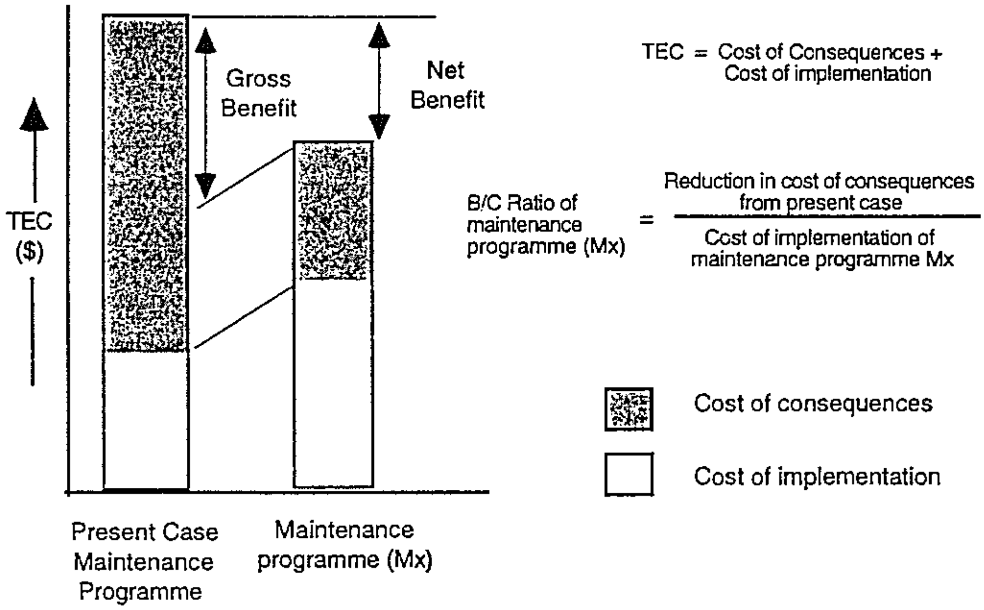
2.2.4 Selection of Optimum Maintenance Programme

Each maintenance programme will result in specific consequences (in terms of accident and maintenance reduction) as well as in specific physical works costs if implemented for a slope. The consequences can be converted to costs and summed together with the implementation costs, giving a total equivalent cost (TEC) for each maintenance programme, as illustrated below. All of the consequences and costs for each maintenance activity will include uncertainty, and these can best be treated in terms of joint probability distributions as a function of the previously estimated probability distributions for each activity applied to the slope (using Monte Carlo simulation techniques).

The optimum maintenance programme can be identified by selection on the basis of the lowest TEC, as illustrated in Figure 2.2. If the maintenance programme with the lowest TEC has too high an implementation cost, the programme with the next lowest TEC is selected until an affordable solution is reached. The result will be the best affordable solution in terms of bringing about the greatest reduction in the TEC, and is termed the net benefit.

Selection of the maintenance programme on the basis of the lowest TEC differs from benefit/cost (B/C) analysis, which is the gross benefit resulting from implementation of a programme divided by the total cost of implementation, as illustrated in Figure 2.2. If selection on the basis of B/C analysis is adopted, then the programme with the highest B/C ratio is selected. The selected programme is checked to ensure it will result in a reduction of consequences to acceptable risk levels. If not, the programme with the next highest B/C ratio is considered, until an acceptable solution is obtained.

Figure 2.2 Determining Benefit/Cost of an optimum maintenance programme.



Both the TEC and B/C ratio methods are valid, the former representing the cheapest overall cost, and the latter representing the best return on capital expenditure. However the two do not necessarily result in selection of the same outcome.

2.2.5 Monte Carlo Simulation

Monte Carlo simulation is a method whereby the distribution of possible outcomes is generated by letting a computer re-calculate a spreadsheet many times over. Each time different randomly selected sets of values are used for the probability distributions in the spreadsheet cell values and formulas. In effect, the computer is trying all valid combinations of the values of input variables to simulate all possible outcomes. @RISK is a commercially available software package which carries out Monte Carlo simulation as part of an Excel or 1-2-3 worksheet. The results of @RISK simulations are presented in the form of probability distributions.

2.2.6 Procedure Adopted for Economic Analysis

For the purpose of this study, the Transfund New Zealand procedures have generally been adopted for the evaluation of roading projects for the treatment of costs, benefits, discounting and other economic matters involved with assessing economic costs and benefits (Transfund New Zealand 1997). The discount rate adopted to convert all costs to present value (PV) costs is 10% and the term is 25 years. However, no allowance for contingencies has been included in our assessment of rough order costs for each of the various maintenance programmes identified (refer Section 3.3.3), as this has been allowed for by modelling cost uncertainty through the use of probability distributions for cost items.

2.2.7 Verification of Roberds' Method

Roberds (1991) provides two worked examples of road maintenance programmes which have been determined on the basis of the methodology detailed above. To verify the methodology, worksheets (Appendix 1) have been established from the various input data provided, and probability distributions determined on the basis of Monte Carlo simulation, using commercially available Excel spreadsheet software incorporating @RISK. A preferred road maintenance programme has been identified which conforms to the result supplied by Roberds, providing verification of the methodology and the worksheets (Appendix 1).

3. CASE STUDY : AREA CHARACTERISTICS

A case study was used to evaluate the applicability of Roberds' (1991) methodology for selection of a slope-failure road maintenance programme for New Zealand roads.

3.1 Site Description

The study area is a 1405-m length of road on the Christchurch - Arthur's Pass section of State Highway (SH) 73, between route positions RP 121/4.975 and 121/6.380. It is located between the small settlements of Cass and Bealey (Figure 3.1). This length of highway crosses moderately steep slopes of Mt Horrible to the south of the wide, glaciated Waimakariri Valley (Figure 3.2). At the eastern (Christchurch) end, the highway closely follows the right bank of the Waimakariri River at a level just above normal river flow, and passes around the toe of several truncated rock spurs. With increasing distance west (towards Arthur's Pass), the road rises on to a cut bench approximately 50 m above river level.

The study area comprises five distinct short sections of highway, each of which have steep slopes (either excavated or natural) above the highway. For this study, the five sections of highway with their Transit New Zealand route positions have been designated as shown in Figure 3.2 and Table 3.1.

Table 3.1 Identification of the 5 highway sections used in the study.

Site Number	Route Position	Length of Highway (m)	Informal Name
1	RP 121/4.975- 5.025	50	
2	RP 121/5.100 - 5.200	100	
3	RP 121/5.225 - 5.370	145	
4	RP 121/6.123 - 6.213	100	"Paddy's Bend"
5	RP 121/6.230 - 6.380	150	

Following a review of the geotechnical conditions and the problem definition (Section 3.2), sites 1, 2 and 3 were found to exhibit similar characteristics, and sites 4 and 5 likewise were similar to each other. Accordingly, to minimise duplication of effort for similar sites, detailed investigations were limited to site 2 (Figures 3.3 and 3.4) (being indicative of sites 1, 2 and 3) and to site 4 (Figure 3.5) (being indicative of sites 4 and 5). As well, sites 2 and 4 were also found to have the highest risk of potential adverse slope instability effects on road users (Section 3.4.2).

Figure 3.1 Sketch map of Canterbury area showing location of SH73 study site.

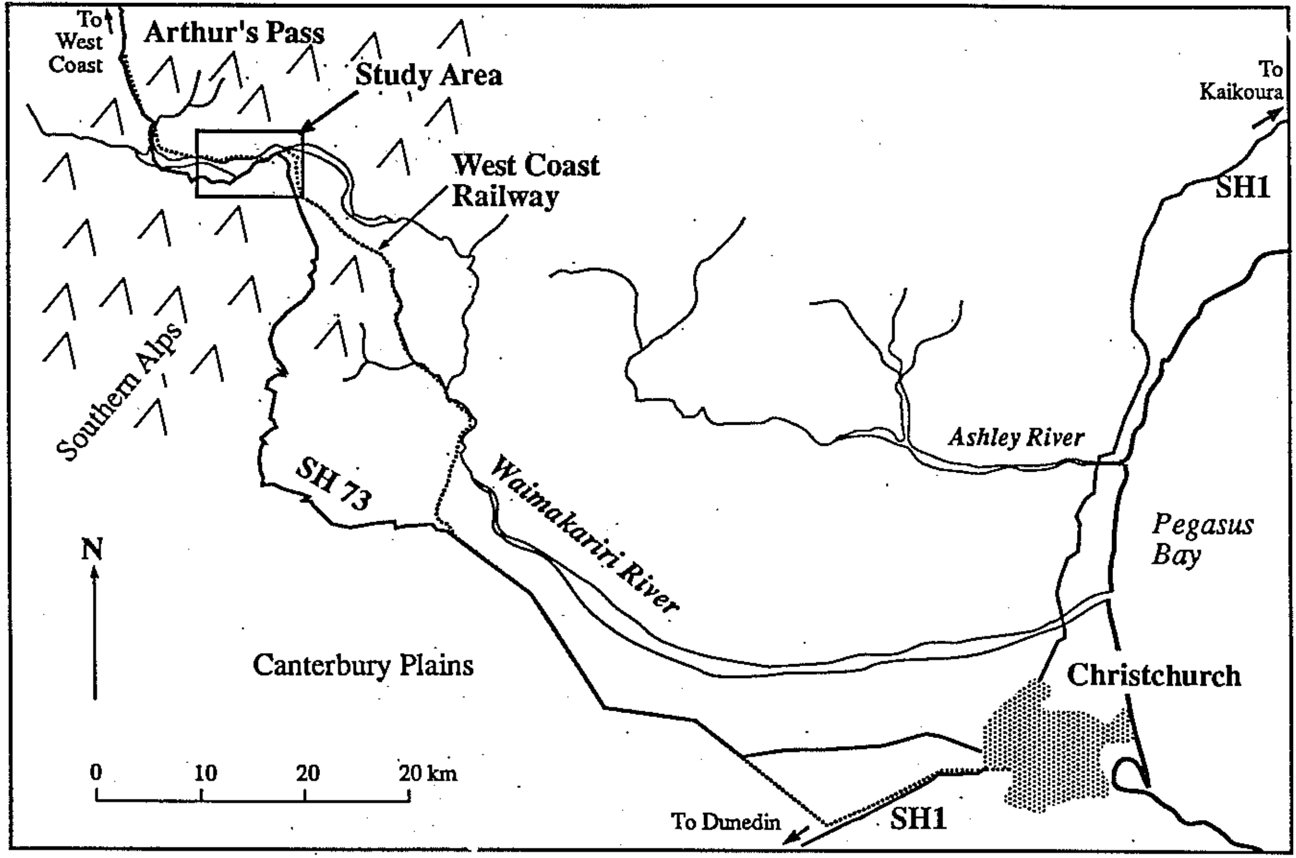
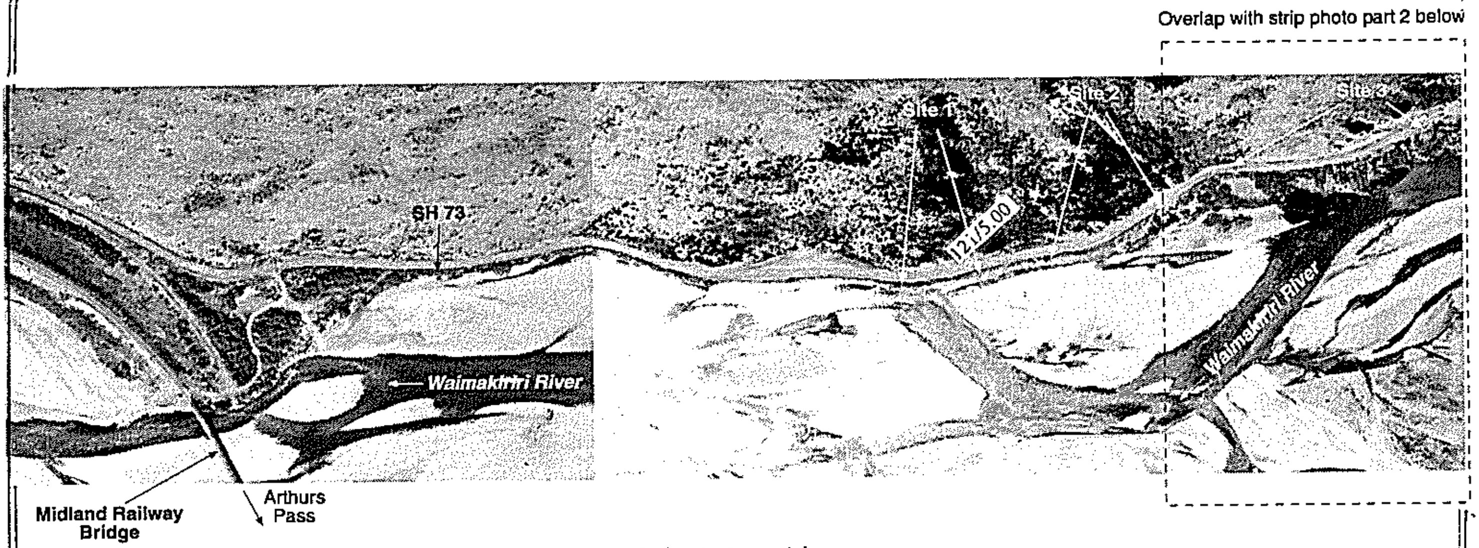
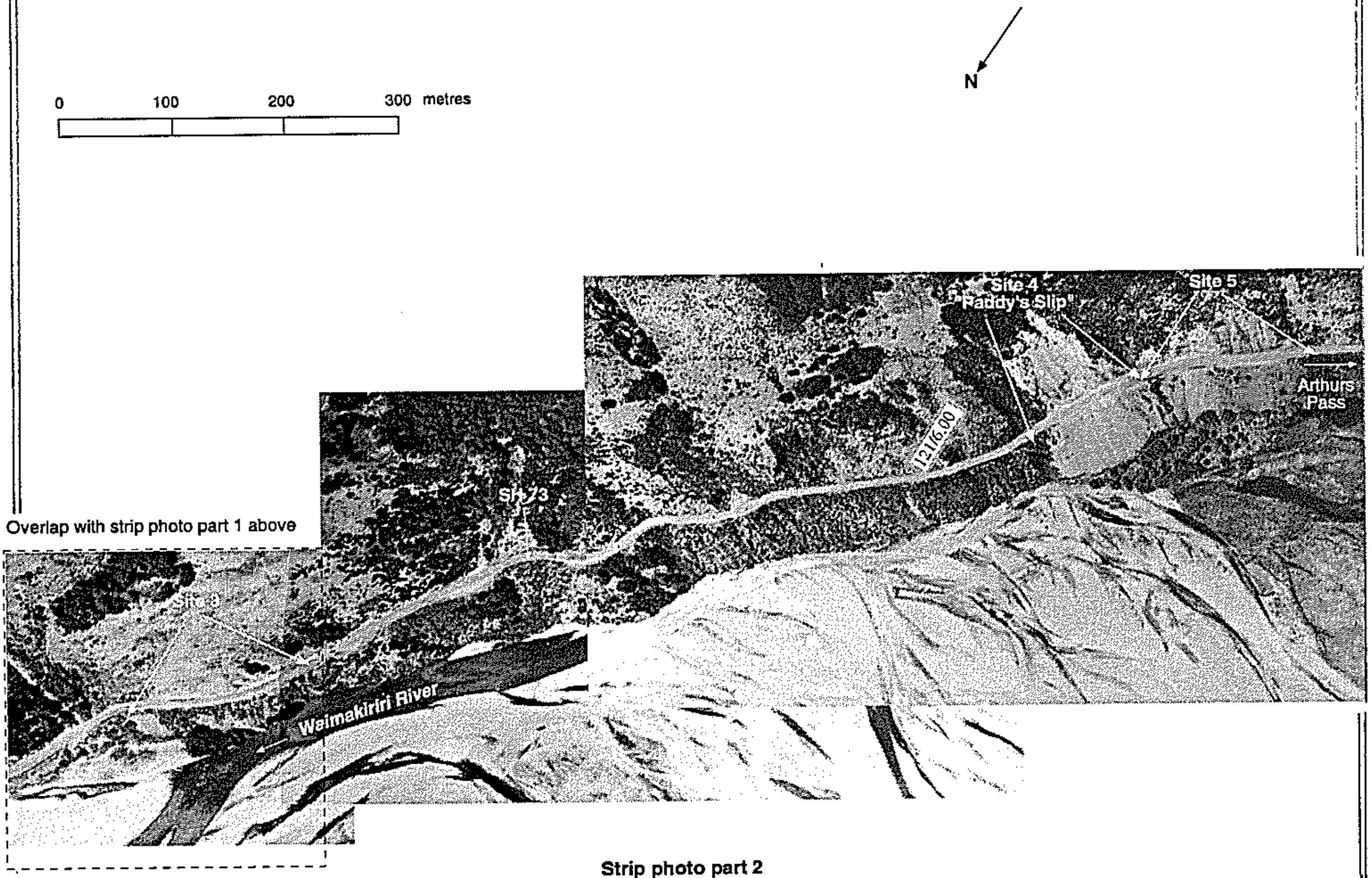


Figure 3.2 **Vertical aerial photograph of SH73 study site: RP 121/4.975 - 6.380.**



Strip photo part 1



Strip photo part 2

Figure 3.3 Site 2, view looking west towards Bealey, on the way to Arthur's Pass.

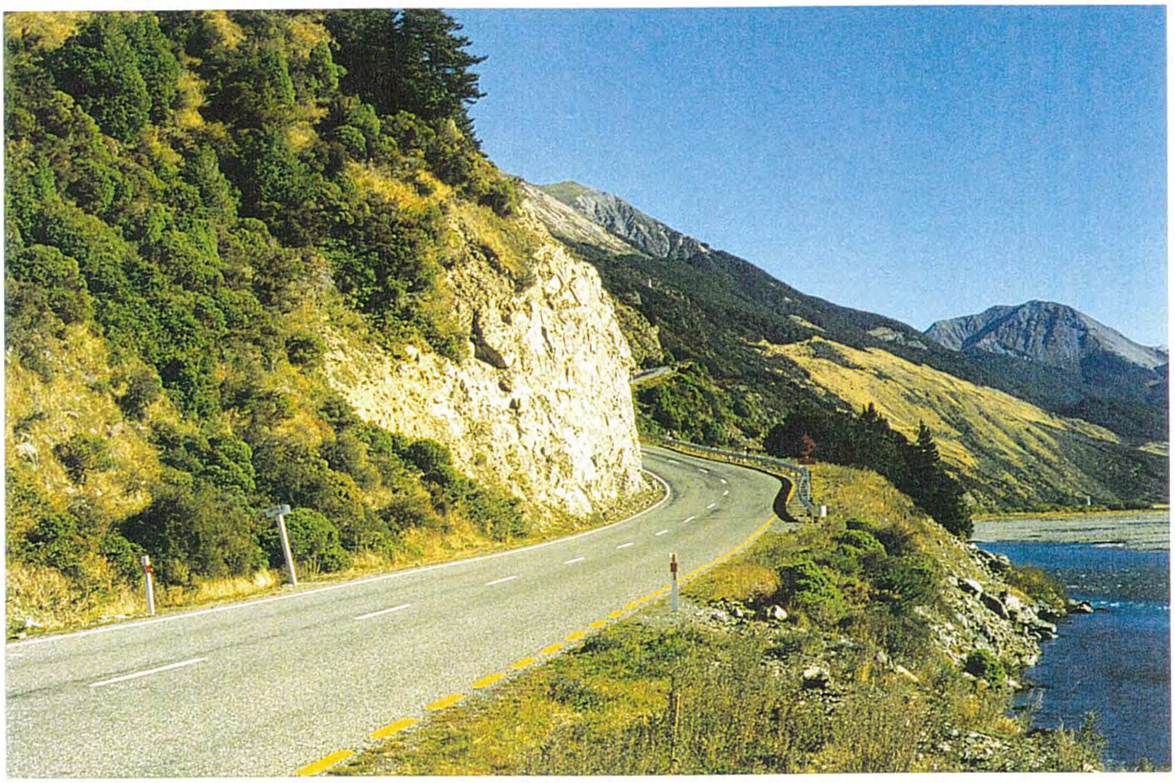
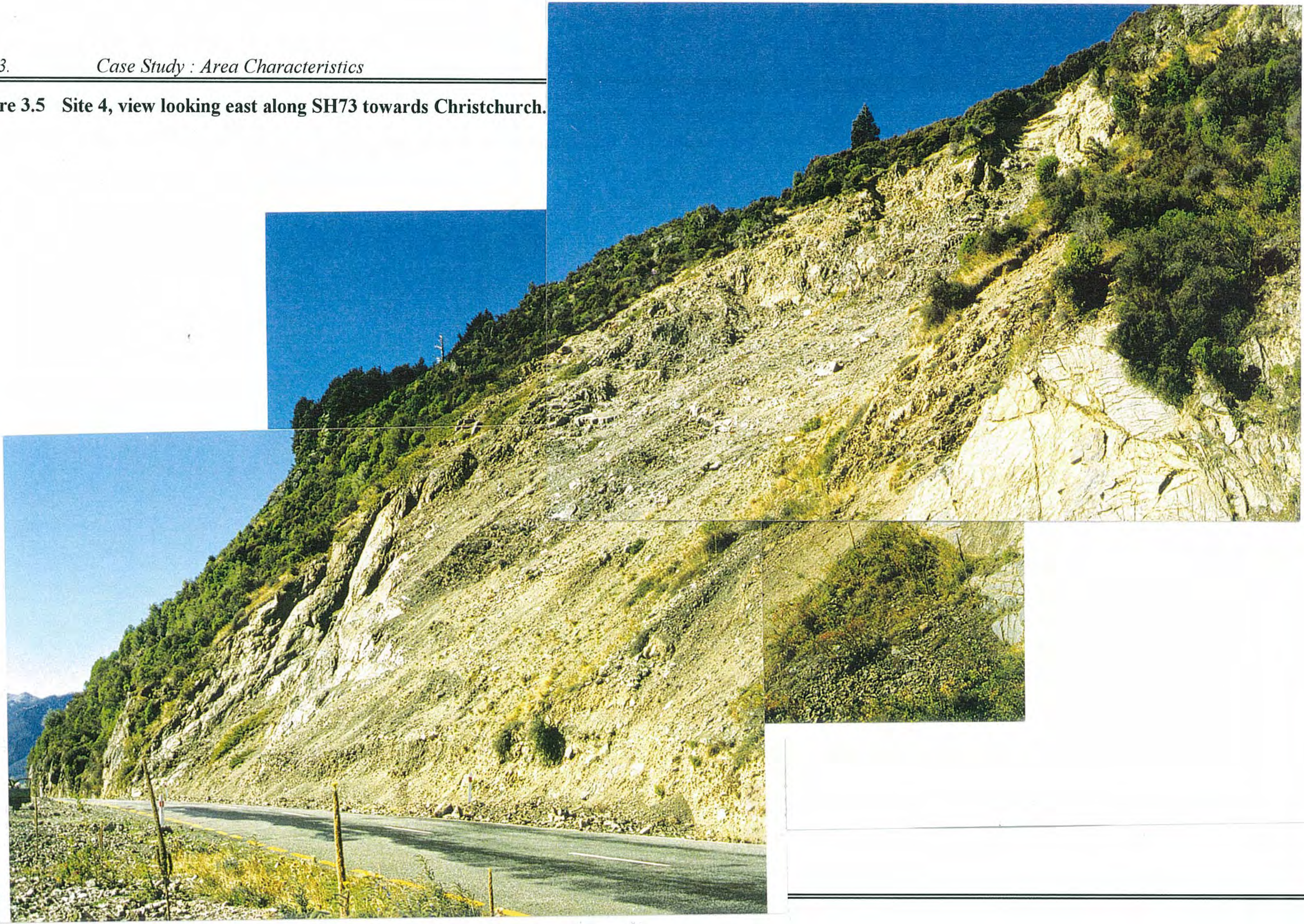


Figure 3.4 Site 2, view looking east towards Mt White bridge, on the way to Christchurch.

Figure 3.5 Site 4, view looking east along SH73 towards Christchurch.



3.2 Definition of Slope Instability Problem

3.2.1 Geotechnical Characteristics of Study Area

The bedrock in the study area is predominantly hard greywacke sandstone and subordinate argillite (mudstone). In general, it is highly fractured, although thick beds of massive sandstone form extensive cliffs particularly above the highway (Paterson 1982a). The rock exposed in the cut batters is highly dilated (open), and there are major defects in the form of faults, clayey crushed zones, and numerous very closely spaced joints. Bedding, which is visible only where argillite crops out, is not a major rock weakness, except at site 4. In general, the orientation of bedding is uniform along the highway, i.e. dipping 45° - 80° obliquely into the slope, except at the western end near site 4 where it is folded (Paterson 1982a).

Where the bedrock is in cut (excavated) batters it is unstable, controlled mainly by the density, orientation and openness of the numerous joints and faults which intersect the rock. The instability occurs predominantly as rockfalls and, less frequently, as rock slides. Initiating events include climatic factors (rainfall, freeze-thaw activity), and earthquake shaking.

Bedrock on the slopes of the Waimakariri Valley is covered in places by remnants of glacial deposits, alluvium, and slope deposits (colluvium) (Paterson 1982a). The latter, which have accumulated in pockets between rock bluffs, are at their natural angle of repose and are subject to slope failure if disturbed, such as during road widening.

3.2.2 History of Slope Instability

In 1982, construction commenced on upgrading a 2.2 km-long section of SH73 between the TranzRail Midland Railway bridge across the Waimakariri River and site 4 (Figure 3.2). The work involved easing the sharpest corners and widening sections of road where retaining walls had failed, by excavating a minimal distance into the slope. Soon after construction commenced at the western end, reactivation of an existing rock slide at site 4 known locally as "Paddy's Bend" occurred, temporarily closing the highway (Paterson 1982a). Further widening was postponed indefinitely, although local widening was later carried out near the eastern (railway bridge) end of the highway.

Before 1982, slope instability consisted of minor rockfalls, particularly during winter, from steep cut batters mainly near the eastern end of this section of highway, while at the western end subsidence of the retained outer edge of the highway and rockfalls from slopes above the highway occurred. In 1982 and 1983, several significant rock debris slides closed this stretch of highway, one of which occurred at site 4 (Paterson 1982a, b).

Since 1982, rockfalls have been a continuing problem at site 4, and more recently at the adjoining site 5 where a large area of exposed bedrock contributes a significant number of rockfalls. At all five sites, small rockfalls occur almost on a daily basis, and much of this material ultimately ends up on the road in the form of detritus. Large falls of discrete blocks also occur infrequently, e.g. in 1997 when "several blocks up to 0.6 m in size" fell at site 2 (Montgomery Watson 1997b). Rockfall activity increases during severe north-west rainfall, and during the winter freeze-thaw.

All the sites were affected by earthquakes on 18 June 1994 (Arthur's Pass), and 29 May 1995 (Mount White), resulting in the loosening and dilation of rock blocks in cut batters, and the dislodgment of blocks on to the road. Also, rockfalls occurred from high rock bluffs above site 5 and open cracks were noted, indicating a possible long-term hazard (Paterson & Coates Associates 1995). The frequency and size of rockfalls have become more frequent at sites 1, 2 and 3 since the 1994 and 1995 earthquakes.

In addition to rockfall, rock slides also originate from site 4 on to the road in response to high rainfall events. These comprise moderate to large volumes of debris up to 100 m^3, though their occurrence is infrequent.

The following measures have been, and are, carried out by Transit New Zealand to mitigate adverse effects on road users:

- the introduction of a "no stopping" zone;
- scaling (using hand methods, wire rope technology and helicopter water sluicing techniques) of cut batters on an irregular basis;
- construction of a low (500 mm) rock-fill bund on the inside of the road at site 4;
- regular mechanical sweeping of the road surface to remove detritus and rock blocks (Section 3.3.5);
- on-demand call outs for the clearance of large rockfalls and slips (Section 3.3.6)

Remedial measures that have also been considered included the construction of a rockfall protection fence at site 4 (Paterson & Coates Associates 1997), but this has not been implemented because benefit/cost analyses suggested that the cost cannot be justified using Transfund New Zealand's funding criteria (Montgomery Watson 1997c).

3.2.3 Engineering Geology of Sites 2 and 4

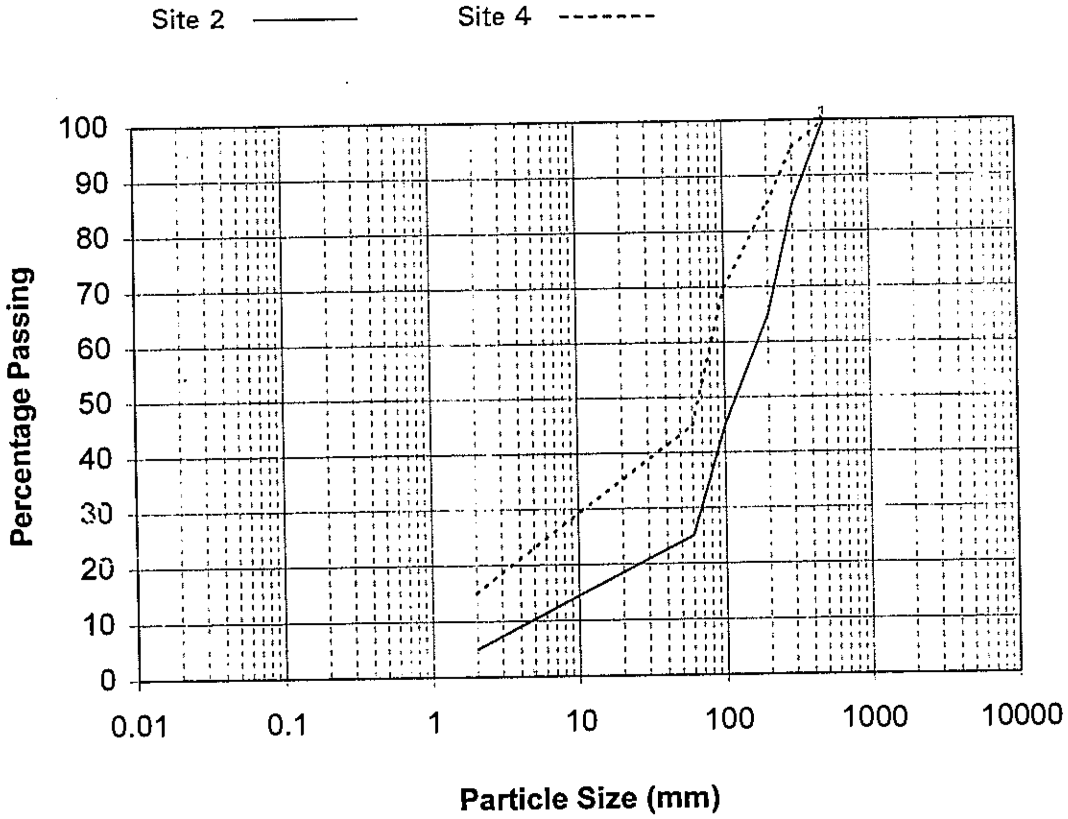
Engineering geological mapping of all five sites was carried out in 1982 (Paterson 1982a, b) as part of proposals for widening of the road along this section of highway, and in 1995 (Paterson & Coates Associates 1995) in response to the 29 May 1995 Mount White earthquake. The results of this work together with additional mapping carried out as part of the present study for sites 2 and 4 are given in Figures 3.6 and 3.7.

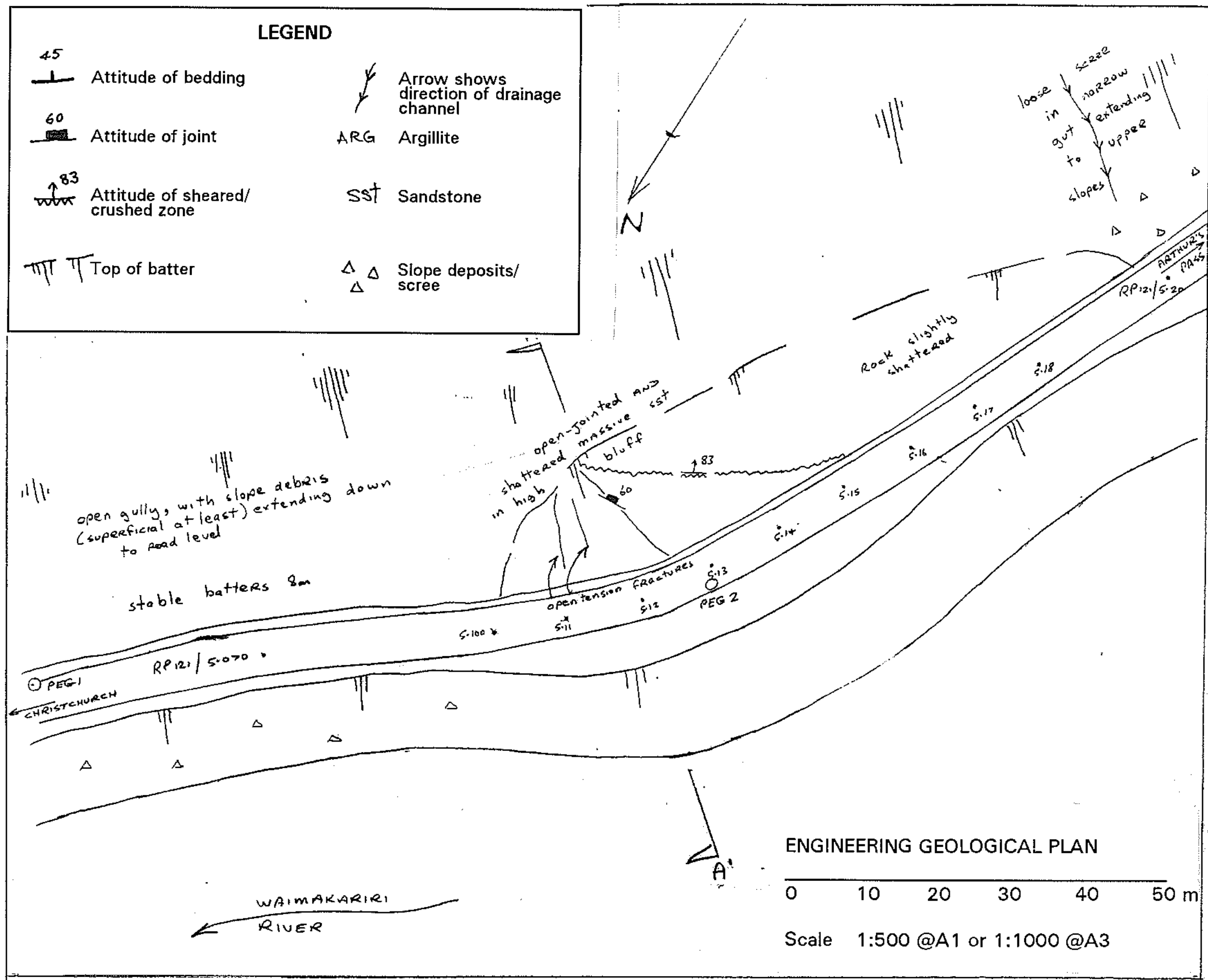
The slope above site 2 (Figure 3.6) forms a 100-m long, 20 to 30-m high, cut batter inclined at 60° from the vertical (1.73v:1h), with the batter toe located only 1 m from the inside edge of the road. The batter consists of massive sandstone, intersected by joints with spacings ranging from widely to very closely spaced. An 83°, upslope-dipping fault zone comprising crushed and shattered rock intersects the batter at RP 121/153. In places, the rock is dilated (open), and blocks of rock overhang the face. Rockfall sources consist of the numerous areas of open jointed and very closely spaced rock, as well as individual loose blocks. Several of these blocks, up to 600 mm in diameter, fell in April 1997, resulting in an inspection of the cut batter by Transit New Zealand's highway network management consultant.

Site 4 (Figure 3.7) comprises an 80 to 90 m-high slope of very to extremely closely jointed sandstone and argillite. The slope is inclined at moderate angles (34°-45°) over its lower portions, steepening to approximately 60° towards its crest. The slope mainly developed initially in response to instability of surface slope materials (colluvium) as a result of road widening, and more latterly of the fractured rock mass which underlies the slope at depth. Because of the closeness of the defect spacing, rockfall activity originates from all areas of the face, while rock slides occur in response to specific rainfall events. The failure area has now retreated upslope close to an area of overhanging and more competent rock, some of which now poses a threat in terms of potential rockfall material.

The principal distinguishing engineering geological characteristic of the two sites is the greater degree of fracturing and hence closer spacing of rock mass defects at site 4. This characteristic is reflected in differences in the grading envelope for rockfall detritus derived from each of the sites. Figure 3.8 is based on a visual-manual assessment of the particle size distribution of rockfall detritus from sites 2 and 4, indicating the general coarsening of rockfall blocks at site 2 compared to site 4.

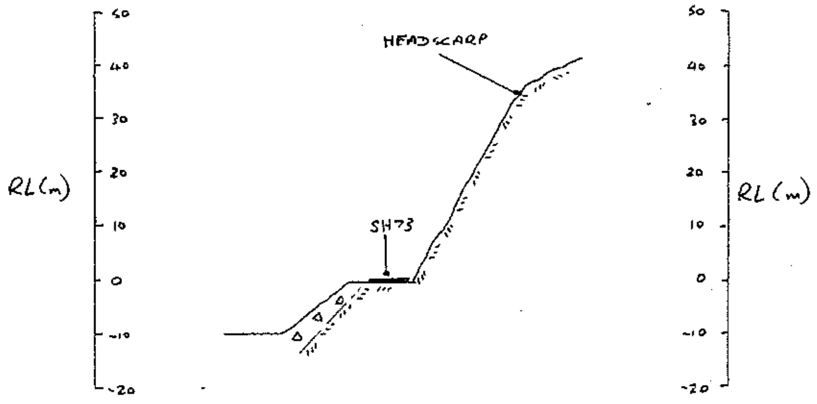
Figure 3.8 Particle size distribution of rockfall detritus.





ENGINEERING GEOLOGICAL PLAN

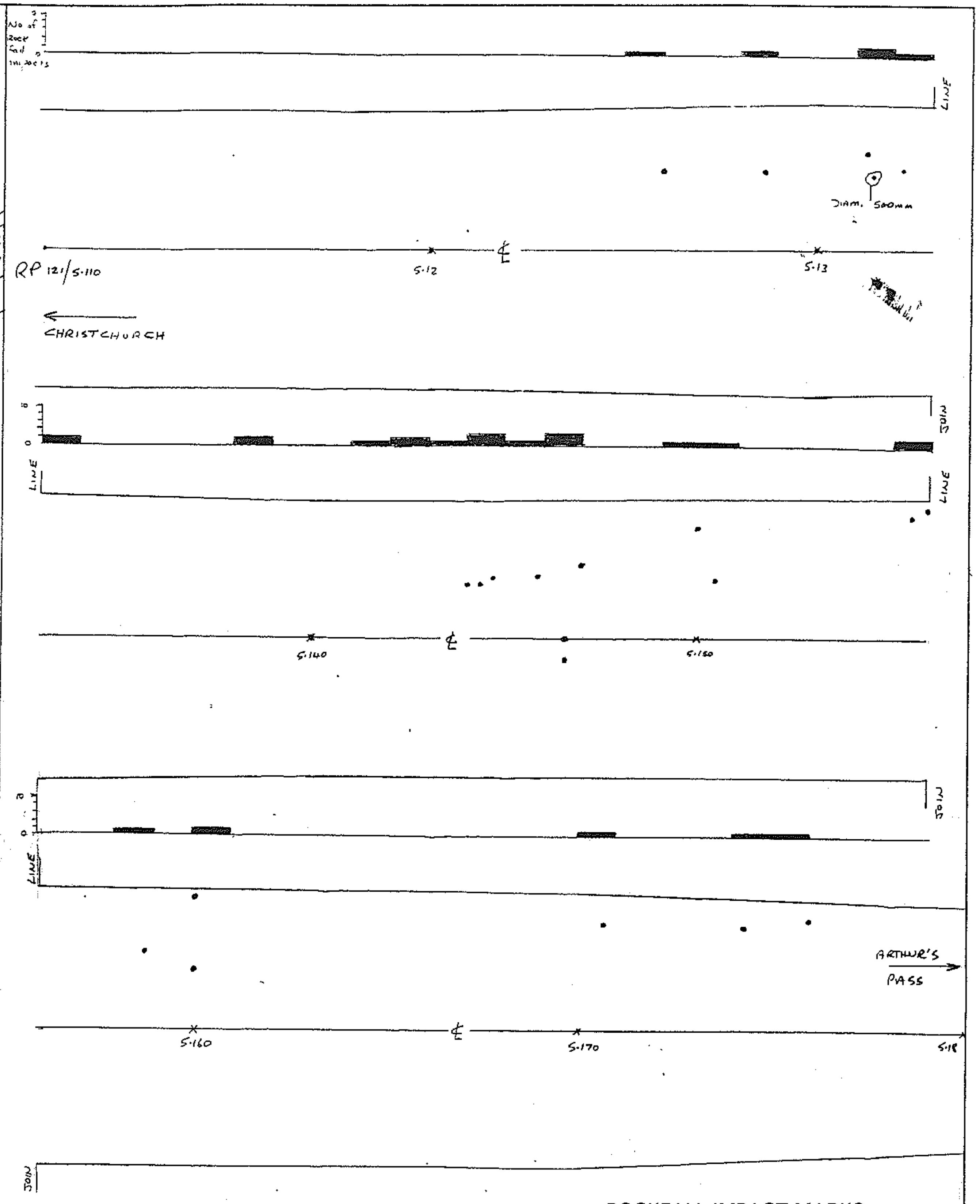
Scale 1:500 @A1 or 1:1000 @A3



ENGINEERING GEOLOGICAL PLAN

0 10 20 30 40 50 metres

Scale 1:1000 @A2 or 1:1428 @A3



ROCKFALL IMPACT MARKS

NOTES
1. Date of mapping 8/4/98
2. No. of impact marks = 22
3. Date of last pavement seal 1994
4. • Impact mark on road seal

GRAPHIC SCALE

EXPLANATION

Engineering Geological mapping from:
1. Paterson, B.R. 1982
2. Paterson, B.R. 1997

ORIGINAL SCALE

DRAWN
TRACED
CHECKED
REVISION

Riddolls & Grocott Ltd
PO Box 2281 • 47 Hereford Street
Christchurch • New Zealand
Tel + 64 3 377 5696
Fax; + 64 3 377 9944

DRAWING
353/D 7

JOB No
353

REPORT No

PROJECT Use of Risk Assessment Techniques for optimising Slope Failure Preventative Maintenance Programmes (Transfund Reference 0212)

TITLE
Site 2 - SH 73 RP 121/5.100 - 121/5.20. Engineering Geological Plan and Cross Sections, and Rockfall Impact Marks.

Figure 3.6

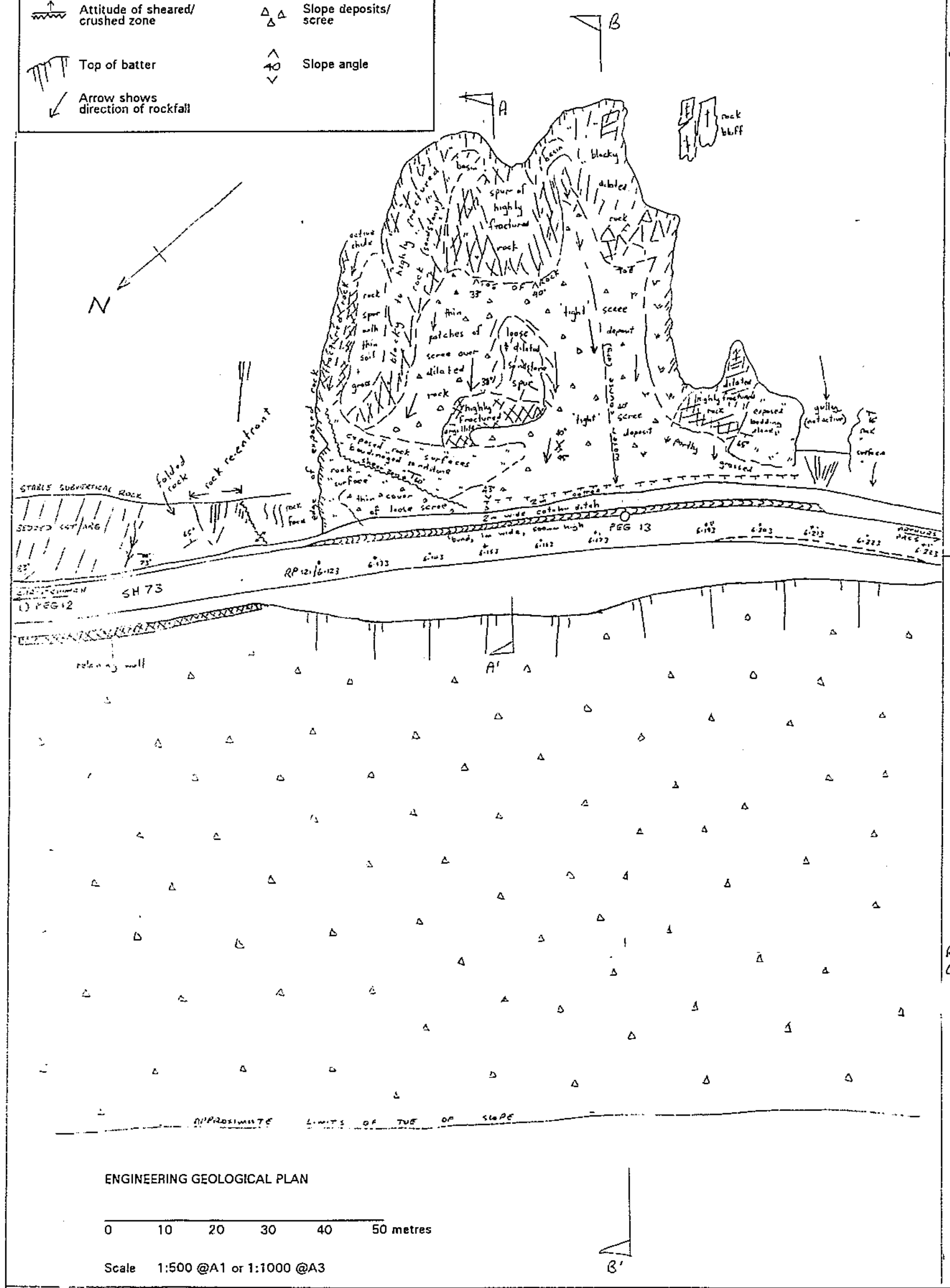
SHEET
of

DATE
August, 1998

ORIGINAL SIZE A2

LEGEND

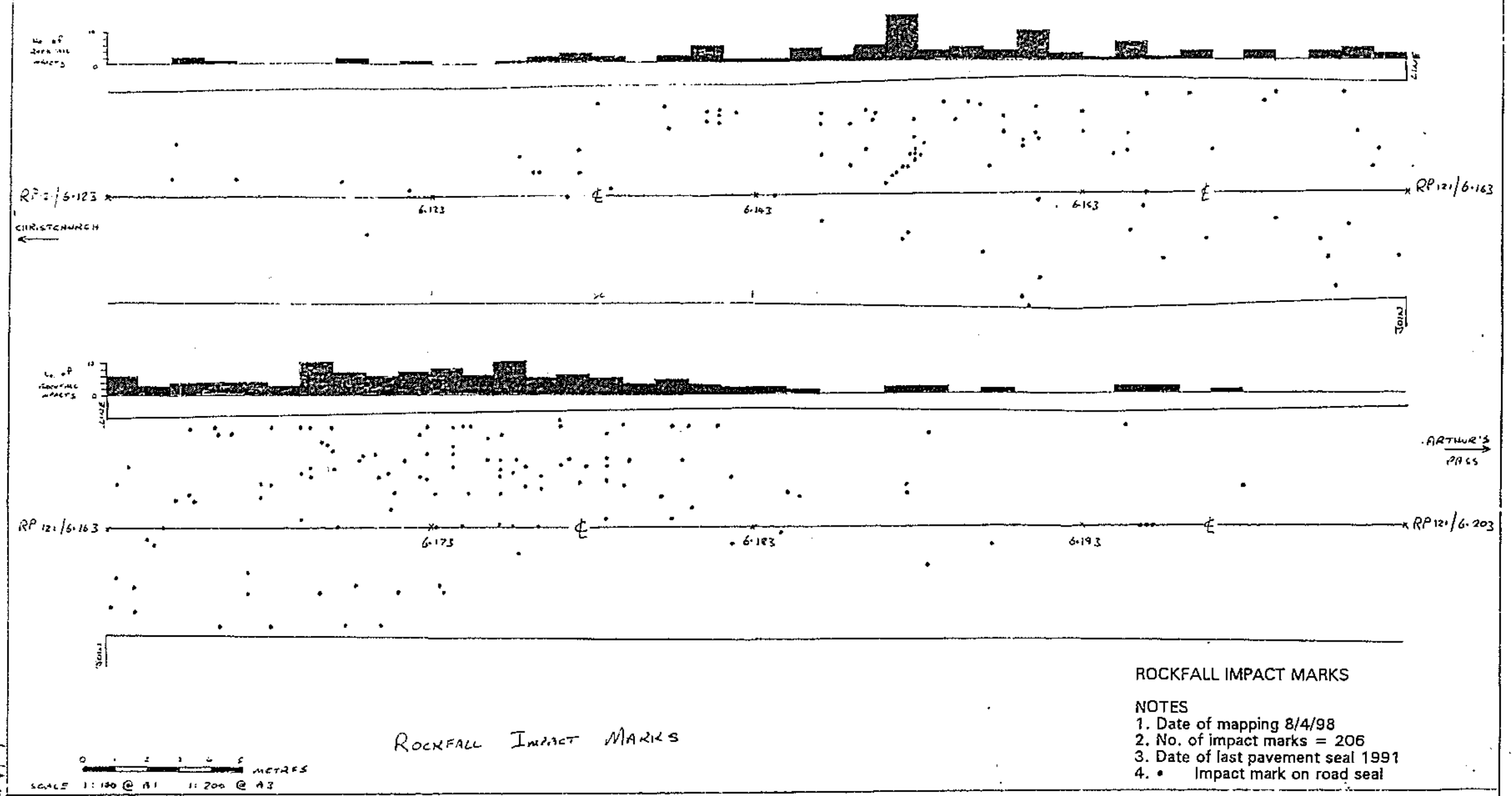
45	Attitude of bedding	ARG	Argillite
80	Attitude of joint	SST	Sandstone
83	Attitude of sheared/ crushed zone	△△	Slope deposits/ scree
	Top of batter	40	Slope angle
↙	Arrow shows direction of rockfall		



ENGINEERING GEOLOGICAL PLAN

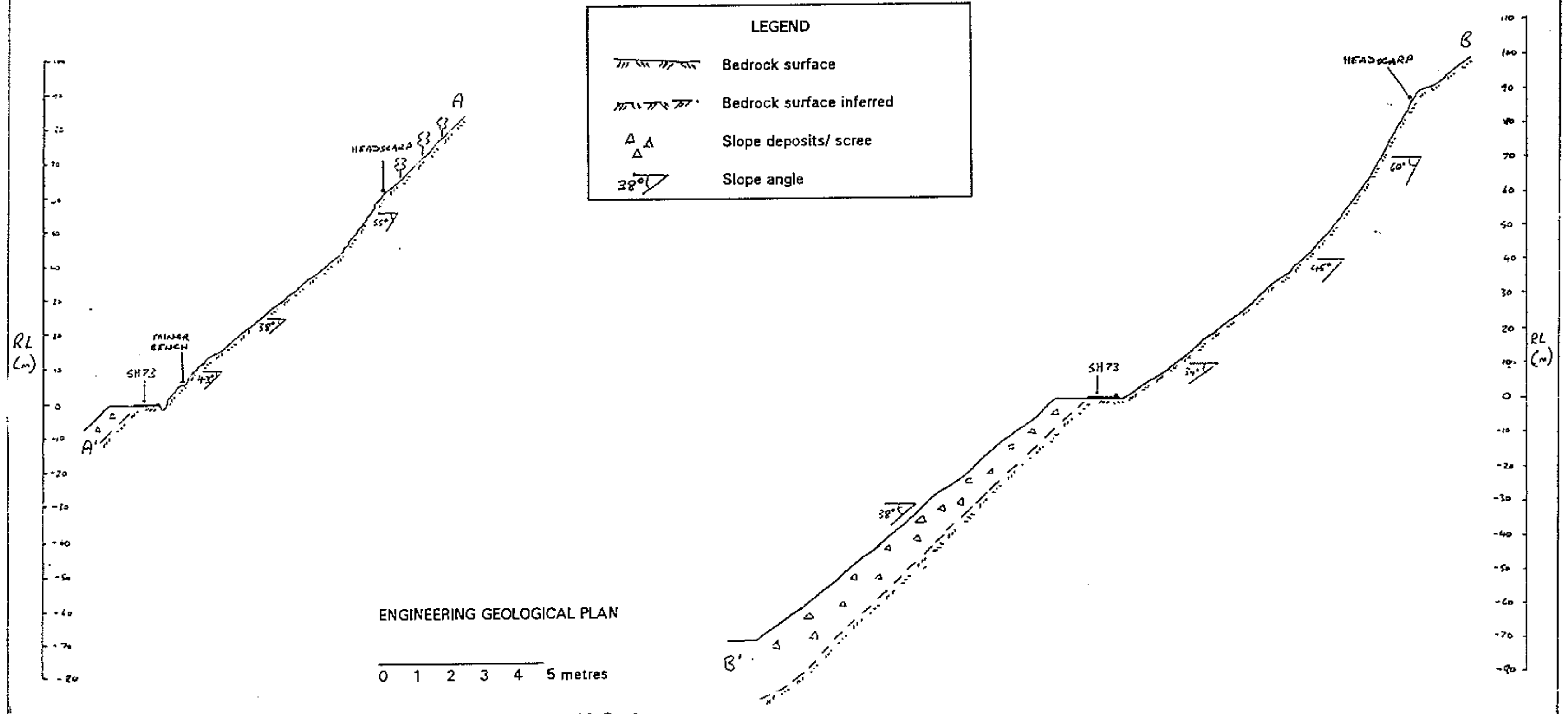
0 10 20 30 40 50 metres

Scale 1:500 @A1 or 1:1000 @A3



ROCKFALL IMPACT MARKS

NOTES
1. Date of mapping 8/4/98
2. No. of impact marks = 206
3. Date of last pavement seal 1991
4. • Impact mark on road seal



LEGEND

	Bedrock surface
	Bedrock surface inferred
△△	Slope deposits/ scree
38°	Slope angle

ENGINEERING GEOLOGICAL PLAN

0 1 2 3 4 5 metres

Scale 1:100 @ A1 or 1:200 @ A3

GRAPHIC SCALE

EXPLANATION

Engineering Geological mapping from:
3. Paterson, B.R. 1982
4. Paterson, B.R. 1997

ORIGINAL SCALE

DRAWN GG
TRACED
CHECKED GG
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DRAWING 353/D8
JOB No 353
REPORT No

PROJECT Use of Risk Assessment Techniques for optimising Slope Failure Preventative Maintenance Programmes (Transfund Reference 0212)

TITLE Site 4 - SH 73 RP 121/6.123 - 121.6.203. Engineering Geological Plan and Cross Sections, and Rockfall Impact Marks.

Figure 3.7

SHEET of

DATE August, 1998

3.3 Road Conditions

3.3.1 Traffic Volumes

The average annual daily traffic (AADT) volume in 1996 was 900, and traffic growth on this stretch of highway was estimated at 3% (Montgomery Watson 1997d).

For the purpose of the economic analysis required to establish the optimum slope-failure maintenance programme (Section 4.2), the AADT is taken as 1500. This is the estimated traffic volume based on 3% per annum growth at year 15 of the 25 year-term over which costs are discounted.

3.3.2 Roading Geometry

A computer run of the study area was done using RG-DAS to evaluate the roading geometry over the highway from RP 121/4.00 - 7.00 (Figure 3.9; Appendix 2).

Here the highway is narrow, winding and passes through rolling (vertical gradients of 3-6%) and mountainous (vertical gradients >6%) terrain. The scope for minor improvements to horizontal alignments is limited because of the terrain. Horizontal curves have tight radii and have steep rock bluffs above their inside edges, resulting in poor horizontal sight distances.

These poor geometric conditions result in an increased risk of traffic accidents, which is exacerbated by the surprise element of rockfall instability.

3.3.3 Reported Accidents

Accident reports of the Land Transport Safety Authority (LTSA), Transit New Zealand and their network management consultant for this section of highway have been reviewed (Montgomery Watson 1987d), and are summarised in Table 3.2.

Table 3.2 Summary of reported accidents.

Crash Database	No. of Accidents in Highway Section	No. of Accidents Attributable to Rockfall
LTSA: 1980 - present	31	0
Montgomery Watson/ Transit NZ	23	1

The one reported accident in the 17-year reporting period that was attributed to rockfall occurred at 16:00 hours on 3 June 1995, when a Greymouth-bound "vehicle ran into a large boulder that landed on the road directly in front of vehicle. No time to stop". The route position was recorded as RP 121/6.02 which is directly east of "Paddy's Bend", but the accuracy of the route position of the accident site has not been able to be verified. The incident was a non-injury accident.

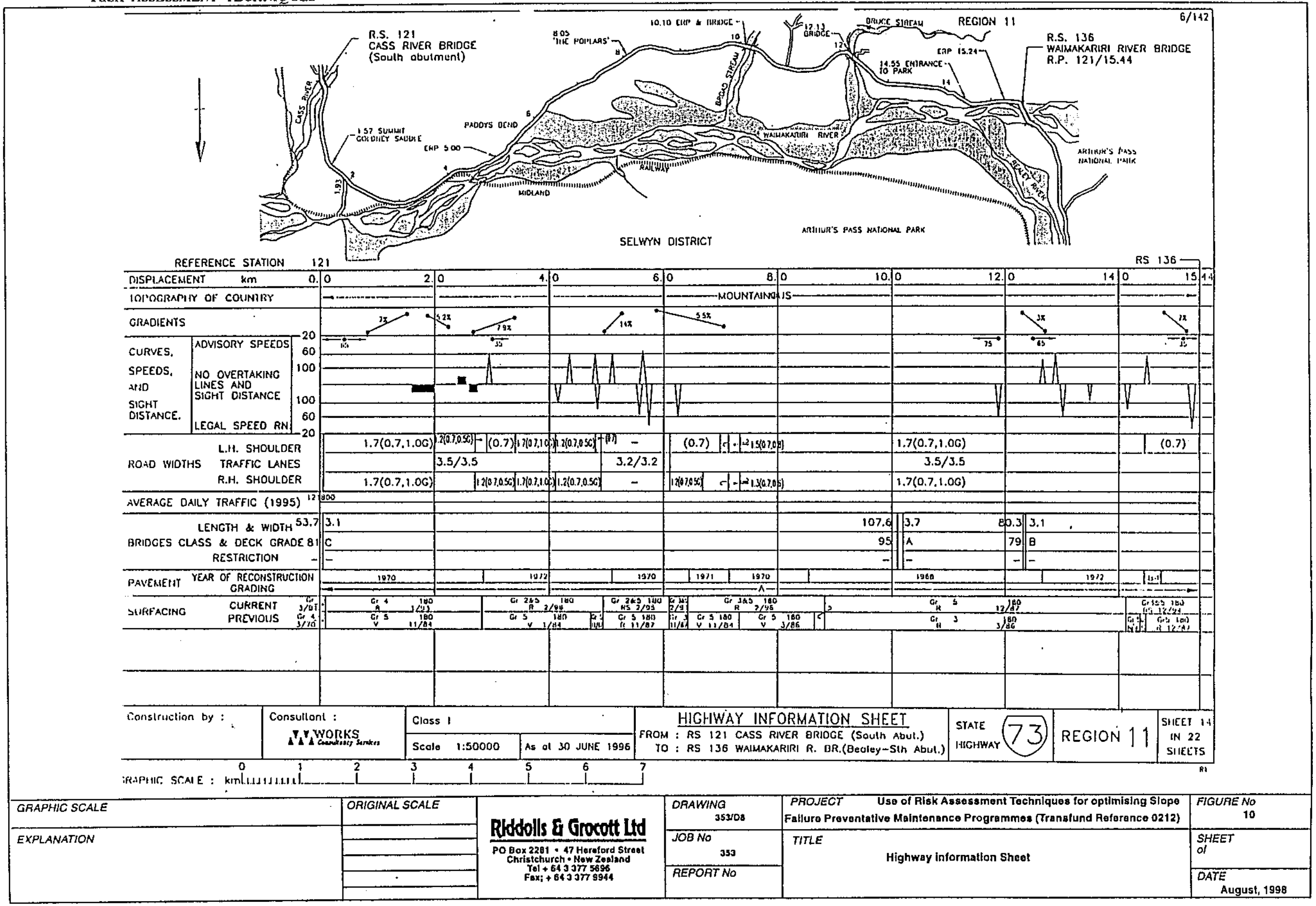


Figure 3.9 Highway information sheet for study area.

The large number of reported accidents on this section of highway caused by factors other than rockfall have included several fatal accidents and minor injury accidents. Generally these have been attributable to the difficult geometry of the road along this section of highway and to poor road conditions at the specific time of accident (including slippery road surfaces and recently sealed surfaces).

3.3.4 Unreported Accidents

Interviews have been held with highway maintenance staff (past and present), Transit New Zealand's network management consultant, garage and tow truck operators at Arthur's Pass and Springfield, Arthur's Pass police, TranzRail staff located at Cass, and the Bealey Hotel publican (summarised in Appendix 3).

The interviews have confirmed that a large number of unreported non-injury accidents on an ongoing annual basis are experienced on this section of highway. An estimated 30 to 35 non-injury accidents/year occur between sites 1 and 5 caused by rockfall, involving tyre punctures and blow outs, broken windows, dented panels, and punctured sumps and petrol tanks. They require tow truck or mechanic assistance from Arthur's Pass or Springfield.

Additional unreported, non-injury accidents not requiring tow truck or mechanic assistance also occur. The number could not be estimated but must be considerable given the number of accidents requiring assistance. Conservatively at least five unreported non-injury accidents not requiring assistance occur each year, making a total of 35 to 40 unreported, non-injury accidents per year for this section of SH73.

Of the estimated 35 to 40 unreported non-injury accidents per year on this section of SH73, the estimated number of accidents at sites 2 and 4 has been based on the frequency of rockfalls (Section 3.4.1) and personal interviews (Appendix 3), summarised in Table 3.3.

Table 3.3 Summary of unreported non-injury accidents caused by rockfall on SH73 study section.

Site No.	No. of Unreported Non-injury Accidents/Year	% All Unreported Non-injury Accidents for Study Area
2	5	15
4	24	60
All other sites	5	25
Total	**34**	**100**

In addition to these unreported non-injury accidents detailed in Table 3.3, the interviews have identified at least two fatal accidents on this section of highway in the 1970s (Graeme Nimmo, Paddy Freaney: Appendix 3). Their cause has not been determined but, in at least one case, the accident occurred during severe north-west storm conditions, leaving open the question that rockfall-related factors may have contributed.

While no reported injury (minor, serious or fatal) accidents have been attributed to slope instability at the study area, the adverse road conditions pertaining to this stretch of SH73 (Section 3.3.2), combined with the considerable frequency of rockfall events (Section 3.4.1), indicate that such accidents are a high probability.

To account for the expected cost of injury accidents, the likely frequency of both injury and non-injury accidents has been estimated using the risk analysis method of Roberds (1991) on the basis of the frequency of slope instability (Section 3.4.1). Discussion of the risk analysis methodology and a summary of the expected number of accidents are provided in Section 3.4.3 and Table 3.8 respectively.

3.3.5 Existing Maintenance Programme

Maintenance records for the 8 km length of SH73 between RP 121/2.00 -10.00 have been reviewed to provide an estimate of maintenance work and costs (Montgomery Watson 1997d). This length of highway is presently identified as a "problem surface detritus site" (Montgomery Watson 1997d), and is subject to regular cleaning of surface detritus under a Pavement, Drainage, and Emergency Callout Contract which in 1998 was carried out by Works Civil Construction Ltd.

Maintenance work involves detritus clearing at the following frequencies: January - March, 0.5 visits per day; April - September, 2 visits per day; October - December, 1.5 visits per day, making a total of approximately 550 visits per year. Maintenance work over the 8 km section of highway is carried out at a fixed cyclic cost of \$5.00[2] /km/month for an annual total cost of only \$480 (Montgomery Watson 1997d).

In addition to detritus clearing, the contractor is also required to respond urgently to the clearance of large rockfalls and slips. Typically some 10 call outs of this type are made per year at a total annual cost of \$4,800 (\$480 per call out) (Montgomery Watson 1997d).

Transit New Zealand's network management consultant and network maintenance contractor both consider that, because the fixed cyclic cost contract is spread over the entire highway, the cost of \$5.00 /km/month is a significant under-statement of the true cost of detritus clearing (Appendix 3). The network management consultant has estimated that the actual cost based on plant hire and labour is in the range of \$84 to \$140 per site visit. Based on the frequency of rockfall activity (Section 3.4.1), the number of visits to sites 2 and 4 for detritus clearing and rockfall call outs has been estimated, together with the total annual cost for maintenance based on the actual cost of plant hire and labour, and are listed in Table 3.4).

---

[2] All costs are in 1998 NZ\$.

Table 3.4 Summary of maintenance visits and costs to SH73 study sections.

Site No.	No. of Visits / Year for Detritus Clearing	No. of Visits / Year for Rockfall Call Outs	Annual Maintenance Cost (1998 NZS)		
			Minimum	Most Likely	Maximum
2	138	1	960	12,072	19,800
4	523	7.5	4,080	47,532	76,820

3.3.6 Service Disruption

Costs for service disruption (road closure) are based on vehicle operating costs, travel time costs and accident costs for the additional travel time when traffic is required to use alternative routes which, in the case of SH73, would be SH7 over Lewis Pass.

Three events have resulted in road closure at this section of highway as a result of slope instability effects. Two are the 1994 Arthur's Pass and 1995 Mt White earthquakes, when considerable sections of SH73 between Cass and Otira were closed for several days by rockfall activity. The third is a rock slide known to have closed the road for a short period (hours) in the 1970s (Paddy Freaney, Appendix 3), but the exact duration is not known.

However, the highway is not subject to regular closures caused by slope instability effects, and therefore the actual time delays related to this cause on an annualised basis are assumed to be low, of the order of 1 - 2 hours per year.

The costs for service disruption have been assumed to be the same as that for the Candy's Bend (RP 151/3.93) to Starvation Point (RP 151/4.78) section of SH73, calculated as $74,600 per day, adjusted to 1998 NZ$ (Opus International Consultants Ltd 1997a, b).

3.4 Risk Assessment

3.4.1 Failure Modes

Based on interviews with road maintenance staff involved with this stretch of highway since 1971 (reported in Appendix 3), the characteristics of each mode of failure at sites 2 and 4 together with their frequency of occurrence have been estimated (Tables 3.5 and 3.6).

To provide a further assessment of the frequency of rockfalls, the number and distribution of rockfall impacts on the road pavement have been mapped, to compare with Tables 3.5 and 3.6 which have been derived by means of personal interviews (Appendix 3). Rockfall impact marks are isolated, concave depressions in the pavement surface, and their distributions are illustrated on Figures 3.6 and 3.7.

Table 3.5 Summary of slope instability characteristics at Site 2, SH73 study site.

Failure Mode	Block Diameter (mm)	Estimated Volume (m^3)	Frequency of Occurrence*	Probability Distribution
F1: Rockfall	0-150	–	293	triangular
F2: Rockfall	150-300	–	150	triangular
F3: Rockfall	300-500	–	5	discrete
F4: Rockfall	>500	–	2	discrete
			450	

* Discrete events per year which impact the road, in terms of expected value; frequency distributions for each failure mode are provided on Worksheet 1 in Appendix 7.

Table 3.6 Summary of slope instability characteristics at Site 4, SH73 study site.

Failure Mode	Block Diameter (mm)	Estimated Volume (m^3)	Frequency of Occurrence*	Probability Distribution
F1: Rockfall	0-150	–	2,025	triangular
F2: Rockfall	150-300	–	570	triangular
F3: Rockfall	300-500	–	30	discrete
F4: Rockfall	>500	–	5	discrete
F5: Rock slide	–	<100	0.2	–
			2,630.2	

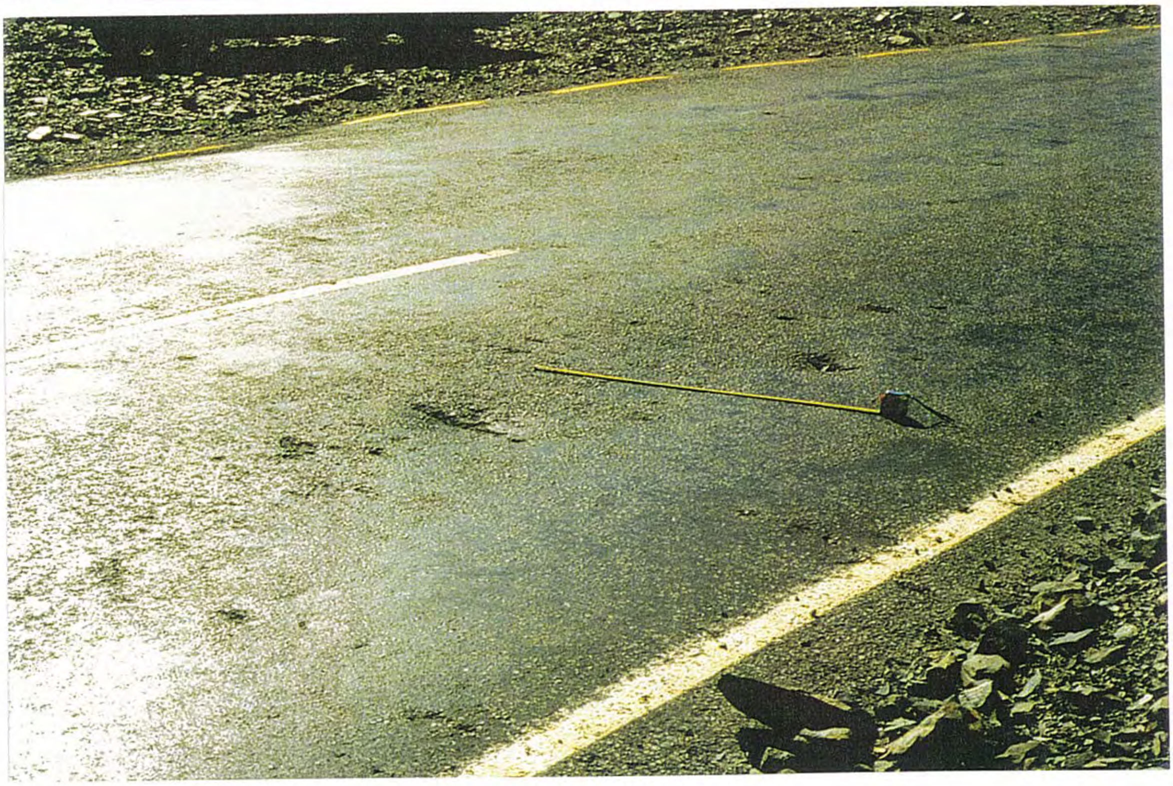
* Discrete events per year which impact the road, in terms of expected value; frequency distributions for each failure mode are provided on Worksheet 1 in Appendix 8.

At site 2, 22 impact marks have been mapped, all of which with one exception occur on the inside lane of the road. This equates to 5.5 rockfall events per year of a size significant enough to form impact marks, given that the pavement was last resealed in 1994.

At site 4, approximately 206 impact marks occur on the 7 year-old pavement surface. This equates to some 30 events occurring per year in which block sizes are significant enough to cause the formation of an impact mark. At this stretch of road, the impacts occur on both inside and outside lanes, but with a concentration on the inside lane indicating that this part of the carriageway is at greater risk of impact (Figure 3.10).

At both sites 2 and 4, the number of impact marks are significantly less than the frequency of rockfall events determined through interviews of road maintenance personnel (Tables 3.5 and 3.6). A number of reasons account for this, including that blocks are not all of sufficient size to generate impact marks, and not all blocks will hit the road surface on full impact. This latter reason is considered to be the principal factor, as rockfall modelling shows that most rocks roll or bounce across the highway without impacting the pavement surface on the full (Appendix 4).

Figure 3.10 Rockfall impact marks at Site 4.
Inside lane closest to cut batter is in foreground.



Therefore the results of personal interviews as summarised in Tables 3.5 and 3.6 are assumed to be a more accurate reflection of the actual frequency of rockfall activity than impact marks, as the very high frequency of site visits by road maintenance personnel mean that, in this case, the level of first hand site-specific information is very high. Furthermore, all interviewed personnel are reasonably consistent in their assessment of the frequency of rockfall activity.

3.4.2 Relative Risk for Sites 1, 2, 3, 4 and 5

To assess the relative risk of slope instability effects at sites 1, 2, 3, 4 and 5 on road users, the Rockfall Hazard Rating System (RHRS) (Section 2.1) has been applied to these slopes (Appendix 5), and the results are summarised in Table 3.7. The RHRS takes into account a number of factors to derive the relative risk rating, including:

- Height of slope above the road at risk;
- Effectiveness of any ditch at the toe of the slope for rockfall control;
- Percentage of time that a vehicle will be present in the hazard area, termed the average vehicle risk (AVR);
- Percentage of decision sight distance (DSD); DSD is length of road way that a driver must have to make an instantaneous decision;

- Road way width including paved shoulders;
- Geotechnical characteristics of the site, such as the condition of the rock mass defects;
- Rockfall characteristics such as the block size/volume and frequency of falls;
- Rainfall and site water conditions.

Table 3.7 Summary of rockfall hazard ratings for SH73 study site.

Site No.	Rating
1	551
2	645
3	401
4	566
5	377

A limitation of the RHRS is that it does not include recommendations on actions to be taken for different ratings (Section 2.1). However, based on personal communications with the principal author of the RHRS (Mr Lawrence Pierson), slopes with relative risk ratings < 300 are assigned a very low priority, while slopes with ratings > 500 are identified for urgent remedial attention.

Significantly, three of the sites (sites 1,2,4) have ratings in excess of 500, with sites 2 and 4 which have been chosen for detailed study having the highest ratings. The very high rating for site 2 is attributable to its very short site distance to minimum decision sight distance ratio. On the basis of the RHRS methodology, sites 1,2 and 4 would receive urgent remedial attention.

3.4.3 Risk Analysis for Sites 2 and 4

To estimate the risk to road users from slope instability, the method of Roberds (1991) requires consideration of both the probability of a slope failure occurring, P(F), and the probability of a consequence occurring given failure has occurred, P(C|F). The overall probability of a consequence occurring, P(C), is therefore given by :

$$\mathbf{P(C) = P(F) \times P(C|F)} \qquad (1)$$

The annual probability of failure, P(F), for each failure mode is taken directly from Tables 3.5 and 3.6 for sites 2 and 4 respectively. The values of P(F) are uncertain and are best represented in the form of a probability distribution. Triangular distributions (i.e. minimum, most likely, maximum) are used for failure modes F1 and F2 as a large number of failures occur per year. Discrete probability distributions are more applicable for failure modes F3 and F4 (at sites 2 and 4) and F5 (at site 4 only), of which very few occur annually.

Table 3.8 Estimation of probability of an accident occurring, given that rockfall has occurred. P(C|F) for Sites 2 and 4; Average Daily Traffic = 1500 (predicted)

A falling rock can cause an accident in two ways:

1. Rock hits moving vehicle

Probability of Accident	
Average vehicle length, Lv,(m)	5.4
Speed Limit, Vv, (km/hr)	100
Average daily traffic, Nv	1500
900 in 1996 + 3%pa=1500 in yr 15	
P(rock hits individual vehicle)	**0.0017**
(Nv x Lv / 24000 / Vv/2)	

Probability of each accident type		
Type of Accident	Fraction of total probability	p(C|F)
C6 Non injury	0.9896	1.67E-03
C5 Minor	0.009	1.52E-05
C4 Serious	0.0009	1.52E-06
C3 Fatal	0.00050	8.44E-07
Checksums	*1.000000*	*0.0017*

2. Vehicle hits rock on road

Probability of accident	
Average Speed. Vv (km/hr)	100
Average daily traffic, Nv	1500
900 in 1996 + 3%pa=1500 in yr 15	
Decision Site Distance, Ldsd (m)	330
P(vehicle hits rock) (all failure modes)	0.0258
(Nv x (Ldsd/2) / 24000 / Vv/2)	

Probability of each accident type		
Type of Accident	Fraction of total probability	p(C|F)
C6 Non injury	0.9896	2.55E-02
C5 Minor	0.009	2.32E-04
C4 Serious	0.0009	2.32E-05
C3 Fatal	0.00050	1.29E-05
Checksums	*1.000000*	*0.0258*

SUM

Total probability of each accident type			
Type of Accident	Probability of accident given failure	Probability of accident given failure for each failure mode *	
		Site 2	Site 4
	P(C|F)	P(C|F)/4	P(C|F)/5
C6 Non injury	2.72E-02	6.80E-03	5.44E-03
C5 Minor	2.47E-04	6.18E-05	4.94E-05
C4 Serious	2.47E-05	6.18E-06	4.94E-06
C3 Fatal	1.37E-05	3.43E-06	2.75E-06

* Assume same risk for each failure mode

To determine the probability of an adverse consequence if slope failure has occurred, P(C|F), the following consequences, assuming the various failure modes identified in Tables 3.5 and 3.6, have been considered:

C1	Detritus clearance
C2	Service disruption (i.e. temporary road closure)
C3	Fatal accident
C4	Serious accident
C5	Minor accident
C6	Non-injury accident

The annual probability of a consequence occurring given failure, P(C|F), for C1 detritus clearance, and C2 service disruption, has been back-calculated from maintenance records discussed in Section 3.3.5.

Estimated values of P(C|F) for the different classes of traffic accident, C3 to C6 detailed in Section 3.4.3 (Table 3.8), have been derived following the methodology of Bunce et al. (1997). This approach is based on consideration of the proportion of time that a vehicle occupies the portion of road potentially affected by rockfall activity.

The risk that a vehicle is hit by a falling rock and a vehicle hits a fallen rock have been determined independently and the total risk from rockfall is the sum of the two.

The derived values of P(C|F) are presented in Table 3.8, for which a judgement has been made for the fraction of total risk attributable to each accident type. The values of P(C|F) are uncertain and are best represented as a triangular probability distribution.

The probability of a consequence occurring, P(C), may therefore be obtained using equation 1, and summed to give P(C) for all failure modes. This calculation is carried out in Worksheets 1 for site 2 (Appendix 7) and site 4 (Appendix 8), and summarised in Table 3.9.

Table 3.9 Summary of expected consequences, P(C), for Sites 2 and 4, SH73 study site.

Consequence: Accident Type	**No. of Accidents / Year (No. / 100 Years) for AADT of 1500**	
	Site 2	**Site 4**
C3 : Fatal	0.005 (0.5)	0.027 (2.7)
C4 : Serious	0.008 (0.8)	0.048 (4.8)
C5 : Minor	0.082 (8.2)	0.481 (48)
C6 : Non-injury	9.06 (906)	52.94 (5294)

4. RISK MITIGATION PROGRAMMES SUITABLE FOR CASE STUDY

4.1 Possible Slope-Failure Maintenance Programmes for Risk Mitigation

For sites 2 and 4 of the case study, a range of maintenance activities for mitigation of slope-failure risk have been identified. One or more activities have been combined to form individual maintenance programmes (Table 4.1).

Table 4.1 Summary of slope-failure maintenance activities and programmes for SH73 study sites 2 and 4.

Maintenance Programme	**Maintenance Activities**									
	Detritus and rockfall clearance	Monitoring	Scaling	Rock bolting	Gabion-wall rockfall catch fence	Wire mesh rockfall catch fence	Wire mesh (netting) protection	Road realignment	Earthworks	Concrete rockfall shed
Site 2: M0	●									
M1		●								
M2			●							
M3			●	●	●					
M4			●	●			●	●		
M5			●	●			●		●	
Site 4: M0	●									
M1		●								
M2						●				
M3			●	●	●					
M4			●	●			●			
M5										●

4.1.1 Descriptions of Maintenance Activities

Detritus and Rockfall Clearance

For both sites 2 and 4, the unmitigated (baseline) option (M0) is taken to represent the existing detritus clearing, and rockfall- and slip-call out maintenance programme (Section 3.3.5). (For site 4, the M0 maintenance programme also incorporates the mitigating effects of the existing 500 mm-high rock-fill bund on the inside of the road (Section 3.2.2)).

Monitoring
As indicated in Table 1.1, this is a reactive (or status quo) management approach, and has been included to allow additional comparison of the range of maintenance strategies. This approach involves the monitoring of slope instability by means of video and image-sensing techniques. Such a scheme would entail mounting a video camera on a pole to cover the site distance with image sensing to detect items greater than 150 mm diameter that are stationary on the road, as a warning to road users. The system would also be linked to the Transit New Zealand network maintenance contractor's base as a signal to clear the road.

Scaling
This involves the removal of loose masses of rock from the cut road batter by either hand or mechanical means. Scaling is generally carried out in combination with other activities at both sites (Table 4.1).

Rock bolting
This is the mechanical reinforcement of rock using drilled and fastened 3 m-long rock bolts into a rock face.

Gabion-wall rockfall catch fence
This is the construction of a 2 m-high by 1 m-wide gabion-wall catch fence for protection against rockfall. This option has been considered only at site 4 (Table 4.1), where rockfall computer simulations (Appendix 4) suggest that it will be successful in blocking most possible rockfall events. Such a structure would have only limited capacity to reduce the effects of a rock slide. The gabion wall would have to be constructed a short distance out from the existing toe of the slope, requiring reconstruction of the carriageway as part of this option.

Wire mesh (netting) protection
This option involves the fastening and placement of double twist hexagonal wire mesh over a rock face to prevent the free fall, roll, bounce or slide of rockfall on to the road.

Wire-mesh rockfall catch fence
This involves the construction of a vertical wire-mesh catch fence incorporating horizontal steel cables for reinforcement, as a defence against rockfall and rock roll. These structures, sited at the toe of the cut slope, are considered capable of impeding rockfalls that generate up to 2500 kilojoules of energy.

For both sites 2 and 4, the results of rockfall computer simulations (Appendix 4) have been used to select a fence height of 3 m, to block most rockfalls. However, in the case of site 4, such a structure would have only limited capacity to reduce the effects of a rock slide.

Road realignment
At site 2, deviation of the road on a new alignment offset that is approximately 7 - 8 m from the existing one, towards the Waimakiriri River, has been considered. It would increase the separation between the existing cut slope and the road.

Earthworks
At site 2, a 10 m excavation (in plan distance) of the existing cut slope has been considered to provide a greater separation between the existing road and the cut slope.

Concrete rockfall shed
At site 4, a reinforced concrete rockfall shed has been considered, similar to the structures constructed in Europe and North America as avalanche sheds. This would be designed to mitigate the effects of all slope instabilites, including rockfall and rock slides.

4.1.2 Effectiveness of Maintenance Programmes

The effectiveness (E) of each maintenance programme in reducing the frequency of failures, P(Fx), or in reducing the consequences of each failure mode, Cx, has been estimated. The effectiveness of each maintenance activity is uncertain, and is best expressed in terms of a probability distribution. A normal distribution truncated at 0 and 1 with standard deviation of 0.2 about the mean estimate is used. Effectiveness is expressed quantitatively in terms of the fractional reduction in both failure probability P(F), and probability of a consequence given failure, P(C|F), from the unmitigated (baseline) case. The effectiveness estimates, P(Fx) and Cx, are summarised in Tables 4.2 and 4.3, and are given in the respective Worksheets 2 in Appendices 7 and 8 for sites 2 and 4.

4.2 Optimum Slope-Failure Maintenance Programme

Rough order costs for each maintenance programme including both one-off implementation costs as well as annual costs for routine maintenance are summarised in Appendix 6. These costs are discounted to a single PV. Cost uncertainty is accommodated by applying triangular probability distributions (i.e. lowest, most likely and highest costs).

Based on the costs and consequences of each maintenance programme applied to each slope, the most cost-efficient programme can be identified. This is achieved by comparing the total equivalent cost (TEC) (Section 2.2.4) for each maintenance programme in one of two ways, namely the maintenance programme with the lowest total equivalent cost (Section 4.2.1), and determination of the maintenance programme with the greatest probability of being the cheapest (Section 4.2.2).

Table 4.2 Effectiveness of slope-failure preventive maintenance programmes in reducing failure frequency, and/or in mitigating failure consequence, for Site 2 of SH73 study site. (From Worksheet 2, Appendix 7)

	Mean Fractional Reduction in P(Fx) and Cx for Maintenance Programme					
	M0	M1	M2	M3	M4	M5
Failure modes						
F1 : Rockfall	0.00	0.00	0.25	0.95	0.60	0.60
F2 : Rockfall	0.00	0.00	0.40	0.99	0.70	0.70
F3 : Rockfall	0.00	0.00	0.60	0.99	0.75	0.75
F4 : Rockfall	0.00	0.00	0.80	0.99	0.85	0.85
Consequences						
C1 : Detritus Clearance ($ /year)	0.00	0.00	0.00	0.00	0.95	0.95
C2 : Service Disruption (h /yr)	0.00	0.00	0.00	0.00	0.95	0.95
C3 : Fatal Accidents (no. /year)	0.00	0.85	0.00	0.00	0.96	0.99
C4 : Serious Accidents (no. /year)	0.00	0.75	0.00	0.00	0.96	0.98
C5 : Minor Accidents (no. /year)	0.00	0.60	0.00	0.00	0.93	0.98
C6 : Non-injury Accidents (no. /year)	0.00	0.50	0.00	0.00	0.90	0.95

Table 4.3 Effectiveness of slope-failure preventive maintenance programmes in reducing failure frequency, and/or in mitigating failure consequence for Site 4 of SH73 study site. (From Worksheet 2, Appendix 8)

	Mean Fractional Reduction in P(Fx) and Cx for Maintenance Programme					
	M0	M1	M2	M3	M4	M5
Failure modes						
F1 : Rockfall	0.00	0.00	0.00	0.95	0.00	0.00
F2 : Rockfall	0.00	0.00	0.00	0.99	0.00	0.00
F3 : Rockfall	0.00	0.00	0.00	0.99	0.00	0.00
F4 : Rockfall	0.00	0.00	0.00	0.99	0.00	0.00
F5 : Rock slide	0.00	0.00	0.00	0.10	0.00	0.00
Conseqnences						
C1 : Detritus Clearance ($ /year)	0.00	0.00	0.90	0.00	0.95	1.00
C2 : Service Disruption (h /yr)	0.00	0.00	0.90	0.00	0.95	1.00
C3 : Fatal Accidents (no. /year)	0.00	0.85	0.95	0.00	0.96	1.00
C4 : Serious Accidents (no. /year)	0.00	0.75	0.95	0.00	0.96	1.00
C5 : Minor Accidents (no. /year)	0.00	0.60	0.90	0.00	0.93	1.00
C6 : Non-injury Accidents (no. /year)	0.00	0.50	0.88	0.00	0.90	1.00

4.2.1 Maintenance Programme with Lowest Total Equivalent Cost

In Section 3.4.3 the probability of a consequence occurring, P(C), was estimated for sites 2 and 4, assuming no change in the existing failure maintenance strategy (M0), summarised in Table 3.9 and the respective Worksheets 1 in Appendices 7 and 8.

The "adjusted" probability of each consequence occurring, P(C), has now been calculated for each maintenance programme that is listed in Table 4.1, allowing for the effectiveness (E) of each programme provided in Tables 4.2 and 4.3. These calculations are carried out on separate Worksheets 3 to 7 provided in Appendices 7 and 8 for sites 2 and 4 respectively. The adjusted P(C) values for each maintenance option are converted to NZ$1998 to derive "The Total Annual Cost of Consequences", and discounted over 25 years to derive a present value (PV), as indicated on the respective Worksheets 8 in Appendices 7 and 8.

The cost of each maintenance programme is also discounted over 25 years to derive a present value. A "Total Equivalent Cost" for each maintenance option is obtained by summing the present value "Total Cost of Consequences" and the present value cost of each maintenance programme (Worksheets 8, Appendices 7 and 8).

Following Monte Carlo simulation (1000 realisations), the maintenance programme with the lowest expected value of total equivalent cost (Table 4.4) would normally be selected subject to any resource constraints and subject to the mitigated risk being "acceptable" (Section 4.3), as illustrated in the respective Worksheets 8 in Appendices 7 and 8 for sites 2 and 4. If this maintenance programme does not reduce consequences to acceptable risk levels, the programme with the next lowest expected TEC would be selected, and so on.

Table 4.4 Summary of the expected value of the total equivalent cost (NZ$ 1998) for all slope-failure maintenance programmes.

	Slope-Failure Maintenance Programme (NZ$1998)					
Site	M0	M1	M2	M3	M4	M5
2	433,007	395,563	341,870	264,306	392,210	1,245,586
4	2,539,440	1,914,674	665,825	717,617	846,341	1,652,054

4.2.2 Maintenance Programme with Greatest Probability of Being Cheapest

Alternatively, the maintenance programme which has the greatest probability of being the cheapest may be determined by comparing each programme against all the others. Following Monte Carlo simulation (1000 realisations), the probability that each option will be the cheapest may be determined. This may or may not be the option with the lowest total equivalent cost. This calculation is carried out on the respective Worksheets 9 in Appendices 7 and 8 for sites 2 and 4, and summarised in Table 4.5.

Table 4.5 **Summary of slope-failure maintenance programme which has the greatest probability of being the cheapest.**

	Slope-Failure Maintenance Programme					
Site	M0	M1	M2	M3	M4	M5
2	4.20	2.40	20.40	72.60	0.40	0.00
4	0.00	0.00	49.20	38.20	12.60	0.00

4.2.3 Selection of Optimum Slope-Failure Maintenance Programme

The optimum maintenance programme for each site determined by the two different procedures, provided in Sections 4.2.1 and 4.2.2, is summarised in Table 4.6.

Table 4.6 **Selection of optimum slope-failure maintenance programme.**

Site	Lowest total equivalent cost	Greatest probability of being cheapest
2	M3	M3
4	M2	M2

In this case, the different methods of selecting the optimum maintenance programme produces the same outcome. However, this may not necessarily be the result in every case for other sites.

4.2.4 Comparison with Selection of Slope-Failure Maintenance Programme Based on Benefit/Cost Analysis

The benefit/cost ratios for each maintenance programme have also been computed in the respective Worksheets 8 of Appendices 7 and 8 for sites 2 and 4, and are summarised in Table 4.7.

Table 4.7 **Summary of the benefit/cost ratios for all slope-failure maintenance programmes.**

	Slope-Failure Maintenance Programme					
Site	M0	M1	M2	M3	M4	M5
2	1.00	1.25	2.69	1.89	1.12	0.33
4	1.00	2.26	13.42	7.75	5.66	1.56

The programme with the lowest TEC (from Table 4.4) and the greatest probability of being the cheapest (Table 4.5) will not necessarily have the highest B/C ratio (Table 4.7). The maintenance programme selected by the two former methods represents the most effective solution in terms of net benefits, while the later represents the best return on expenditure.

As an alternative to selecting the maintenance programme with the lowest TEC or the greatest probability of being the cheapest, the programme with the highest B/C ratio may be selected subject to the associated reduction in risk being acceptable (Section 4.3). If this maintenance programme does not reduce the risks to acceptable levels, the programme with the next highest B/C ratio would be selected, and so on.

B/C ratios are also useful to compare the cost-effectiveness of maintenance programmes with those at other sites and are routinely used by Transfund New Zealand for prioritising expenditure on highway improvements.

4.3 Comparison of Assessed Risk with Acceptable Risk for Sites 2 and 4

4.3.1 Present Risk

To assess if the risk posed to SH73 road users from slope instability at sites 2 and 4 is acceptable, the probability of a fatal accident has been estimated for the present case and compared with acceptable risk guidelines. This risk has been calculated as the combined risk of a death to a road user from a moving vehicle being hit by a falling rock, and a moving vehicle hitting a fallen rock. The method proposed by Bunce et al. (1997) has been used to calculate risk levels.

Risk acceptability guidelines have been promulgated by a number of individuals and organisations including Morgan et al. (1992) who suggested that the annual probability of death to an individual, P(DI), accepted by society is less than 1×10^{-4}. Fell (1994) considered an annual P(DI) of less than 1×10^{-5} might be acceptable, and Ale (1991) has suggested P(DI) between 1×10^{-6} and 1×10^{-8}. The so-called "Proposed BC Hydro Societal Risk" is a widely recognised risk guideline for the annual probability of fatalities caused by dam failures, which sets a P(DI) limit of 1×10^{-4} deaths per year (one death per 1000 years). Consensus is also developing that this risk guideline also defines the limit between voluntary and involuntary risk (Nielson et al. 1994).

Figure 4.1 is a summary of the risks accepted by society for a range of different activities. For comparison purposes, the risk of a fatal accident at sites 2 and 4 for an individual road user, P(DI), has been calculated for the present case of 900 AADT, based on the methodology detailed in Section 3.4.3 and the results are shown on Figure 4.1. Figure 4.1 is subdivided into voluntary and involuntary risk; the former is considered to reflect a single trip per year (say for example a holiday maker travelling to the West Coast), while involuntary risk has been based on say 500 trips per year ($P(DI_{500})$) which would be the case for a freight truck operator returning daily between Christchurch and the Coast.

Figure 4.1 Probability of death of an individual at Sites 2 and 4, compared with involuntary and voluntary social activities (from Bunce et al. 1997).

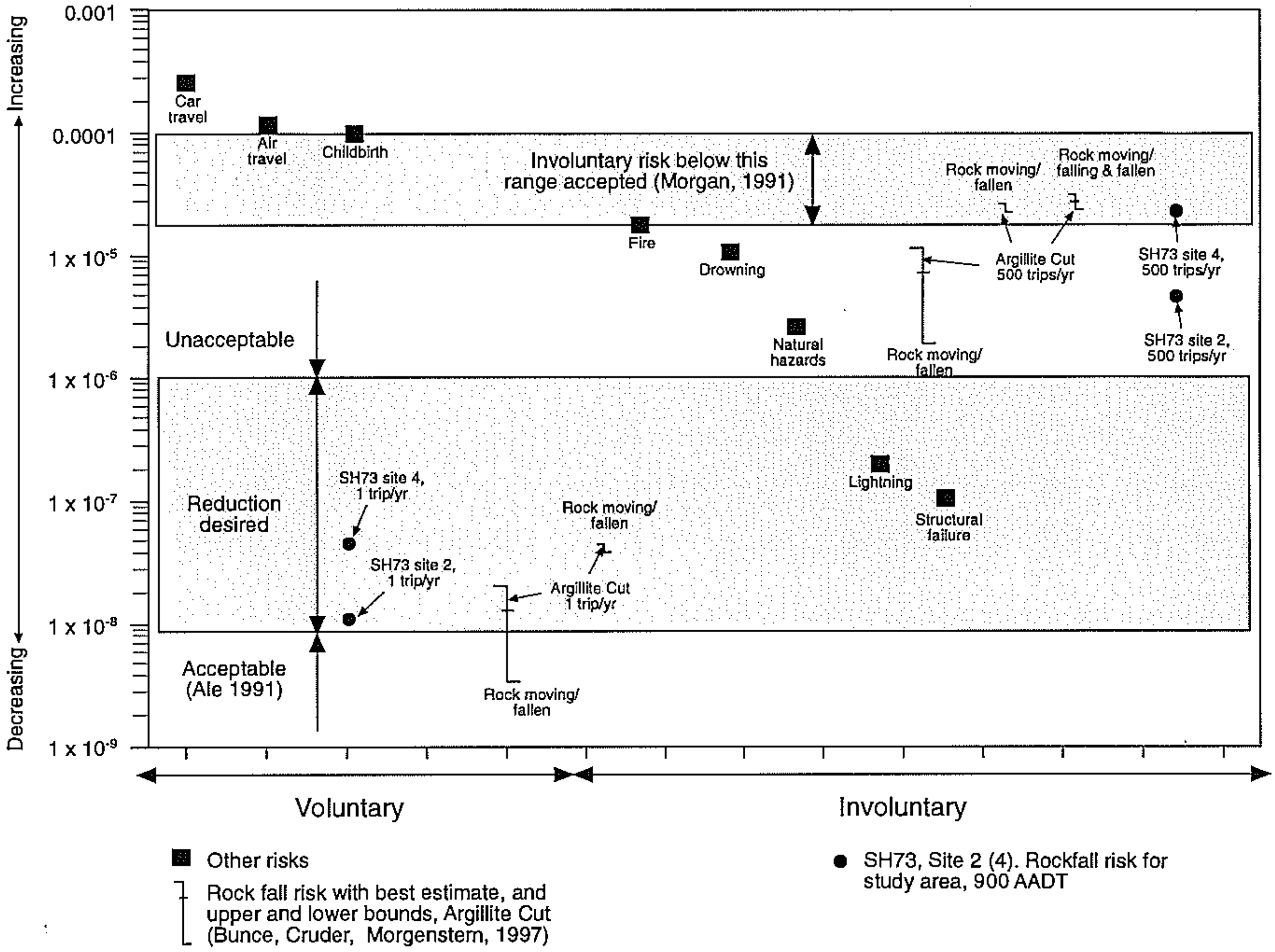


Table 4.8 Mitigated risk of a fatal accident at Sites 2 and 4.

Slope Failure Maintenance Programme		Risk of Fatal Accident / Trip P(DI), 1500 AADT	Risk of Fatal Accident / 500 Trips P(DI_{500}), 1500 AADT
Site 2:	M0	8.4 x 10^{-9}	4.2 x 10^{-6}
	M1	1.9 x 10^{-9}	9.4 x 10^{-7}
	M2	5.6 x 10^{-9}	2.8 x 10^{-6}
	M3	1.5 x 10^{-10}	7.3 x 10^{-7}
	M4	8.2 x 10^{-10}	4.1 x 10^{-7}
	M5	5.2 x 10^{-10}	2.6 x 10^{-7}
Site 4:	M0	4.9 x 10^{-8}	2.4 x 10^{-5}
	M1	1.1 x 10^{-8}	5.6 x 10^{-6}
	M2	8.8 x 10^{-9}	4.4 x 10^{-6}
	M3	8.6 x 10^{-9}	4.3 x 10^{-6}
	M4	8.6 x 10^{-9}	4.3 x 10^{-6}
	M5	0.0	0.0

Inspection of Figure 4.1 shows that the risk of rockfall at both sites 2 and 4 is below the 10^{-4} limit. There is some consensus that above this limit involuntary risk of a fatal accident $P(DI_{500})$ is unacceptable (Nielson et al. 1994). Based on the criteria suggested by Ale, both sites are above the upper limit of the involuntary risk levels and, for a single trip (P(DI)), within the range where some reduction of the risk is considered desirable.

Significantly, however, the probability of a fatal accident for both P(DI) and $P(DI_{500})$ is of the same order of magnitude as that for the Argillite Cut, where the Supreme Court of Canada found the "Department of Highways could readily foresee the risk that harm might befall users of a highway if it were not reasonably maintained. That maintenance could be found to extend to the prevention of injury from falling rock" (Morgenstern 1997). Given this precedence, the British Columbia Supreme Court may well have established a lower level of acceptable risk for future cases (Section 5.4).

4.3.2 Mitigated Risk

The mitigated risk of a fatal accident at sites 2 and 4 for an individual road user, P(DI), and for an involuntary road user, $P(DI_{500})$, has also been calculated for the range of maintenance programmes detailed in Section 4.1 and summarised in Table 4.1, to determine the level of reduction in risk if any of the maintenance programmes were to be implemented. The results of this risk assessment have been based on an AADT of 1500 and are shown in Table 4.8.

Inspection of Table 4.8 shows that there is a range of levels of improvement from the unmitigated risk (M0) to the mitigated risk (M1 - M5) of a fatal accident. As would be expected, the optimum maintenance programme for site 2 (M2) and site 4 (M3) does not result in the lowest mitigated risk. Also the zero probability of a fatal accident at site 4 for the M5 programme assumes that the concrete rockfall shed entirely eliminates all risk to road users from adverse slope instability effects.

5. APPLICABILITY TO NEW ZEALAND ROADS

5.1 Advantages and Limitations of Methodology

5.1.1 Limitations

Roberds' (1991) methodology for developing optimum slope failure maintenance programmes is considered to have two main limitations.

1. Uncertainty

The problem example addressed as part of this research study contains uncertainty in all stages of the problem resolution. This ranges from uncertainty in the geotechnical factors such as the modes and frequency of slope instability, through to uncertainty in the determination of the site accident history and the cost of the consequences in the event of failure. With the availability of Monte Carlo simulation using @RISK software, uncertainty can now be allowed for by deriving probability distributions for the range of possible outcomes of an uncertain situation.

In the case of the study area, no recorded serious accidents have been attributed to slope instability effects since LTSA began keeping accident records in 1980. Accordingly, a judgement estimate has been made of the relative percentages of potential fatal, serious and minor accidents for the purpose of the risk analysis (Section 3.4.3), and for estimating the "adjusted" value of P(C) as input into the slope-failure maintenance optimisation analysis (Section 4.2.1).

2. Complexity

Because of the rigorous nature of the method, considerable time is required to collect and collate all data relevant to problem resolution. This time will be warranted for slope failure projects involving either large costs or significant cost consequences, but it may not be worthwhile for small slopes where the costs for problem mitigation are relatively low.

5.1.2 Advantages

1. Rigorous methodology

As the method is quantitative in terms of the cost consequences of various slope-failure maintenance programmes, it provides a rigorous technique for assessing the trade-offs between the effectiveness (benefit) against the cost of implementation (cost). On this basis, it provides a measure of assessing the benefits of implementing a pro-active slope maintenance programme compared with remedying the consequences of failure after the fact.

2. Use with other applications

While this study is primarily concerned with rockfall and rock slide hazards, the technique would seem to have no limitations for use with other slope stability hazards affecting road maintenance, provided that reasonable estimates of their frequency of occurrence and their cost consequences can be estimated.

Similarly, the method could be applied to other types of road construction activities where cost optimisation commensurate with acceptable risk is required. For example, Transit New Zealand (1998) has recently developed a new policy on the calculation and management of contingency and risk on physical works projects undertaken by professional services consultants. The policy has risen out of the large number of projects where unacceptable cost over-runs have occurred because risk uncertainty had not been adequately allowed for in the financial costings.

An example of risk uncertainty associated with road earthworks is the optimisation ofbatter steepness. Steepness has significant cost implications if batters are cut either too steep (resulting in failure) or too shallow (over-excavation). Conventional geotechnical analysis of cut batter stability is based mainly on the safety factor approach, whereby compliance with an accepted safety factor of say 1.5 remains the accepted design criteria. However, these approaches do not allow the optimum slope angle to be constructed in terms of the trade-off between cost and the risk of slope instability affecting the road network.

Numerical techniques are now sufficiently well advanced that, for any given slope (either rock or soil), the probability of failure can be computed for different angles of batter as illustrated in Figure 5.1 (McMahon 1971).

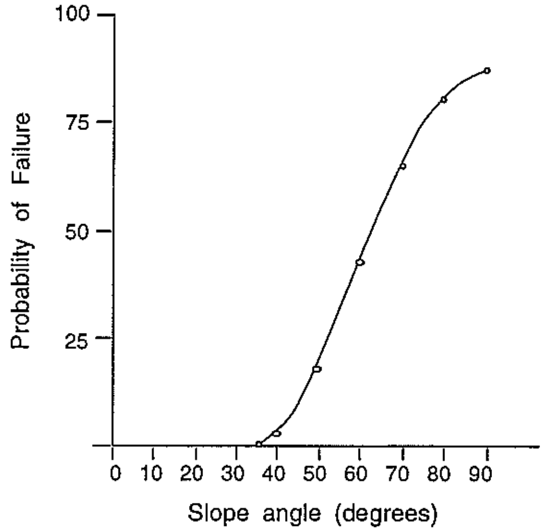


Figure 5.1 Curve of probability of failure versus slope (from McMahon 1971).

In any earthworks project for constructing cut batters, the trade-off between the cost of excavation and the cost of failure of the batter occurring can be expressed by:

$$C_t = C_o + C_f \tag{2}$$

where: C_t = total cost of batter construction
C_o = initial cost of earthworks excavation
C_f = cost of batter failure

The initial cost of excavation, C_o, can be considered to be the cost of excavation of the volume of ground in excess of that required to construct a vertical cut batter, so that:

$$\mathbf{C_o = co. V_o} \tag{3}$$

where: co = unit cost of earthworks excavation
V_o = volume of earthworks excavated in excess of that required for a vertical batter

The cost of batter failure, C_f, is given by:

$$\mathbf{C_f = P(F)\ (C_a + C_b\ .\ V_f)} \tag{4}$$

where: P(F) = probability of batter failure (for a given slope angle)
C_a = costs which are mainly independent of the volume of batter failure, such as road maintenance, service disruption and accident costs
C_b = unit cost of batter failure
V_f = volume of batter failure

As well as the probability of failure, which is itself uncertain, the other variables such as the volume of batter failure and the costs of failure are also uncertain, and best treated in terms of probability distributions using Monte Carlo simulations. Based on equation (4) above, the unit cost of failure can be determined as an incremental procedure by consideration of the product Vf.P(F) for a range of slope angles, as illustrated in Figure 5.2.

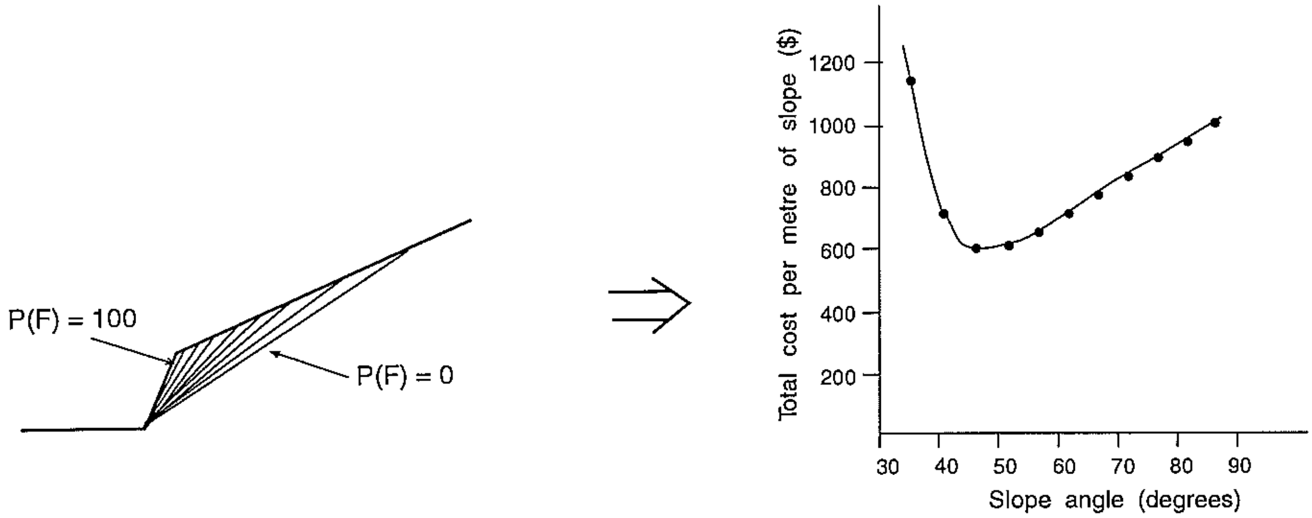


Figure 5.2 Relationship between failure volume V_f (in terms of slope angle) and failure probability P(F).

Where a slope needs to be designed with safety as the over-riding consideration, the slope angle, which has a probability of failure approaching zero, would be the appropriate design criterion. In this instance, a batter angle of 33 ° would meet this criteria, and the cost of construction would be $1130 per metre length of slope.

However the batter with the least total cost ($600 per unit length of slope) is between 45° and 50°, and the probabilities of failure for these slope angles are 10% and 19% respectively.

Cost optimisation techniques such as these can be used, first as the basis for selecting the optimum slope angle commensurate with the level of acceptable risk and second, as the basis for selecting the appropriate level of contingency sum to be applied once the level of risk has been adopted. For example, a 45° batter would attract a lower contingency sum compared with a 50° batter because it has a lower probability of failure, even though both have the same cost per unit length of slope.

5.2 Cost Implications for SH73 Case Study

The results of this research have significant costs implications for the SH73 study area. Table 4.4 (Section 4.2.1), shows that the existing programme of detritus clearing and rockfall call out (M0 maintenance programme; Table 4.1) at both sites 2 and 4 is significantly more costly over a 25-year time frame than the optimum maintenance programmes identified in Table 4.6. Significant benefits are therefore possible if either optimum maintenance programme was to be implemented, with the present values of the net benefits being approximately NZ$91,000 and M$2.1 over 25 years for sites 2 and 4 respectively. The present value net benefit for the two sites combined is therefore of the order of M$2.2.

While sites 1, 3 and 5 have not been considered in the study, it is likely that even greater cost benefits would accrue if these were to be included in any slope maintenance programme.

5.3 Use with Transit New Zealand's 1998 Preventive Maintenance Programme

5.3.1 Funding Framework

Repairs to all of Transit New Zealand's roads from the effects of slope instability are funded by Transfund New Zealand under Output Classes 1 and 2, referred to as the *Roading Maintenance* output (Transfund New Zealand 1997b). The *Roading Maintenance* output is for the provision of maintenance projects on all public roads and includes three work categories for which funds are provided, namely *routine maintenance, preventive work,* and *emergency work,* as well as other maintenance activities.

1. The *routine maintenance* category includes funding for the normal care and attention of the roadway to maintain its structural integrity, and which might be routinely expected in any one year. It provides, among other items, for the routine maintenance and repair of surface water channels and subsoil drainage, stream

clearing and debris removal to maintain water courses and culverts, and snow clearing and ice control.

2. The *preventive work* category provides for non-routine work required to protect the serviceability of the road network and to minimise the threat of road closure. The work covered by this category includes physical works which protect existing roads from sea or river damage, drainage of landslips, buttressing of landslips, protection planting, and physical work required to overcome the effects of river channel migration but which is not attributable to one climatic event.

3. The *emergency work* category is for the funding of unforeseen significant expenditure which arises from one defined, major, short duration natural event. It allows for roads and road structures to be reinstated to a condition no better than that which existed before the damage occurred.

This emergency category of funding does not include minor scour in water channels, landslips that do not require restriction of a traffic lane, the effects of active processes which have accumulated over time, and any other deficiency which has developed from events over a period greater than one month. In the case where it is clear that an improvement to the road or road structures is desirable, the improvement work is required to be economically justified in terms of Transfund New Zealand's Project Evaluation Manual (1997a).

5.3.2 Optimising Slope-Failure Preventive Maintenance Programme

Transit New Zealand has developed a ranking procedure (Transit New Zealand undated) for prioritising *preventive maintenance* expenditure on its road network, which includes a range of assessment factors including the risk of failure, road user safety, road strategic importance, economics, and legal and political implications if use of the road were to be lost (Appendix 9).

When priorities have been determined for expenditure under the *preventive maintenance* budget, the method detailed in this research study could be used as the basis for determining the optimum maintenance programme for mitigating slope-failure effects at individual road sites. Alternatively, the optimum slope-failure maintenance programme can be determined for a highway corridor by aggregating the total equivalent costs for two or more individual sites which require maintenance, from which the maintenance programme with the lowest net present value total equivalent cost or the greatest probability of being the cheapest can be identified (Sections 4.2.1 and 4.2.2). Such procedures would provide Transit New Zealand with the assurance that the selected slope-failure maintenance programme resulted in the greatest net benefits.

5.4 Development of an Appropriate Standard of Care

To date, litigation arising out of injury and/or death to road users attributable to slope instability effects has not occurred in New Zealand. However, the review of the literature indicates that litigation overseas is not uncommon and, given that the New Zealand legal climate is becoming increasingly litigious, we suggest that similar trends can be expected to occur here.

There is also an increasing trend towards quantifying the risk of exposure of the public to a range of hazards, and then to compare these risks against accepted risk guidelines.

The Supreme Court of Canada, by way of the case of a woman killed in 1982 from a rockfall while delayed in traffic on British Columbia Highway 99 at the Argillite Cut (Section 2.1), and which disabled her father, has set a very conservative precedent with respect to rockfall risk (Bunce et al. 1997). The father successfully sued the Government for damages. The Court found that the provincial Ministry of Transportation and Highways "owed a duty of care to those using its highways which ordinarily extends to the reasonable maintenance of the highway". The Court argued that "the Ministry could readily foresee the risk that harm might befall users of the highway if it were not reasonably maintained. That maintenance could be found to extend to the prevention of injury from falling rock" (Morgenstern 1997).

Even though only four rockfalls had been recorded in the 24-year history of the Argillite Cut, and the Ministry of Transport and Highways had implemented considerable remedial treatment after two falls in 1971, the Court found it was deficient in meeting a reasonable standard of care. "This case set a legal precedent ... because it effectively identified the level of risk at which the judicial system considers the public should be protected" (Morgenstern 1997).

While the risk assessment carried out for SH73 at sites 2 and 4 indicate that the present risks to road users from rockfall are within generally accepted levels (Section 4.3.1), the British Columbia Highway 99 (Argillite Cut) case has set very conservative and much lower levels of risk. If these levels were considered to be appropriate for New Zealand, they are likely to have significant implications for roading authorities throughout the country. The methodologies detailed in this research such as the Rockfall Hazard Rating System (RHRS) (Section 3.4.2), the risk analysis presented in Sections 3.4.3 and 4.3, and the identification of the optimum slope-failure maintenance programme (Section 4.2), will provide roading authorities with appropriate procedures for fulfilling their duty of care to road users.

6. RECOMMENDATIONS

6.1 Developing Optimisation Procedures for Slope-Failure Maintenance

The specific objective of this research study was to evaluate whether existing systems for optimising slope-failure preventive maintenance programmes, such as that developed by Roberds (1991), can be applied to the New Zealand roading industry.

Because the Roberds' methodology can be applied to New Zealand roads, developing optimisation procedures for slope-failure maintenance would have merit as it would allow New Zealand roading authorities to implement optimised preventive maintenance programmes within their own jurisdiction or territory. Accordingly, a second stage of research is recommended to achieve this objective of developing a procedures standard.

6.2 Recording Hazard Information

So that meaningful quantitative risk assessments can be made, and appropriate engineering responses can be implemented when risks are above acceptable limits, New Zealand roading authorities should implement procedures to record slope stability hazard information. As such procedures are currently lacking, recording slope stability hazard data on existing computer databases, such as the Transit New Zealand RAMM system, would be the simplest procedure.

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GLOSSARY

Symbols

AADT: average annual daily traffic

AVR: average vehicle risk; used in conjunction with the RHRS

B/C: benefit/cost ratio

C1....C6 (Cx): Different consequences given failure to have occurred in terms of road maintenance (detritus clearing, service disruption), and accidents (fatal, serious, minor, non-injury)

C_a: costs which are mainly independent of the volume of cut slope batter failure, such as road maintenance, service disruption and accident costs

C_b: unit cost of cut slope batter failure

C_f : cost of cut slope batter failure

C_o : initial cost of earthworks excavation for a cut slope batter being the cost of excavation in excess of that required to construct a vertical cut slope batter

C_t : total cost of cut slope batter construction

co: unit cost of earthworks excavation

CHSL: Capilano Highway Services Ltd

DSD: decision sight distance, used in conjunction with the RHRS

E: effectiveness of a maintenance programme

F1....F5 (Fx): slope failure modes

LTSA: Land Transport Safety Authority (of New Zealand)

M0...M5: slope failure maintenance programmes

MOTH: British Columbia Ministry of Transportation and Highways

ODOT: Oregon Department of Transportation

P(C): overall probability of a consequence occurring

P(C|F): probability of a consequence given that failure has occurred

P(DI): probability of death to an individual

$P(DI_{500})$: probability of death to an individual for 500 trips on SH73

P(F): probability of a failure occurring; P(Fx) for failure mode Fx

PV: present value or present worth of a cost or benefit, being its discounted value at the present day

RAMM: Transit New Zealand's Road Assessment & Maintenance Management system

RHRS: Rock Hazard Rating System

RG-DAS: road geometry - data acquisition system

RP: Transit New Zealand's route position for highway position identification

TEC: total equivalent cost

V_f: volume of cut slope batter failure

V_o: volume of earthworks excavated in excess of that required for a vertical cut slope batter

Terminology

Accident: an unexpected event involving one or more road vehicles which results in personal physical injury and/or damage to property, brought about unintentionally

Alluvium: a general term for all detrital deposits resulting from the process of river systems

Bedding: parallel planes dividing sedimentary rocks of the same or different lithology

Colluvium: a general term applied to loose and incoherent deposits mantling a slope

Defect: general term to describe natural fractures, joints and faults intersecting a rock mass

Detritus: material produced by the disintegration and weathering of rocks; it has been removed from its place of origin

Fault: a fracture or fracture zone in a rock along which there has been some displacement of the sides relative to one another and parallel to the fracture

Fatal accident: when death follows within 30 days of an accident

Frequency: a proportion measuring how often, or how frequently, something occurs in a sequence of observations

Glacial deposits: pertaining to material deposited by glacial action

Greywacke sandstone and argillite: relatively coarse and fine grained rocks respectively, of sedimentary origin composed of quartzo-feldspathic constituents

Hazard: a condition or situation which has the potential to create or increase harm to people, property or the environment.

Hazard analysis: the determination of the probabilities of occurrence of slope in stability for a given period of time and place

Joint(s): fracture in rock along which no appreciable displacement has occurred

Minor accident: an accident causing injuries other than serious which require first aid or cause discomfort or pain, including bruising and sprains

Non-injury: an accident causing no injury, sometimes referred to as "property-damage-only" accidents

Probability: a measure of the likelihood of an event, expressed with numerical values ranging from 0 to 1, where 0 represents impossibility and 1 certainty, or as a probability percentage (probability x 100%)

Problem: a doubtful or difficult matter requiring a solution; sudden deviation from an unexpected performance; or the existence of a permanent deviation from an expected performance

Relative risk: the comparison of risk between products, systems or facilities by qualitative or semi-quantitative means

Risk: the probability of a potential hazard being realised, and the probability of the harm itself
Risk, related to slope instability, is the expected number of lives lost, persons injured, damage to property or disruption to economic services

Risk analysis: the estimation of given risk by statistical and/or numerical modelling process

Risk assessment: the integrated analysis of the risks inherent in a product, system or facility and their significance in an appropriate context

Risk mitigation: the reduction of risk by, in this case, appropriate slope failure maintenance programmes

Rockfall: a hard or firm mass that was intact and in its natural place before the initiation of movement, and which, on detachment, little or no shear displacement took place

Rock slide: a hard or firm mass that was intact and in its natural place before the initiation of movement, and which, on detachment from a rock slope, moved dominantly on surfaces of rupture or on relatively thin zones of intense shear strain

Serious accident: an accident causing injuries requiring medical attention or detention in hospital, and including fractures, concussion, and severe cuts

Slope instability/slope failure: the movement of a mass of rock, debris or earth down a slope

APPENDICES

APPENDIX 1
VERIFICATION OF ROBERDS' METHODOLOGY

1. Effectiveness of Maintenance Options

SD= 0.2

Verification of Spreadsheet using Roberds Example 1

	Mo : Do Nothing		M1 : Scale		M2 : Isolated Rock Bolt		M3 : Rock Bolt/Mesh/Shotcrete		M4 : Tie back/ret Wall		M5 : Slope Flattening		M6 : Dewater		M7 : Toe Protection	
	mean	F	mean	F	mean	F	mean	F	mean	F	mean	F	mean	F	mean	F
F1 Isolated Rockfall	0.00	0.00	0.60	0.59	0.10	0.20	0.90	0.80	0.95	0.82	0.40	0.41	0.00	0.00	0.00	0.00
F2 Small wedge/block (<100 t)	0.00	0.00	0.30	0.33	0.60	0.59	0.90	0.80	0.95	0.82	0.40	0.41	0.00	0.00	0.00	0.00
F3 Large wedge/block (>100 t)	0.00	0.00	0.10	0.20	0.30	0.33	0.60	0.59	0.90	0.80	0.40	0.41	0.30	0.33	0.00	0.00
F4 Small rock mass (<100 t)	0.00	0.00	0.10	0.20	0.20	0.26	0.50	0.50	0.95	0.82	0.60	0.59	0.30	0.33	0.00	0.00
F5 Large Rock Mass (>100 t)	0.00	0.00	0.00	0.00	0.10	0.20	0.40	0.41	0.90	0.80	0.60	0.59	0.70	0.67	0.00	0.00
C1 Repair ($)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50
C2 Disruption (days)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.26	0.00	0.00	0.50	0.50
C3 Injuries/Death (Persons)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.74
C4 Litigation Costs ($)	0.00	0.00	0.00	0.00	0.20	0.26	0.20	0.26	0.20	0.26	0.20	0.26	0.20	0.26	0.20	0.26

Optimisation of slope maintenance programme

Verification of Spreadsheet using Roberds Example 1

1. Determine probability of failure

No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	F	Dist
Failure Mode	PDF Input Parameters, Unmitigated Case (Mo)																						
F1 Isolated Rockfall	0.20	0.100	0.050	0.050	0.050	0.050	0.080	0.080	0.080	0.080	0.080	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	1.00	5.55
F2 Small wedge/block (<100 t)	0.70	0.200	0.025	0.025	0.025	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	0.55
F3 Large wedge/block (>100 t)	0.95	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	0.05
F4 Small rock mass (<100 t)	0.80	0.100	0.025	0.025	0.025	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	0.45
F5 Large Rock Mass (>100 t)	0.95	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	0.05

Checksums	
1.0000	*OK*
1.0000	*OK*
1.0000	*OK*
1.0000	*OK*
1.0000	*OK*

2. Determine Consequences

	C1 Repair ($1000)				C2 Disruption (days)	C3 Injury/Death (Persons)				C4 Litigation Costs ($M)
Dependencies					X1= 5.667					X2= 1.17
	Min	ML	Max	Dist	Days	Min	ML	Max	Dist	$M
Failure Mode:	F= *1.00*				F= *1.00*	F= *1.00*				F= *1.00*
F1 Isolated Rockfall	1	2	5	2.7	*0.5*	0	0	1	0.3	*0.4*
F2 Small wedge/block (<100 t)	1	5	10	5.3	*0.9*	0	0	1	0.3	*0.4*
F3 Large wedge/block (>100 t)	2	10	50	20.7	*3.6*	0	1	2	1.0	*1.2*
F4 Small rock mass (<100 t)	1	5	20	8.7	*1.5*	0	0	1	0.3	*0.4*
F5 Large Rock Mass (>100 t)	5	20	100	41.7	*7.4*	0	1	5	2.0	2.3
Sum Cost x Prob				*24.75*	*4.37*				2.33	*2.72*

Optimisation of slope maintenance programme
Verification of Spreadsheet using Roberds Example 1

1. Determine probability of failure

No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	F	Dist
Failure Mode	**Conditioned PDF input parameters**																						
F1 Isolated Rockfall	0.67	0.041	0.021	0.021	0.021	0.021	0.033	0.033	0.033	0.033	0.033	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.41	2.28
F2 Small wedge/block (<100 t)	0.80	0.135	0.017	0.017	0.017	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.67	0.37
F3 Large wedge/block (>100 t)	0.96	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.80	0.04
F4 Small rock mass (<100 t)	0.84	0.080	0.020	0.020	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.80	0.36
F5 Large Rock Mass (>100 t)	0.95	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	0.05

2. Determine Consequences

	C1 Repair ($1000)				C2 Disruption (days)	C3 Injuries/Death (Persons)				C4 Litigation Costs ($M)
Dependencies					X1= 5.667					X2= 1.167
	Min	ML	Max	Dist	Days	Min	ML	Max	Dist	$M
Failure Mode:	F=	1.00			F= 1.00	F=	1.00			F= 1.00
F1 Isolated Rockfall	1	2	5	2.7	0.47	0	0	1	0.3	0.39
F2 Small wedge/block (<100 t)	1	5	10	5.3	0.94	0	0	1	0.3	0.39
F3 Large wedge/block (>100 t)	2	10	50	20.7	3.65	0	1	2	1.0	1.17
F4 Small rock mass (<100 t)	1	5	20	8.7	1.53	0	0	1	0.3	0.39
F5 Large Rock Mass (>100 t)	5	20	100	41.7	7.35	0	1	5	2.0	2.33
Sum Cost x Prob				14.06	2.48				1.14	1.33

Optimisation of slope maintenance programme
Verification of Spreadsheet using Roberds Example 1

1. Determine probability of failure

No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	F	Dist
Failure Mode	**Conditioned PDF input parameters**																						
F1 Isolated Rockfall	*0.36*	*0.080*	*0.040*	*0.040*	*0.040*	*0.040*	*0.064*	*0.064*	*0.064*	*0.064*	*0.064*	*0.008*	*0.008*	*0.008*	*0.008*	*0.008*	*0.008*	*0.008*	*0.008*	*0.008*	*0.008*	*0.80*	4.43
F2 Small wedge/block (<100 t)	*0.88*	*0.082*	*0.010*	*0.010*	*0.010*	*0.010*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.41*	0.23
F3 Large wedge/block (>100 t)	*0.97*	*0.034*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.67*	0.03
F4 Small rock mass (<100 t)	*0.85*	*0.074*	*0.019*	*0.019*	*0.019*	*0.019*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.74*	0.33
F5 Large Rock Mass (>100 t)	*0.96*	*0.040*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.80*	0.04

2. Determine Consequences

	C1 Repair ($1000)				C2 Disruption (days)		C3 Injuries/Death (Persons)				C4 Litigation Costs ($M)	
Dependencies					X1=	5.667					X2=	1.167
	Min	ML	Max	Dist		Days	Min	ML	Max	Dist		$M
Failure Mode:	F=	*1.00*			F=	*1.00*	F=	*1.00*			F=	*0.74*
F1 Isolated Rockfall	*1*	2	5	2.7		*0.47*	*0*	*0*	*1*	0.3		*0.29*
F2 Small wedge/block (<100 t)	*1*	5	*10*	5.3		*0.94*	*0*	*0*	*1*	0.3		*0.29*
F3 Large wedge/block (>100 t)	2	*10*	*50*	20.7		*3.65*	*0*	*1*	*2*	1.0		*0.87*
F4 Small rock mass (<100 t)	*1*	5	*20*	8.7		*1.53*	*0*	*0*	*1*	0.3		*0.29*
F5 Large Rock Mass (>100 t)	5	*20*	*100*	41.7		*7.35*	*0*	*1*	5	2.0		*1.73*
Sum Cost x Prob				*18.27*		*3.22*				*1.78*		*1.54*

Optimisation of slope maintenance programme
Verification of Spreadsheet using Roberds Example 1

1. Determine probability of failure

No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	F	Dist
Failure Mode	**Conditioned PDF input parameters**																						
F1 Isolated Rockfall	0.84	0.020	0.010	0.010	0.010	0.010	0.016	0.016	0.016	0.016	0.016	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.20	1.12
F2 Small wedge/block (<100 t)	0.94	0.040	0.005	0.005	0.005	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.20	0.11
F3 Large wedge/block (>100 t)	0.98	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.41	0.02
F4 Small rock mass (<100 t)	0.90	0.050	0.013	0.013	0.013	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.50	0.23
F5 Large Rock Mass (>100 t)	0.97	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.59	0.03

2. Determine Consequences

	C1 Repair ($1000)				C2 Disruption (days)	C3 Injuries/Death (Persons)				C4 Litigation Costs ($M)
Dependencies					X1= 5.667					X2= 1.167
	Min	ML	Max	Dist	Days	Min	ML	Max	Dist	$M
Failure Mode:	F=	1.00			F= 1.00	F=	1.00			F= 0.74
F1 Isolated Rockfall	1	2	5	2.7	0.47	0	0	1	0.3	0.29
F2 Small wedge/block (<100 t)	1	5	10	5.3	0.94	0	0	1	0.3	0.29
F3 Large wedge/block (>100 t)	2	10	50	20.7	3.65	0	1	2	1.0	0.87
F4 Small rock mass (<100 t)	1	5	20	8.7	1.53	0	0	1	0.3	0.29
F5 Large Rock Mass (>100 t)	5	20	100	41.7	7.35	0	1	5	2.0	1.73
Sum Cost x Prob				7.18	1.27				0.56	0.49

Optimisation of slope maintenance programme
Verification of Spreadsheet using Roberds Example 1

1. Determine probability of failure

No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	F	Dist
Failure Mode	**Conditioned PDF input parameters**																						
F1 Isolated Rockfall	*0.86*	*0.018*	*0.009*	*0.009*	*0.009*	*0.009*	*0.014*	*0.014*	*0.014*	*0.014*	*0.014*	*0.002*	*0.002*	*0.002*	*0.002*	*0.002*	*0.002*	*0.002*	*0.002*	*0.002*	*0.002*	*0.18*	0.99
F2 Small wedge/block (<100 t)	*0.95*	*0.036*	*0.004*	*0.004*	*0.004*	*0.004*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.18*	0.10
F3 Large wedge/block (>100 t)	*0.99*	*0.010*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.20*	0.01
F4 Small rock mass (<100 t)	*0.96*	*0.018*	*0.004*	*0.004*	*0.004*	*0.004*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.18*	0.08
F5 Large Rock Mass (>100 t)	*0.99*	*0.010*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.20*	0.01

2. Determine Consequences

	C1 Repair ($1000)				C2 Disruption (days)	C3 Injuries/Death (Persons)				C4 Litigation Costs ($M)
Dependencies					X1= 5.667					X2= 1.167
	Min	ML	Max	Dist	Days	Min	ML	Max	Dist	$M
Failure Mode:	F=	*1.00*			F= *1.00*	F=	*1.00*			F= *0.74*
F1 Isolated Rockfall	*1*	*2*	*5*	2.7	*0.47*	*0*	*0*	*1*	0.3	*0.29*
F2 Small wedge/block (<100 t)	*1*	*5*	*10*	5.3	*0.94*	*0*	*0*	*1*	0.3	*0.29*
F3 Large wedge/block (>100 t)	*2*	*10*	*50*	20.7	*3.65*	*0*	*1*	*2*	1.0	*0.87*
F4 Small rock mass (<100 t)	*1*	*5*	*20*	8.7	*1.53*	*0*	*0*	*1*	0.3	*0.29*
F5 Large Rock Mass (>100 t)	*5*	*20*	*100*	41.7	*7.35*	*0*	*1*	*5*	2.0	*1.73*
Sum Cost x Prob				*4.50*	*0.79*				*0.42*	*0.36*

Optimisation of slope maintenance programme
Verification of Spreadsheet using Roberds Example 1

1. Determine probability of failure

No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	F	Dist
Failure Mode	**Conditioned PDF input parameters**																						
F1 Isolated Rockfall	0.53	0.059	0.029	0.029	0.029	0.029	0.047	0.047	0.047	0.047	0.047	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.59	3.27
F2 Small wedge/block (<100 t)	0.82	0.118	0.015	0.015	0.015	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.59	0.32
F3 Large wedge/block (>100 t)	0.97	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.59	0.03
F4 Small rock mass (<100 t)	0.92	0.041	0.010	0.010	0.010	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.41	0.18
F5 Large Rock Mass (>100 t)	0.98	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.41	0.02

2. Determine Consequences

	C1 Repair ($1000)				C2 Disruption (days)		C3 Injuries/Death (Persons)				C4 Litigation Costs ($M)	
Dependencies					X1=	5.667					X2=	1.167
	Min	ML	Max	Dist		Days	Min	ML	Max	Dist		$M
Failure Mode:	F=	1.00			F=	0.74	F=	1.00			F=	0.74
F1 Isolated Rockfall	1	2	5	2.7		0.35	0	0	1	0.3		0.29
F2 Small wedge/block (<100 t)	1	5	10	5.3		0.70	0	0	1	0.3		0.29
F3 Large wedge/block (>100 t)	2	10	50	20.7		2.71	0	1	2	1.0		0.87
F4 Small rock mass (<100 t)	1	5	20	8.7		1.14	0	0	1	0.3		0.29
F5 Large Rock Mass (>100 t)	5	20	100	41.7		5.46	0	1	5	2.0		1.73
Sum Cost x Prob				13.52		1.77				1.33		1.15

Optimisation of slope maintenance programme
Verification of Spreadsheet using Roberds Example 1

1. Determine probability of failure

No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	F	Dist
Failure Mode	**Conditioned PDF input parameters**																						
F1 Isolated Rockfall	0.20	0.100	0.050	0.050	0.050	0.050	0.080	0.080	0.080	0.080	0.080	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	1.00	5.55
F2 Small wedge/block (<100 t)	0.70	0.200	0.025	0.025	0.025	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	0.55
F3 Large wedge/block (>100 t)	0.97	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.67	0.03
F4 Small rock mass (<100 t)	0.87	0.067	0.017	0.017	0.017	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.67	0.30
F5 Large Rock Mass (>100 t)	0.98	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.33	0.02

2. Determine Consequences

	C1 Repair ($1000)				C2 Disruption (days)		C3 Injuries/Death (Persons)				C4 Litigation Costs ($M)	
Dependencies					X1=	5.667					X2=	1.167
	Min	ML	Max	Dist		Days	Min	ML	Max	Dist		$M
Failure Mode:	F=	1.00			F=	1.00	F=	1.00			F=	0.74
F1 Isolated Rockfall	1	2	5	2.7		0.47	0	0	1	0.3		0.29
F2 Small wedge/block (<100 t)	1	5	10	5.3		0.94	0	0	1	0.3		0.29
F3 Large wedge/block (>100 t)	2	10	50	20.7		3.65	0	1	2	1.0		0.87
F4 Small rock mass (<100 t)	1	5	20	8.7		1.53	0	0	1	0.3		0.29
F5 Large Rock Mass (>100 t)	5	20	100	41.7		7.35	0	1	5	2.0		1.73
Sum Cost x Prob				21.73		3.84				2.20		1.91

Roberds Example.xlsM7

Optimisation of slope maintenance programme
Verification of Spreadsheet using Roberds Example 1

1. Determine probability of failure

No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	F	Dist
Failure Mode	**Conditioned PDF input parameters**																						
F1 Isolated Rockfall	0.20	0.100	0.050	0.050	0.050	0.050	0.080	0.080	0.080	0.080	0.080	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	1.00	5.55
F2 Small wedge/block (<100 t)	0.70	0.200	0.025	0.025	0.025	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	0.55
F3 Large wedge/block (>100 t)	0.95	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	0.05
F4 Small rock mass (<100 t)	0.80	0.100	0.025	0.025	0.025	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	0.45
F5 Large Rock Mass (>100 t)	0.95	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	0.05

2. Determine Consequences

	C1 Repair ($1000)				C2 Disruption (days)	C3 Injuries/Death (Persons)				C4 Litigation Costs ($M)
Dependencies					X1= 5.667					X2= 1.167
	Min	ML	Max	Dist	Days	Min	ML	Max	Dist	$M
Failure Mode:	F=	0.50			F= 0.50	F=	0.26			F= 0.74
F1 Isolated Rockfall	1	2	5	1.3	0.24	0	0	1	0.1	0.29
F2 Small wedge/block (<100 t)	1	5	10	2.7	0.47	0	0	1	0.1	0.29
F3 Large wedge/block (>100 t)	2	10	50	10.3	1.82	0	1	2	0.3	0.87
F4 Small rock mass (<100 t)	1	5	20	4.3	0.76	0	0	1	0.1	0.29
F5 Large Rock Mass (>100 t)	5	20	100	20.8	3.68	0	1	5	0.5	1.73
Sum Cost x Prob				12.38	2.18				0.60	2.02

Verification of Spreadsheet using Roberds Example 1

Cost of service disruption = $ 20,000.00 per day
Ccost of death/injury = $100,000.00 per person

	Maintenance Activity							
	Mo	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**
Cost of Maintenance options($)								
Min	0	1000	5000	20000	100000	50000	10000	10000
ML	0	2000	10000	50000	200000	100000	25000	15000
Max	0	5000	50000	100000	500000	150000	50000	20000
Dist	0	2667	21667	56667	266667	100000	28333	15000
Consequences								
C1($1000)	*24.750*	*14.064*	*18.274*	*7.178*	*4.500*	*13.525*	*21.734*	*12.375*
C2 (days)	*4.368*	*2.482*	*3.225*	*1.267*	*0.794*	*1.773*	*3.835*	*2.184*
C3 (Persons)	*2.333*	*1.142*	*1.777*	*0.564*	*0.421*	*1.332*	*2.201*	*0.600*
C4 ($M)	*2.722*	*1.332*	*1.540*	*0.489*	*0.365*	*1.154*	*1.907*	*2.022*
Utility, U ($)	*3067658*	*1512394*	*1821923*	*634737*	*693929*	*1435905*	*2253620*	*2152893*
E(U) (following simulation)	**3119787**	**1591063**	**1823004**	**642957**	**705079**	**1429811**	**2339292**	**2473276**

Degree of Preference Among Alternative Activities

	M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**
over Mo	*-1555264*	*-1245735*	*-2432922*	*-2373730*	*-1631754*	*-814038*	*-914765*
over M1		*309529*	*-877657*	*-818465*	*-76490*	*741226*	*640499*
over M2			*-1187186*	*-1127994*	*-386019*	*431697*	*330970*
over M3				*59192*	*801168*	*1618883*	*1518156*
over M4					*741976*	*1559691*	*1458965*
over M5						*817716*	*716989*
over M6							*-100727*

Probability that Mx is preferred over My

	M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**
over Mo	*1*	*1*	*1*	*1*	*1*	*1*	*1*
over M1		*0*	*1*	*1*	*1*	*0*	*0*
over M2			*1*	*1*	*1*	*0*	*0*
over M3				*0*	*0*	*0*	*0*
over M4					*0*	*0*	*0*
over M5						*0*	*0*
over M6							*1*

Verification of Spreadsheet using Roberds Example 1

Implimentation Costs, Consequence Costs and Total Equivalent Costs (Roberds' Table 5)

Costs and Consequences	PREVENTATIVE MAINTENANCE ACTIVITIES							
	Mo: Existing Situation	**M1: Scale**	**M2: Isolated Rock Bolt**	**M3: Rock Bolt, Mesh, Shotcrete**	**M4: Tie back/ret Wall**	**M5: Slope Flattening**	**M6: Dewater**	**M7: Toe Protection**
Implementation Costs ($1000)	0 0 0	1 2 5	5 10 50	20 50 100	100 200 500	50 100 150	10 25 50	10 15 20
C1($1000)	0 25 67	0 14 57	0 18 56	0 7 38	0 4.4 31	0 13 48	0 22 63	0 13 40
C2 (days)	0 4.8 14	0 2.7 10	0 3.7 12	0 1.4 7.7	0 0.8 5.4	0 2 7.8	0 4.1 11	0 2.4 6.9
C3 (Persons)	0 2.3 7	0 1.1 5	0 1.7 5.8	0 0.5 2.9	0 0.4 3	0 1.3 6.1	0 2.2 7.7	0 0.6 2.7
C4 ($M)	0 2.6 8.5	0 1.3 5.7	0 1.4 5.1	0 0.4 2.6	0 0.3 2.1	0 1.3 5.2	0 2 6.8	0 2.1 7.2
U($)	0 3 9.3	0 1.5 6.4	0 1.7 5.9	0 0.6 3	0 0.7 2.7	0 1.4 5.8	0 2.3 7.5	0 2.2 7.4

Consequences (Cx) and Total Equivalent Costs (U) are in terms of 5%, Expected Value, 95 %

Verification of Spreadsheet using Roberds Example 1

Degree of preference among Maintenance Options (Roberds' Table 6)

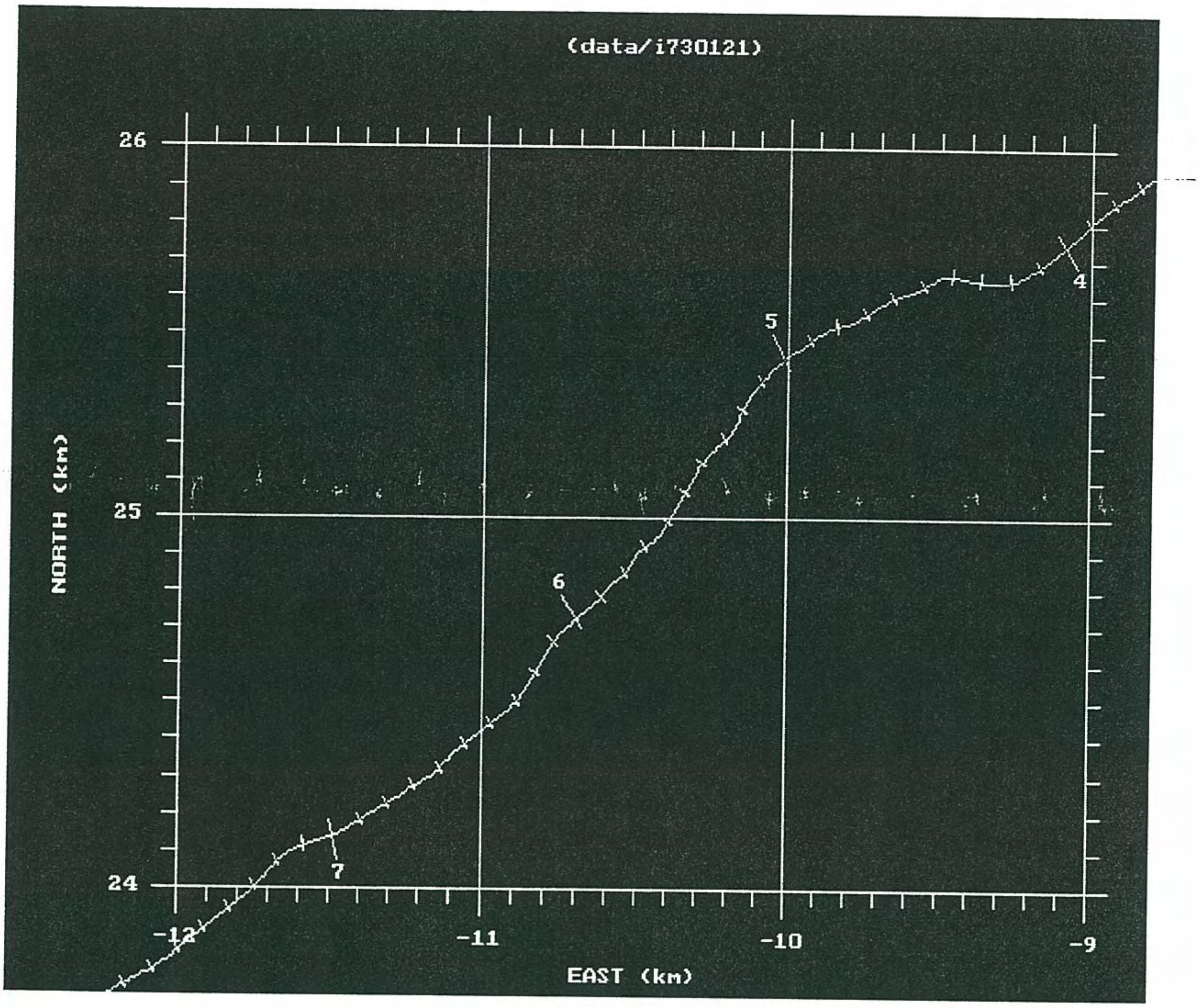
Upper value: Expected value of Ux-Uy following Monte Carlo simulation
Lower value: P(Ux>Uy) as p[ercentage following Monte Carlo Simulation

PREVENT MAINT ACTS	**PREVENTATIVE MAINTENANCE ACTIVITIES**						
	M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**
Mo	*-1465* *65*	*-1258* *62*	*-2391* *80*	*-2292* *79*	*-1547* *68*	*-642* *54*	*-738* *57*
M1		*207* *40*	*-925* *51*	*-827* *49*	*-817* *40*	*823* *33*	*726* *33*
M2			*-1132* *67*	*-1034* *62*	*-288* *51*	*616* *40*	*519* *43*
M3				*98* *26*	*843* *21*	*1748* *21*	*1652* *23*
M4					*745* *48*	*1650* *28*	*1554* *29*
M5						*905* *37*	*808* *36*
M6							*-97* *52*

Probability than Option will be cheaper than the next cheapest option (%)

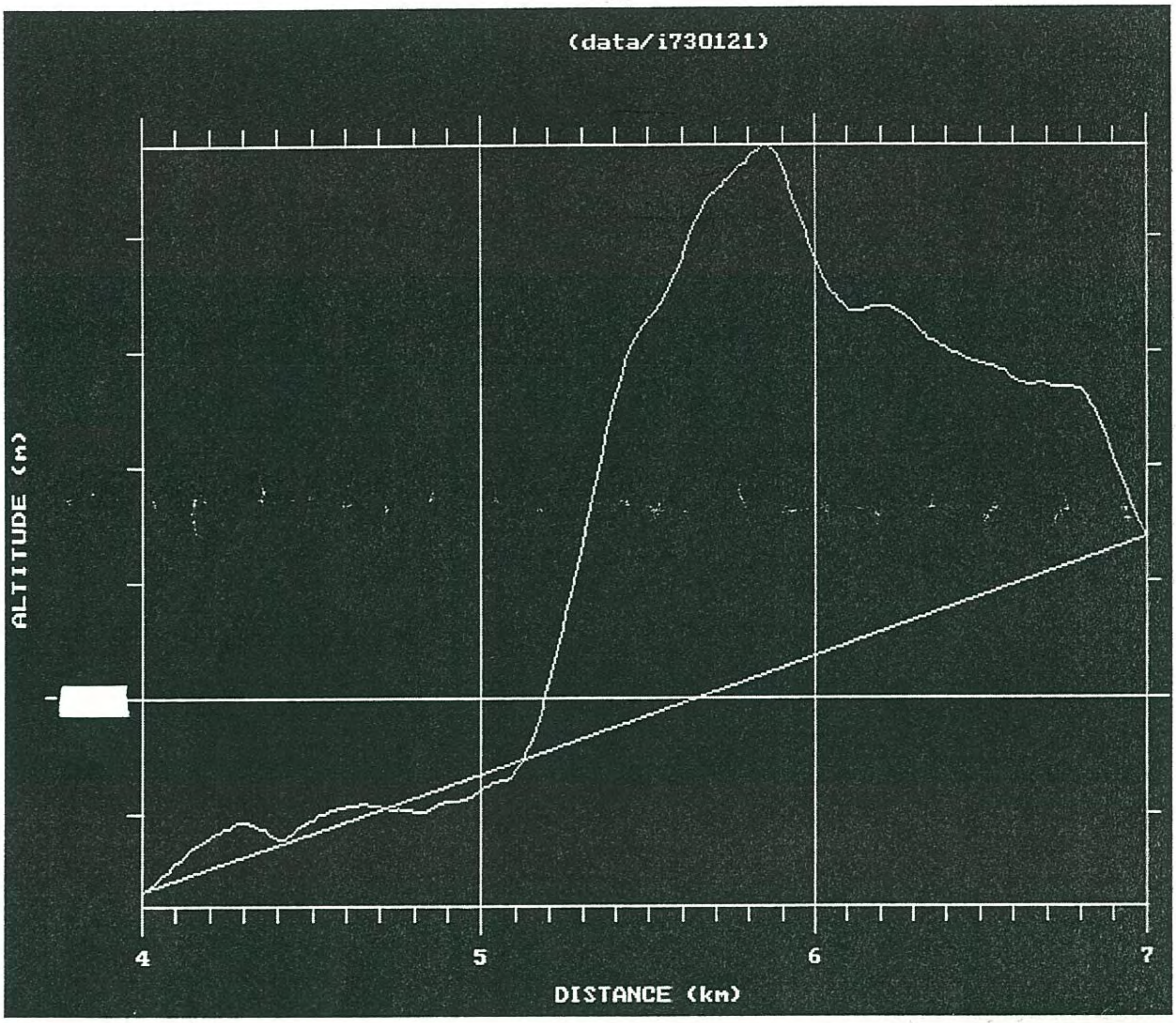
Mo	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**
20	49	33	51	26	21	21	23

APPENDIX 2
RG-DAS OUTPUT FOR RP 121/4.00 - 7.00



Plan showing SH73 RP121/4-7

Scale: 10 m intervals



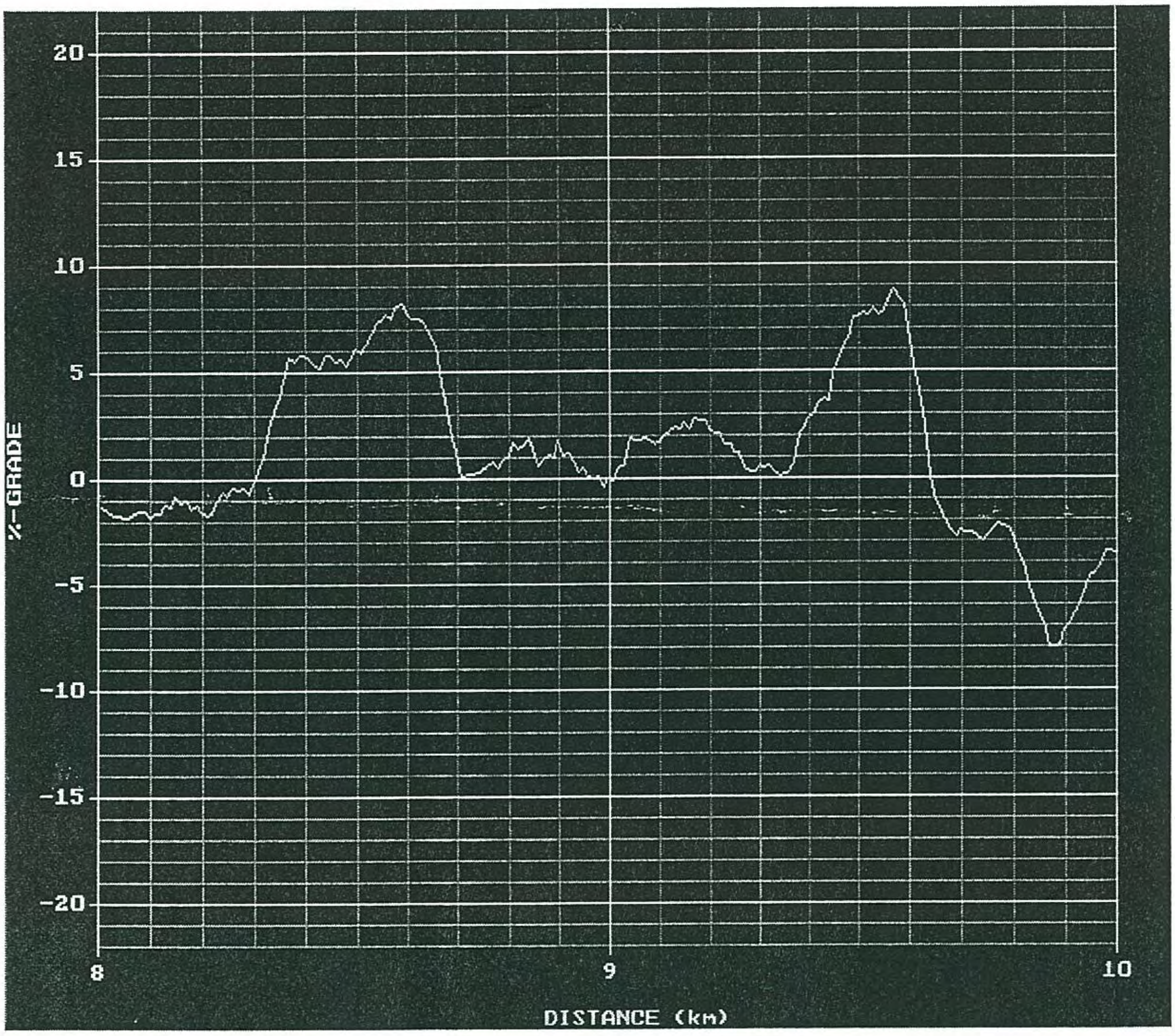
Vertical section SH73 RP121/4-7

Increasing RP direction

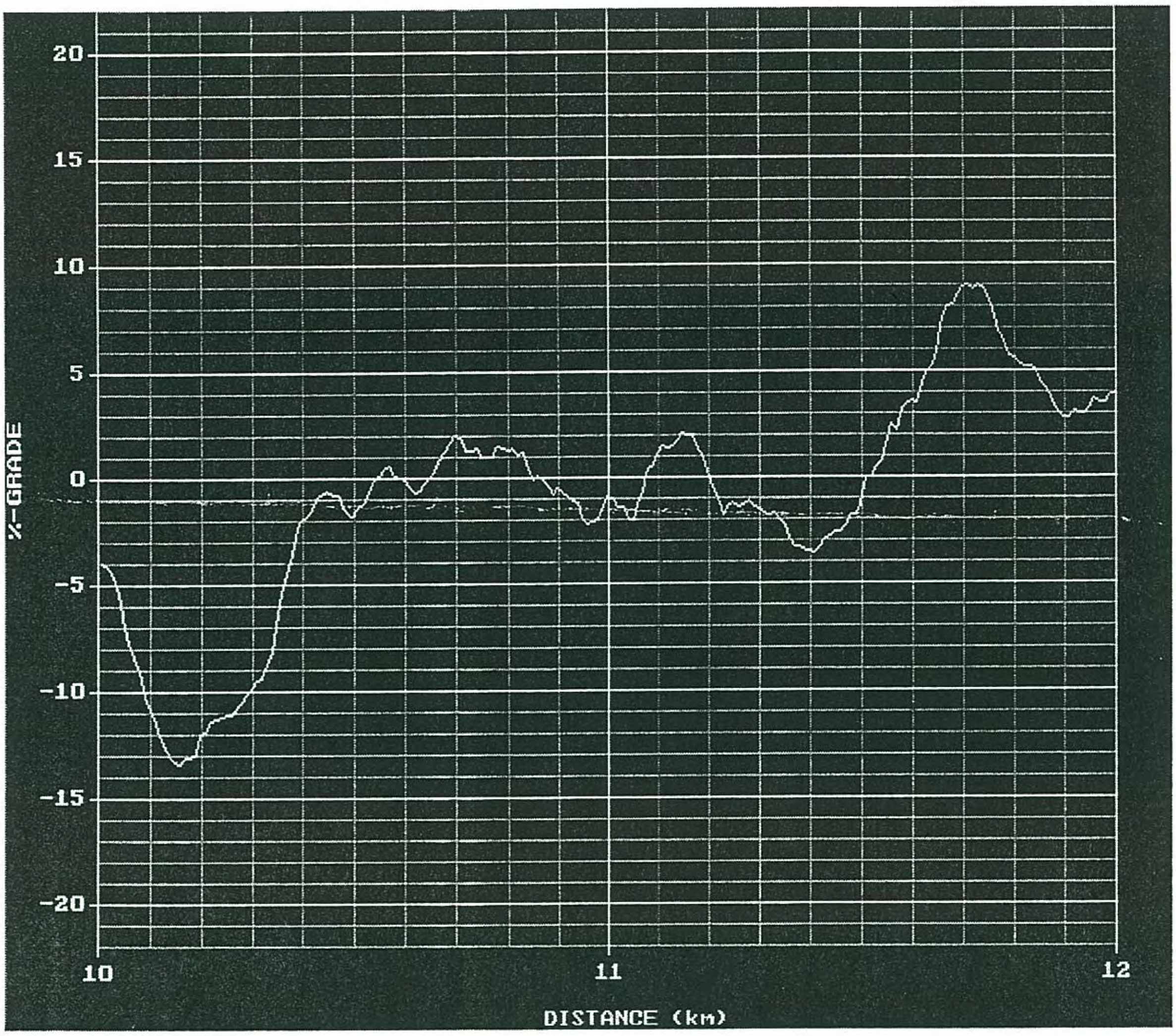
Gradient SH73 RP121/4-6

Gradient SH73 RP121/6-8

Decreasing RP direction



Gradient in decreasing RP lane, i.e. RP136/8-10 km back



Gradient in decreasing RP lane, i.e. RP136/10-12 km back

APPENDIX 3
INTERVIEW TRANSCRIPTS

RECORD OF INTERVIEW

1. Name: Ken Avant

2. Employer: Works Civil Construction

3. Position: Maintenance Manager

4. Date of interview: 21 January 1998

5. Relevance of Interviewed Person to Transfund Study: SH73 Highway Maintenance Manager for Works Civil Construction from July 1995 to present.

Comments on Site 1 (RS 121/4.975 - 121/5.025); Site 2 (RS 121/5.090 - 121/5.185); Site 3 (RS 121/5.225 - 121/5.370)

- Most of the rockfall material is contained on the inside verge of the road and the inside edge of the road pavement. Only minor amounts of rockfall material spills on to the road pavement proper. This is because material does not originate form a great height, and therefore the material does not bounce far across the road.

- The location of fresh rockfall activity in the cut face of the road batter can usually be seen due to the fresh appearance of the face after a block has dropped out.

- The worst periods of the year for rockfall activity are during freeze/thaw activity, the spring thaw and during severe northwest winds (April - September).

- Maximum size of rockfall material is up to 500 mm diameter, with the typical size being 100 - 300 mm diameter.

- During the worst period of the year for slips (April - September), typically 4 to 5 rockfall events per site visit are required to be cleared from the road, increasing to a maximum of 6 - 7 during severe northwest winds.

- Construction of one or more intermediate level benches on the cut slope could be a possible measure to mitigate the rockfall problem.

Comments on Site 4 (RS 121/5.6.130 - 121/6.216 "Paddys Bluff")

- Size of rockfall material typically 100 - 200 mm diameter. Only very occasional material above this size.

- Rockfall material originates from a great height, causing rock to spread out right across the road.

- During worst time of year, hundreds of pieces of rockfall material are picked up off the road during each site clearance visit.

- Worst time of year for rockfall activity is in the spring thaw, but activity carries on all through winter.

- The low bund which has been constructed at the toe of the slope picks up material which originates from a low height on the slope, but does not stop material from higher up which breaks up and over shoots the bund on to the road.

- A snow plough is used to clean up the rockfall material during winter, which blades the material to the side of the road. This material is later picked up during spring/summer during a single cleaning up exercise and carted to dump.

- The rockfall catch net as suggested by GeoBrug is probably suitable as a mitigation measure against rockfall activity.

Comments on Site 5 (RS 121/5.6.230 - 121/6.380)

- This area is immediately adjacent to Paddys Bluff.

- This area is similar to Paddys in terms of the size and distribution of material which comes down on to the road, but the frequency of rockfall material is similar to sites 1, 2 and 3.

- There was a recent large rockfall of 400 - 500 mm diameter which occurred on 22 December 1997, indicating occasional larger rockfall at this locality.

- The overall frequency of rockfall activity does not seem to be increasing at this site.

General Comments

- All sites have "rockfall" warning signs and no stopping signs, but there is no speed restriction on any part of this section of SH73.

- The cost to Transit NZ from rockfall clearance activities carried out by Works Civil is approximately $65 000 per annum along the section of highway between sites 1 and 5.

- Sites 1, 2 and 3 are regarded as a higher risk of accident to the road user than is site 4 (Paddys Bluff) because although the frequency of rockfall activity is lower at sites 1, 2 and 3, the approaches to these locations all have poor approach visibility and the size of rockfalls are much larger than at Paddys. Given the steepness of the country below the road, there is little room for manoeuvring if an approaching motorist were to hit a rock at sites 1, 2 and 3. Also, the approaches to Paddys Bluff generally have better visibility, and the slip scar can be observed from some distance which gives the motorist some indication of approaching bad driving conditions.

- Date of pavement reseals: RP 121/4.4 - 5.0 1995
  RP 121/5.0 - 6.0 1994 (site 2)
  RP 121/6.0 - 6.4 1991 (site 4)
  RP 121/6.4 - 7.2 1995

- Other people to be contacted who are likely to have a good knowledge of road conditions along this section of SH73 include:

  i) Niall Shepherd, Arthurs Pass police (03) 318 9212 fax 318 9263
  ii) Shaun Jackson, Arthurs Pass Towing (03) 318 9266
  iii) Mt White Station - no name
  iv) Barry Drummond, Tranz Rail employee (03) 318 8809

- Fulton Hogan had highway maintenance contract from 1989 - July 1995, after which Works picked up the maintenance contract which expires in September 1998.

Additional discussion with Ken Avant on 6/4/98:

- Spoke to ken Avant regarding road closuresresulting from rockfalls.

- Since 1995 when Works took over the maintenance contract there have been no road closures from rockfalls.

- SH73 was closed in 1994 following the Otira earthquake.

RECORD OF INTERVIEW

1. Name: Mike Smith and Len Collett

2. Employer: Montgomery Watson New Zealand Ltd.

3. Position: Mike Smith Road Safety Manager
Len Collett Highway Maintenance Manager

4. Date of interview: 23 January 1998

5. Relevance of Interviewed Persons to Transfund Study:

Mike Smith	1984 - 94: Highway Design engineer, Royds Consulting 1994 - 96: Maintenance Project Manager, Works Civil Construction (includinh SH73) 1996 - 97: Area Manager for Central Canterbury, Montgomery Watson 1997 - 98: Road Safety Manager, Montgomery Watson
Len Collett	1975 - 88: National Roads Board/Transit New Zealand State Highways Overseer (including SH73) 1988 - 92: Works Consultancy Serrvices, Maintenance Manager State Highways (including SH73) 1992 - 96: Consultant 1996 - 98: Highway Maintenance Manager, Montgomery Watson

Comments on Site 1 (RS 121/4.975 - 121/5.025); Site 2 (RS 121/5.090 - 121/5.185); Site 3 (RS 121/5.225 - 121/5.370)

- Blocks come off the slope and hit the water table. Most of the blocks stay in the water table, but those that shatter spread out over the road to about the centreline.

- Most of the blocks that land on the road are typically 75 mm diam and below. Blocks in the water table are typically 150 - 200 mm diam.

- Could be up to 12 - 15 blocks on the road at any one time during the worst time of year. It is difficult to say whether these are all from a single rockfall or several events.

- There are no preferred areas on the slope where rockfalls originate from.

Comments on Site 4 (RS 121/5.6.130 - 121/6.216 "Paddys Bluff")

- Most of the rockfall material now ends up behind the bund which has been constructed along the inside of the road.

- Bigger rockfall material which comes from higher up on the slope breaks up on its way down the slope.

- Bigger sized material in the 150 - 200 mm diam range comes from lower down on the slope, which ends up behind the bund.

- Rockfall that ends up on the road is typically 75 mm diam and down.

- Rockfall material on road covers the entire carriageway.

- Occasional bigger blocks up to 150 mm diam come on to road, say every 2 - 3 days during the most active periods of the year. These are less frequent during less critical periods of the year.

- Rockfall activity has probably dropped off during recent years compared to the period following 1982 (when the road was widened).

- Wire rope with a monsoon bucket was anchored across the slope face by means of railway irons for scaling operations.

Comments on Site 5 (RS 121/5.6.230 - 121/6.380)

- Large rockfall on 22 December 1997 which had dimensions of 700 x 400 mm.

- Mike Smith confirms Ken Avant's comments on the size and frequency of rockfalls at site 5, that is, similar to sites 1, 2 and 3.

General Comments

- Two scaling operations have been carried out along the "Paddys section" of SH73, in 1994 and again in 1995 (dates approximate).

- Worst time of year for rockfall activity is spring to autumn.

- There was little rockfall activity along this section of SH73 prior to road widening in 1982, with rockfall activity gradually increasing since that time.

- Len Collettt says that road widening has undoubtably contributed to rockfall activity since 1982.

- The earthquake event of June 1994 and the later earthquake with its epicentre on Hawden Valley resulted in a short term increase in rockfall activity.

- Mike Smith says the ratio of unreported to reported accidents is probably in the order of 20 - 30:1.

- Unreported accidents are unreliable because most are non specific about their location.

- Transit's cyclic costs (km/month cost) for detritus clean ups along this section of SH73 which is $480 per year is considered to be far to low compared to the actual cost for this work. This is because the cost is subsidised over the entire highway covered by the central Canterbury contract.

- Len Collett believes that if the cost of detritus clearance was costed on an actual cost basis, the total cost for each clean up visit would be in the order of $120 (staff and truck hire). Based on the present number of clean up trips (550 per year) this equates to $66 000 per annum.

- Mike Smith's estimate for detritus clean ups is $57 680 per annum based on actual costs for staff time and plant hire and the present number of clean up visits. However, if the maintenace contract was restructured to reflect the actual costs for the work, then the time per visit could be reduced from two hours per round trip to say about 1.2 - 1.5 hours. One way this could be achieved would be by requiring the maintenance team to dispose of detritus off the site at the time of each clean up visit, rather than by stockpiling the material along the water table and removing the material in several clean up operations throughout the year.

RECORD OF INTERVIEW

1. Name: i) Niall Shepherd, ii) Barry Drummond

2. Employer: i) NZ Police, ii) Tranz Rail Ltd.

3. Position: i) Arthurs Pass Community Policeman since 1986
ii) Midland line railway maintenance and frequent user of SH73

4. Date of interview: 28 January 1998

5. Relevance of Interviewed Persons to Transfund Study:

i) Resident at Arthurs Pass since 1986, ii) Resident at Cass since since 19?

General Comments

- The worst time of year for rockfall activity is during frost periods and heavy rain, and after earthquake activity.

- New slip areas appear to be developing all the time, rather than just being restricted to sites 1, 2, 3, 4 and 5.

- Damage to vehicles include front suspension repairs and punctures to petrol tanks.

- Works Civil Constrcution Ltd.'s site visit statisics over state the number of times there are rocks on the road.

- 3 vehicles have been hit by rockfalls between Porters Pass and Otira in 11 years since Niall Shepherd has been at Arthurs Pass.

- If this stretch of highway was only one lane, then it would be regarded as being at least as bad as "Candys" from the point of view of rockfall material on road - Mrs Shepherd.

- Most rockfall activity appears to be at night, except during winter time when it tends to be mid afternoon when the sun reaches the icy slopes above.

Comments on Site 1 (RS 121/4.975 - 121/5.025); Site 2 (RS 121/5.090 - 121/5.185); Site 3 (RS 121/5.225 - 121/5.370)

- These sites are more of a problem than "Paddys".

- Constant problems with rockfalls on to road at site 2, material always coming down.

- Vehicle sight distances are very short for sites 1, 2 and 3 making them potentially more dangerous than "Paddys".

- Rockfall material ends up all over road, but with most of the material on the inside lane. Motorists stop and pick up rock off road, giving the impression that material lands in the verge.

- Big slip and rockfall came down in June 1996, requiring a digger to clear the road. This occurred at the bottom of the hill approximately 75 m from where the "white cross" is fixed to the guard rail (site 2).

Comments on Site 4 (RS 121/5.6.130 - 121/6.216 "Paddys Bluff")

- Construction of the bund at "Paddys" has stopped 50 - 70% of the material coming on to the road. Only large blocks of rock now coming on to road.

- The size of rockfall material at "Paddys" is generally smaller than the other problem sites along this stretch of highway.

- Rockfall material breaks up into smaller pieces as it comes down the hill.

- Barry Drummond hit by rockfall at "Paddys" 4 - 5 years ago.

RECORD OF INTERVIEW

1. Name: Shaun Jackson

2. Employer: Arthurs Passing Towing

3. Position: Manager, Arthurs Pass Towing

4. Date of interview: 28 January 1998

5. Relevance of Interviewed Persons to Transfund Study:

Resident at Arthurs Pass for 6 years.

General Comments on Paddys Bluff section of SH73

- Vehicle damage from rockfall activity at "Paddys" section of SH73 includes tyres, petrol tanks and sumps.

- Accidents attended by Arthurs Passing Towing could be of the order of 10 - 30 per year. There could also be a number of accidents that are not serious enought to call out Arthurs Pass Towing.

- The construction of the bund at "Paddys" has improved the rockfall situation at this area.

- In addition to rockfall activity, there was also a snow avalanche reported last year (1997) as a result of a south west storm.

RECORD OF INTERVIEW

1. Name: i) Keith Pedley, ii) Brian Dowdle

2. Employer: Works Civil Construction

3. Position: i) Project supervisor (Maintenance), ii) Highway maintenance staff

4. Date of interview: 28 January 1998

5. Relevance of Interviewed Persons to Transfund Study: SH73 maintenance contractors.

General Comments

- Earthquake occurred during Labour weekend 1995 resulting in rockfall material from all sites along the "Paddys" section of highway.
- Worst time of year for rockfall activity is during heavy rainfall and spring thaw.
- Most of the trips (call outs) past this section of SH73 result in rock clearance operations.
- Brian Doudle knows of 5 incidences of cars being hit by falling rock over the last 12 years, with damage including broken windows and dented panels.
- Brian Doudle knows of some 50 - 60 cases of cars running into stationary rocks lying on the road over the last 12 years.
- After weekends when there has been a lot of rockfall activity, if there has been road clearance operation, rocks are "windrowed" on the road due to vehicle tracks cutting through the debris casing the rocks to pile up on either side of the tracks.
- Flashing lights are put as a warning sign in winter and in spring during the worst times of the year.

Comments on Site 1 (RS 121/4.975 - 121/5.025); Site 2 (RS 121/5.090 - 121/5.185); Site 3 (RS 121/5.225 - 121/5.370)

- Rockfall material impacts on to the inside lane of the road, then rockfall material spreads to either inside or outside shoulder of road.
- Cracks in the rock face at site 2 have increased in width over the last few years.

RECORD OF INTERVIEW

1. **Name:** Graeme Nimmo

2. **Employer:** Fulton Hogan Ltd.

3. **Position:** Highway maintenance staff for Fulton Hogan

4. **Date of interview:** 29 January 1998

5. **Relevance of Interviewed Persons to Transfund Study:**

i) 1971 -91: SH73 maintenance contractor for Works Civil Construction/MWD.
ii) 1991 - 95: highway maintenance contractor for Fulton Hogan Canterbury.

General Comments

• Windy and wet conditions result in rockfall activity. Can guarantee rockfall material on road after wet and windy conditions.

• 70 - 80% of visits (call outs) to this section of highway result in rockfall material on road.

• On very windy days and days with heavy northwest rainfall, road maintenace crews have spent 3/4 of a day travelling back and forth between sites 1 and 5 picking up rocks off the road. On these occasions, rockfall activity is more or less continuous. Road crews have to return to the same spot at very short time intervals.

• Northwest winds and rain result in bringing down larger sized rockfall material compared with freeze and thaw activity which brings down smaller sized material.

• During very rough weather, Graeme Nimmo has observed rockfalls occurring ahead and behind passing vehicles along this section of highway. The falling rocks have been seen on all areas of this section of highway.

• Whiskey Creek. The section of road cut immediately east of Whiskey Creek is also a problem area for rockfall activity. The batter is not high (4 - 5 m), but there is always a shower of 75 - 100 mm diameter rockfall material here.

• On the outside of the road at Whiskey Creek, a gabion basket has been built over the culvert, resulting in a shear drop below the culvert down to the river below. There was a fatal car accident at this section of highway in the 1970's (exact date unknown). A car with a woman driver left the road during a heavy northwest rainfall, which ended up in the river below. The river was in flood at the time.

• Graeme Nimmo has seen numerous disabled vehicles on this section of highway due to cars hitting stationary rocks lying on road. Damage has included lots of flat tyres, broken sumps, and the odd smashed windscreen.

• Road maintenance staff are at greater risk than general road traffic due to the greater time of exposure to rockfall activity during highway cleanup operations. It is a very common situation for road maintenance staff to dodge rockfall material during cleanup operations. Road maintenance staff find it very difficult to judge the direction of falling rock. Machines give some degree of protection to staff, but there is also the handicap of not being able to see and sensing falling rock when positioned inside a machine.

• Graeme Nimmo considers that under today's standards, something should be done about improving road safety along this section of highway.

Comments on Site 1 (RS 121/4.975 - 121/5.025); Site 2 (RS 121/5.090 - 121/5.185); Site 3 (RS 121/5.225 - 121/5.370)

- Rockfall material at sites 1, 2 and 3 "chunkier" than at site 4 ("Paddys"). Commonly there are blocks the size of a car sump or bigger on the road at these localities.

- Oil patches are commonly found on the road, suggesting punctured car sumps.

- Often rocks are required to be rolled off road, rather than just picked up and thrown away, due to their size.

- Rocks which originate from a low height on the batter (several metres above road) land in the gutter/road verge. Rocks from a greater height land on the road itself, from the centreline to the outside lane of the road. Some rocks land on the road and bounce straight over the edge.

- Graeme Nimmo has had rocks come down while working on the road, resulting in a number of near misses.

- Second fatal accident occurred in about 1979. A young woman driver (Miss Youngman) went off the road at the top of "Paddys" hill, possibly 100 - 200 m beyond (west) of site 2. The car went between guard rails and into the river. The accident was only discovered 2 days after the event after the river which was in flood at the time cleared.

- Cars have been observed driving on the wrong side of the road in order to avoid fallen rock, resulting in their not being able to observe oncoming vehicles.

Comments on Site 4 (RS 121/5.6.130 - 121/6.216 "Paddys Bluff")

- Crib wall between sites 4 ("Paddys") and 5 was removed in 1982 as part of road a widening exercise. Minor blasting was carried out at "Paddys" as part of this work, which resulted in the slip which occurred in mid October 1982.

- Fulton Hogan implemented a small 600 mm high bund along the inside of the road for rockfall control. This structure is good for catching small rockfall material, and probably stops about 30% of the rockfall material from reaching the road. Larger diameter rockfall material and rockfall from greater height continues on to road.

- Even with the bund rockfall material covers the whole of the road, but the coverage is worst on the inside lane.

- The size of rockfall is smaller than at sites 1, 2 and 3.

- On some bad days, cars have been observed driving on the wrong side of the road or on to the adjacent fill area to avoid rockfall material on the road.

Comments on Site 5 (RS 121/5.6.230 - 121/6.380)

- Nil

Comments on Site 5 (RS 121/5.6.230 - 121/6.380)

- a lot of small rock lands on the road here.
- rock fall material is mainly brown slaty rock, which is sharp edged.
- there is not much in the way of a shoulder here, so most of the rock ends up on the road.

General Comments

- there is rock fall material to be removed from the road on about 50% of the visits (call outs). This does not mean that there was no rock on the road for those visits when rock was not removed, merely that there was no rock at the time of the visit. Rock may have been removed bu others (eg motorists).
- 5 incidents of cars being hit by falling rock that BD is aware of (ie since 1985).
- BD has been hit by falling rock on several occasions while doing maintenace and traffic control.
- Miss Mahony of Arthurs Pass rolled her vehicle near Whiskey Creek 15- 20 December 1997. Check details with Niall Shepherd.
- 1985 - 88 (exact date uncertain) a vehicle with a woman driver left the road west of site 5.
- BD has never seen any repairs to the road pavement due to rock fall puncture marks.
- there are small dents in the pavement which seem to heal up again.
- BD has never had to carry out any repairs due to rock falls, only from cleaning operations ie seal cracks from loader.
- the 1995 earthquake caused numerous rocks on road at all sites.
- at Paddys, the earthquake resulted in rock fall material everywhere, up to 500 - 600 mm diameter.
- the greatest road danger to road safety is from vehicles manouvreing to avoid rocks, resulting in the potential to run into other vehicles or run off the road.
- there is less risk of vehicles being hit by falling rocks.
- at Paddys, the risk could be overcome by building a concrete wall 1.8 - 2 m high along the shoulder.
- at site 5, the risk could be overcome by building a catch fence at the toe of the slope above the water table.
- at the "chute", the risk could be overcome by constructing a gabion curtain at the mouth of the chute to slow down rocks. This would need to allow rocks to pass under the basket after they have been caught by the basket.

RECORD OF INTERVIEW

1. Name: Paddy Freaney

2. Employer: Bealey Hotel

3. Position: Manager

4. Date of interview: 26 February 1998

5. Relevance of Interviewed Persons to Transfund Study:

i) PF has lived in the Arthurs Pass area for 27 years.

ii) PF is the manager of the Bealey Hotel and is regularly called on to assist the occupants of cars involved in minor accidents due to rock fall.

General Comments

- PF is called on approximately 10 times per year by the occupants of vehicles who have had minor accidents at the Paddys.

- PF can recall a fatal accident in the mid 1970's involving an Elizabeth Williams (daughter of All Black Claude Williams) who ran off the road at the bottom of the Paddys hill *(probalbly close to site 2).* The accident happened during a very bad northwest storm. The car and body were not found until several days later; the body was approximately 2 km downstream and had been thrown or washed out of the car. The cause of the accident was never determined but PF believes that due to the weather conditions, debris on the road cannot be discounted as a cause.

- In the mid 1970's, PF was driving east at night at night towards Paddys during a bad northwest storm. The road at Paddys was blocked by a large slip/rockfall to a height of about 700 mm (2 feet) over a road distance of about 10 m. This required him and others to return with shovels to clear the road.

- PF is aware of anecdotal evidence of a woman passenger in a car driving east up the Candys section of road being killed by a small rock fall in the 1950's.

RECORD OF INTERVIEW

1. Name: Wayne Glassey

2. Employer: Springfield Garage

3. Position: Owner, Springfield Garage

4. Date of interview: 8 May 1998

5. Relevance of Interviewed Persons to Transfund Study:

Tow truck operator and vehicle repairs for cars damaged by rock fall on SH73.

General Comments on Paddys Bluff section of SH73

- Vehicle damage from rockfall activity at "Paddys" section of SH73 includes tyres, petrol tanks and sumps.
- Accidents attended by Springfield Garage could be of the order of 6 - 12 per year.
- The average cost of repairs to vehicles is of the order of $500 - $1 000

RECORD OF INTERVIEW

1. **Name:** David Tucker

2. **Employer:** Retired

3. **Position:**

4. **Date of interview:** 13 May 1998

5. **Relevance of Interviewed Persons to Transfund Study:**

- Christchurch residency, MOW 1967 - '73
- Christchurch District Office, Materials & Investigations Division, MOW 1973 - '80

General Comments on Paddys Bluff section of SH73 -

- SH73 was first sealed during the period 1967 - 73, with the "Paddys" section probably sealed during the latter part of this period. Retaining walls were constructed and a small amount of cutting on the inside of the road carried out at this time.

- No major slips occurred during this time.

- Suggest that R&G contact Hamish Ballentyne who was the Christchurch MOW resident engineer from 1977 - '90 for further comment (383 2006) regarding a major slip after 1982.

SUMMARY OF ROCK FALL CHARACTERISTICS AS DETERMINED FROM INTERVIEWS

1. Site Characteristics

(i) Sites 1 - 3:

Ken Avant
- maximum size 500 mm; typical size 100 - 300 mm
- April - September: 4 - 5 rockfall events per site visit
- during northwest weather: 6 - 7 rockfall events per site visit

Mike Smith, Len Collett
- blocks that come off the slope hit the water table. Most blocks stay in the water table but those that shatter spread ~~out~~ ~~over~~ the road to about the centreline.
- most of the blocks that land on the road are typically 75 mm diam. and below. Blocks in the water table are typically 150 - 200 mm diam.
- could be up to 12 - 15 blocks on the road at any one time during the worst time of year. Cannot say whether these are all from a single event or several events.

Graeme Nimmo
- rockfall material "chunkier" than at site 4; commonly rocks occur the size of a car sump or bigger
- rocks which originate from a low height on the batter land in the gutter/verge, while those from higher up land on the road itself from the centreline to the outside lane. Some rocks land on the road and bounce over the outside edge of the road.
- rocks are often required to be rolled off the road, rather than just picked up and thrown away.

Niall Shepherd, Barry Drummond
- these sites are more of a problem than Paddys, vehicle sight distances are very short.
- rockfall material ends up all over the road, but with most of the material on the inside lane. Motorists stop and pick up rockfall off the road, giving the impression that material lands in the verge.
- big rockfall in June 1996 close to site 1 or 2, requiring a digger to remove the debris.

Brian Dowdle
- these sites not so much influenced by bad weather, than by earthquake and freeze thaw.
- large rock falls 500 - 1000 mm diam occur on average 1 - 2 times per year.
- falls of small rock < 200 mm diam. occur most of the time.

(ii) Sites 4 ("Paddys), 5

Ken Avant
- rockfall material typically 100 - 200 mm; only very occasional material above this diam.
- site 4, worst time of year (spring thaw), hundreds of rockfall pieces picked up off road each site visit.
- worst time of year for rock fall activity is in the spring thaw, but activity carries on all through the winter.
- the low bund which has been constructed at the toe of the slope picks up material which orginates from a low height on the slope, but does not stop material from higher up which breaks up and over shoots the bund.
- site 5, size of rockfall material is the same as site 4, but frequency is like sites 1, 2, 3.
- site 5, large rockfall of 400 - 500 mm diam. occurred 22/12/97 - material of this size infrequent but does indicate occasional larger rockfall activity.

Mike Smith, Len Collett
- most of the rockfall material now ends up behind the bund.
- bigger sized rockfall which comes from higher on the slope breaks up on the way down.
- large rockfall at site 5 on 22/12/97 which had dimensions of 700 x 400 mm diam.

Graeme Nimmo
- even with the new bund at Paddys, rockfall material covers the whole road, but is worst on the inside lane. Bund probably stops about 30% of rockfall material from encroaching on to the road.

Niall Sheperd, Barry Drummond
- the bund at Paddys has stopped 50 - 70% of the rock coming on to the road. Only larger blocks now coming on to road.
- rockfall material breaks up. into smaller sizes as it comes down the slope.

Shaun Jackson
- the bund has improved the rockfall situation at this site.

Paddy Freaney
- road was blocked by a large rock slide in the mid 1970's to a height of about 700 mm and over a road distance of 10 m.

Brian Dowdle
- the bund has been successful in catching smaller diam. rocks and rocks that slide down the slope.
- falls of bigger 400 - 500 mm diam. rocks reach the road. 2 - 3 blocks of this diam. reach the road each month.
- greater range of rock sizes compared to sites 1, 2, 3 from very small to 400 - 500 mm.
- very few times that the site is visited when there are not rocks on the road. The amount of rock material on the road varies considerably.

2. Failure Modes

(i) Site 2:

- rock fall 0 - 150 mm diam.
- rock fall 150 - 300 mm diam.
- rockfall 300 - 500 mm diam.
- rockfall > 500 mm diam.

(ii) Site 4 ("Paddy's Slip):

- rock fall 0 - 150 mm diam.
- rock fall 150 - 300 mm diam.
- rock fall 300 - 500 mm diam.
- rock fall > 500 mm diam.
- rock slide/debris slide: up to approximately 100 m^3

3. Probability Distribution For Each Failure Mode

(i) Site 2:

- **Assess the number of rock fall events per year.**

- based on number fo call outs
  (i) total number of call outs per year for surface detritus maintenance: 550
  (ii) call outs per year for surface detritus attributable to site 2 @ 25%: 138
  (iii) total number of emergency call outs for large slips/rocks: 10
  (iv) emergency call outs for large slips/rocks attributable to site 2 @ 25%: 2.5
  (v) total number of call outs for rocks on road = 140
  (vi) assume an average of 2 - 4 seperate rock fall events per call out:
  140 x 2(4) = 280 (560) rock fall events per year

- based on Ken Avant's data:
  - (i) 4 - 5 rock falls per visit April - September: 183 x 2 x 25% x 5 = 458
  - (ii) northwest weather 6 - 7 rock falls per site vist. Now assume approximately 20 severe northwest storms per year: 20 x 1.5 x 25% x 7 = 53
  - (iii) total number of rock falls = 511 per year

- based on Mike Smith, Len Collett
  - (i) 12 - 15 rock blocks on road at any one time during worst time of year (ie April - September): 183 x 2 x 25% x 15 = 1373 blocks and now assume that say 3 - 4 blocks make up one rock fall event: 1373/4 = 343 rock fall events for worst time of year.
  - (ii) no information given for remainder of year, but assume the number of rock falls for the worst time of the year needs to be factored up by 125% to provide an indication of the total number of rock falls per year: 343 x 1.25 = 428

- calculate the number of rock falls per year based on all the evidence:
  - (i) minimum = 300
  - (iii) maximum = 600
  - (iii) mean = 450

- **Assess the probability distribution for each failure mode.**

- based on Ken Avant's data:
  - (i) typical size: 100 - 300 mm diam.
  - (ii) maximum size: 500 mm diam.

- based on Mike Smith/Len Collett's data:
  - (i) rocks on road typically 75 mm and below; blocks in water table 150 - 200 mm.

- based on Graeme Nimmo's data:
  - (i) rock fall material "chunkier" than site 4

- based on Brian Dowdle's data:
  - (i) large rock falls 500 - 1000 mm diam occur on average 1 - 2 times per year
  - (ii) falls of small rock < 200 mm diam occur most of the time

- assessed probability distribution for rock falls reaching the road for different failure modes:
  - (i) 0 - 150 mm diam: 65 % or 293 rock fall events per year
  - (ii) 150 - 300 mm diam: 33% or 150 rock fall events per year
  - (ii) 300 - 500 mm diam: 0.01% or 5 rock fall events per year
  - (iv) > 500 mm diam: 0.004% or 2 rock fall events per year

(ii) Site 4 ("Paddys")

- **Assess the number of rock fall events per year.**

- based on number of call outs
  - (i) total number of call outs per year for surface detritus maintenance: 550
  - (ii) call outs per year for surface detritus attributable to site 4 @ 95%: 523
  - (iii) total number of emergency call outs for large slips/rocks: 10
  - (iv) emergency call outs for large slips/rocks attributable to site 4 @ 75%: 7.5
  - (v) total number of call outs for rocks on road = 530
  - (vi) assume an average of 10 - 20 separate rock fall events per call out: 530 x 5 = 5 300 - 10 600 rock fall events per year, but could be much greater than this. Assume a skwed probability distribution, with a long tail on the high side.

- based on Ken Avant's data:
  - (i) worst time of year (spring thaw), hundreds of rock fall pieces picked up off road each visit.
  - (ii) worst time of year for rock fall activity is in the spring thaw, but activity carries on all through the winter.
  - (iii) the low bund which has been constructed at the toe of the slope picks up material which orginates from a low height on the slope, but does not stop material from higher up which breaks up and over shoots the bund.

- based on Graeme Nimmo's data:
  - (i) even with the new bund, rock fall material covers the whole road, but is worst on the inside lane. Bund probably stops about about 30 % of the rock fall material from encroaching on to the road.
  - (ii) the size of the rock fall is smaller than at site 2

- based on Niall Shepherd/Barry Drummond's data:
  - (i) the bund has stopped about 50 - 70% of the rock coming on to the road. Only larger blocks now coming on to road.

- based on Paddy Freaney's data:
  - (i) road was blocked by a large rock slide in the mid 1970's to a height of about 700 mm and over a road distance of 10 m.

- based on Brian Dowdle's data:
  - (i) the bund has been successful in catching smaller diam. rocks and rocks that slide down the slope
  - (ii) very few times that the site is visited when there are not rocks on the road. The amount of rock material on the road varies considerably.

- calculate the number of rock falls per year based on all the evidence:
  - (i) minimum = 5 000
  - (iii) maximum = 7 500
  - (iii) mean = 10 000

- **Assess the probability distribution for each failure mode.**

- based on Ken Avant's data:
  - (i) rock fall material typically 100 - 200 mm diam.; only very occasional material above this diam.

- based on Graeme Nimmo's data:
  - (i) the size of rock fall is smaller than at site 1

- based on Niall Sheperd/Barry Drummond's data:
  - (i) rock fall material breaks up into smaller sizes as it comes down the slope

- based on Brian Dowdle's data:
  - (i) falls of bigger 400 - 500 mm diam rocks reach the road. 2 - 3 blocks of this diam. reach the road each month.
  - (ii) greater range of rock sizes compared to site 2, from very small to 400 - 500 mm.

- assessed probability distribution for rock falls reaching road for different failure modes without existing bund:
  - (i) 0 - 150 mm diam: 90 % or 6 750 rock fall events per year
  - (ii) 150 - 300 mm diam: 9.5% or 715 rock fall events per year
  - (ii) 300 - 500 mm diam: 0.004% or 30 rock fall events per year
  - (iv) > 500 mm diam: 0.0006% or 5 rock fall events per year
  - (v) rock slides/debris slides: 1 event per 5 years

- assessed probability distribution for rock falls reaching road for different failure modes with existing bund. Assume that the bund stops 70% of all small rock falls (0 - 150 mm diam)., 20% of rock falls of 150 - 300 mm diam., but has no effect on larger (> 300 mm diam) rock falls or rock slides/debris slides:
  - (i) 0 - 150 mm diam: 30 % of 6 750 rock falls = 2 025 rock falls per year which reach the road
  - (ii) 150 - 300 mm diam: 80% of 715 rock falls = 570 rock falls per year which reach the road
  - (ii) 300 - 500 mm diam: 0.004% or 30 rock fall events per year
  - (iv) > 500 mm diam: 0.0006% or 5 rock fall events per year
  - (v) rock slides/debris slides: 2.6 x 10^{-5}% or 0.2 rock slides events per year

SUMMARY OF ACCIDENT HISTORY AND COSTS
AS DETERMINED FROM INTERVIEWS

1. Assessment of Accident History

1.1 Reported accidents cause unknown

i) Fatal accidents

The section of highway from RP 121/0 - 121/10 has experienced a number of fatal accidents over a long period of time. LTSA accidents reports are available for 2 fatal accidents which occurred on 3 December 1987 and 2 March 1996 for which it would appear unlikely that the cause of accident was rock fall.

Anecodotal evidence provided by highway maintenance staff and by Paddy Freaney support the conclusion that rock fall cannot be discounted as the cause of two fatal accidents, but the LTSA records for these events have not been located:

Graeme Nimmo

- On the outside of the road at Whiskey Creek, a gabion basket has been built over the culvert, resulting in a shear drop below the culvert down to the river below. There was a fatal accident at this section of highway in the 1970's (exact date unknown). A car with a woman driver left the road during a heavy northwest rainfall, which ended up in the river below. The river was in flood at the time.

- Second fatal accident occurred in about 1979. A young woman driver (Miss Youngman) went off the road at the top of "Paddys" hill, possibly 100 - 200 m beyond (west) of site 2. The car went between guard rails and into the river. The accident was only discovered 2 days after the event after the river which was in flood at the time cleared.

Paddy Freaney

- PF can recall a fatal accident in the mid 1970's involving an Elizabeth Williams (daugher of All Black Claude Williams) who ran off the road at the bottom of Paddys hill (*probably close to site 2).* The accident happened during a very bad northwest storm. The car and body were not found until several days later; the body was approximately 2 km downstream and had been thrown out of or washed out of the car. The cause of accident was never determined but PF believes that due to the weather conditions, debris on the road cannot be discounted as a cause. *(This is likely to be one of the two accidents reported by Graeme Nimmo).*

The available data therefore indicates tow fatal accidents on this section of highway (RP 121/0 - 121/10) in 17 years possibly attributable to rock fall, although the evidence is insufficient to substantiate this. There have been no fatal accidents at either of the two study areas, with the closest possible fatal accident occurring 100 - 200 m west of site 2.

- Number of reported accidents due to rock fall: 1 accident in 17 years (0.06)

- Annual cost of reported accidents due to rock fall: 0.06 x $2 400 = $144 per year

1.2 Unreported accidents attributable to rock fall.

i) General

Ken Avant

- although the frequency of rockfall activity is lower, sites 1, 2 and 3 regarded as a higher risk than sites 4 and 5 due to the poor visibility of the approaches and there being little room for manoeuvring to avoid rockfall on the road.

Mike Smith, Len Collett

- two scaling operations have been carried out along the "Paddys section" of highway, in 1994 and again in 1995.
- worst time of year for rockfall activity is spring to autumn.
- earthquakes of 1994 and 1995 resulted in a short term increase in rockfall activity.
- the ratio of unreported to reported accidents is probably in the order of 20 - 30:1.
- unreported accidents are unreliable because most are non specific about their location

Graeme Nimmo

- GN has seen numerous disabled vehicles on this section of highway due to cars hitting stationary rocks lying on the road. Damage has included lots of flat tyres, broken sumps, and the odd smashed windscreen.
- 70 - 80% of call outs to this section of highway result in rockfall on the road.
- on very windy days and days with heavy northwest rainfall, road maintenance crews have spent 3/4 of a day travelling back and forth between sites 1 and 5 picking up rocks off the road. On these occasions, rock fall activity is more or less continuous. Road crews have to return to the same spot at very short time intervals.
- during very rough weather, GN has observed rock falls occurring ahead and behind passing vehicles along this section of highway
- has observed numerous disabled vehicles due to cars hitting stationery rocks on road.
- road maintemance staff are at greater risk than motorists due to the greater exposure time. There have been a number of near misses while working on the road.
- cars have been observed driving on the wrong side of the road to avoid stationary rocks.
- Two fatal accidents have occurred thought to be in the 1970's. There is no indication that these were attributable to rockfall, though both occurred during heavy northwest rainfall.

Niall Shepherd, Barry Drummond

- Works Civil Construction site visit statistics overstate the number of rocks on the road.
- 3 vehicle have been hit by rock falls between Porter's Pass and Otira in 11 years since NS has been Arthurs Pass
- if this stretch of highway was only one lane, then it would be regarded as being at least as bad as Candys from the view point of rock fall material on road - Mrs Shepherd

Shaun Jackson

- vehicle damage from rock fall activity at "Paddys" section of SH73 includes tyres, petrol tanks and sumps.
- accidents attended by Arthurs Pass Towing could be of the order of 10 - 30 per year. • there could also be a number of accidents that are not serious enough to call out Arthurs Pass Towing

Paddy Freaney

- is called on approximately 10 times per year to assist motorists with minor accidents.
- fatal accident occurred during the mid 1970's close to site 2. Cause of accident not known, but there was a severe northwest strom at the time, such that rockfall cannot be discounted as a cause of accident.

Brian Dowdle

- there is rockfall material to be removed from the road on about 50% of the call outs.
- 5 incidents of cars being hit by fallling rockthat he is aware of since 1985, and he has been hit by falling rock when carrying out maintenance work.
- vehicle rolled near Whiskey Creek 15 - 20 December 1997.
- woman driver left the road west of site 5 in 1985 - 88.
- no repairs have been carried out to the pavement due to rockfall since he has been involved with highway maintenance.
- 1995 earthquake caused numerous rocks on the road at all sites. At Paddys, the earthquake caused rockfall material everywhere, up to 500 - 600 mm diam.

the greatest danger to traffic is a result of manouvreing to avoid rocks on the road, rather than being hit by falling rocks.

- at Paddys, the risk could be mitigated by building a concrete wall 1.8 - 2 m high.
- knows of 5 incidences of cars being hit by falling rock over the last 12 years, with damage including broken windows and dented panels
- knows of some 50 - 60 cases of cars running into stationary rocks lying on the road over the last 12 years
- has been hit by falling rock on several occasions while doing maintenance
- there is less risk of vehicles being hit by falling rocks.

Wayne Glassey
- 6 - 12 minor accidents per year over this stretch of highway
- typical damage includes sumps, fuel tanks and tyres.
- typical cost of damage is $500 - $1 000.

ii) Site 2

Nial Shepherd, Barry Drummond
- these sites are more of a problem than Paddys
- vehicle sight distances are very short for site 2 making it potentially more dangerous than Paddys (site 4)

Graeme Nimmo
- GN has had rocks come down while working on the road, resulting in a number of near misses
- cars have been observed driving on the wrong side of the road in order to avoid fallen rock, resulting in their not being able to observe oncoming vehicles

iii) Site 4 "Paddys"

Nial Shepherd, Barry Frummond
- BD hit by rock fall at "Paddys" 4 - 5 years ago

Graeme Nimmo
- on some bad days, cars have been observed driving on the wrong side of the road or on to the adjacent fill area to avoid rock fall material on the road

Based on the data by Shaun Jackson and Wayne Glasey, there are approximately 16 - 42 (average 30) unreported accidents per year attributable to rock falls that require mechanic assistance and repairs to damage. Undoubtably there are also unreported accidents which do not require mechanic assistance and damage repairs. This number is difficult to estimate but has been assumed as an additional 5 accidents per year, making a total of 35 unreported accidents per year. Accident costs for non injury accidents for a 100 kph speed environment have been extracted from the Transfund Manual ie $2 400/accident, all vehicle movements.

- Number of unreported accidents due to rock fall: 35 per year

- Annual cost of unreported accidents due to rock fall: 35 x $2 400 = $84 000 per year

2. Assessment of Cost of Accidents

2.1. General Comments on Costs

Ken Avant
- The cost to Transit of rockfall clearance between sites 1 - 5 is approximately $65 000 per year.

Mike Smith, Len Collett
- ratio of unreported to reported accidents is approximately 20 - 30:1

2.2 Site 2

Assume that 15% of the non-injury accidents that occur between RP 121/0.0 - 121/10.0 take place at site 2. Therefore the cost of non-injury accidents at site 2 is:

- 5.25 accidents per year x $2 400 = $12 600/year

2.3 Site 4

Due to the much greater frequency of rockfall at site 4, the assumed non-injury accident rate at this site will be much greater at say 60%. Therefore the cost of non-injury accidents at site 4 is:

- 21 accidents per year x $2 400 = $50 400/year

ASSESSMENT OF MAINTENANCE COSTS AS DETERMINED FROM INTERVIEWS

1. Cost of Surface Detritus Maintenance

Mike Smith/Len Colllit

- Transit's cyclic costs for detritus clean ups which is $480 per year is far too low.
- LC considers that the total cost for each callout visit would be in the order of $120 per visit. This equates to $66 000 based on 550 call outs per year.
- MS's estimate for detritus call outs is $57 680 based on actual costs for staff time and plant

- There are 550 visits per year for problem surface detritus clean ups along RP 121/0/0 - 121/10.0.

- Assume that site 2 is visited on 25% of the occasions = 138 visits

- assume that site 4 is visited on 95% of the occasions = 523 visits

- cost of surface detritus maintenance under the present Pavement Drainage and Emergency callout Contract between RP 121/2.0 - 121/10.0 (8 km) is $5/km/month, which equates to an annual cost of $480 per year. This is judged by the Network Maintenance Contractor to be far too low and not representative of the actual cost of carrying out the work.

- Network Management Consultant has calculated the actual cost of surface detritus maintenance based on the requirements of the Pavement Drainage and Emergency callout Contract is $76 860 per year (based on actual time and plant hire) for this stretch of highway, or $140/ visit. Therefore the actual cost for surface detritus is:

site 2: 138 visits x $140/visit = $19 320/year
site 4: 523 visits x $140/visit = $73 220/year

- Network Maintenance Contractor has assessed that the cost of surface detritus maintenance could be reduced if the Contractor was paid for what they actually do at each site. This would treduce the base to base call out time from the present 2 hours to approximately 1.2 hours, and hence reduce the actual costs from $76 860 to $46 116 per year, or $84/visit. Therefore the actual cost for surface detritus would reduce to:

site 2: 138 visits x $84/visit = $11 592/year
site 4: 523 visits x $84/visit = $43 932/year

2. Cost of Callouts

Based on the Network Maintenance Contractor and the Network Maintenance Consultant, there are 10 callouts per year between RP 121/0.0 - 121/10.0. Tyoically the evebts are of 2 hours duration. Of these incidents, it is assessed that 75% occur at site 4 "Paddys Slip" and 10% at site 2. Therefore the cost for callouts is:

- site 2: 10 events x 2 hrs x $240/hr (plant/labour) x 10% = $480 per year

- site 4: 10 events x 2 hrs x $240/hr (plant/labour) x 75% = $3 600 per year

3. Summary of Total Annual Costs

	Minimum	**Most Likely**	**Maximum**
(i) Site 2:			
• surface detritus maintenance	480	11 592	19 320
• callouts	480	480	480
Total	960	12 072	19 800
(ii) Site 4:			
• surface detritus maintenance	480	43 932	73 220
• callouts	3 600	3 600	3 600
Total	4 080	47 532	76 820

APPENDIX 4
RESULTS OF ROCKFALL COMPUTER SIMULATIONS

0 5 MAY 1998

Laurie Richards

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RD5 Christchurch • New Zealand

Rock Engineering Consultant

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email: LaurieRichards@Compuserve.com

1 May, 1998

Riddolls & Grocott Ltd
PO Box 22 81
St Elmos Court
47 Hereford Street
Christchurch

Attn Mr G G Grocott

Dear Guy

Re: Paddys Slip rockfall modelling

In your memo of 31 March, you enclosed two cross sections of the slopes for which rockfall modelling was required. Subsequently your memo of 6 April included some further data on the required rock parameters. The analyses have now been carried out using the *CADMA* program that was developed by the research group ISMES in Italy. This allows the rockfall source to be defined over a nominated area of the slope cross section, which makes it useful for situations like Paddys Slip where rockfalls may initiate anywhere on the closely jointed slopes.

Prasad Rayudu carried out preliminary analyses for Sites 2 and 4 with control points at the toe of the slope, the inside edge of the westbound lane and the outside edge of the eastbound lane. Each analysis consisted of 200 runs, i.e. simulation of 200 boulders falling from the rock slopes adjacent to the highway.

The parameters used for the modelling were as follows:

Rock sizes	.075, .147, .225, .297, .400, .495 & 1.000m spheres
Coefficient of normal restitution	0.45 slope;
Coefficient of tangential restitution	0.65 slope;
Roughness	15°
Starting velocity	0.1 m/s

The results of the modelling are provided in Appendix A, which also includes a summary tabulation of the results. For the range of block sizes analysed, the variations in the velocity and height at the various control points are not great. The energy however increases according to the cube of the block size, as would be expected. For the present purposes, the blocks have been analysed as spherical although the program allows elliptical shaped blocks to be modelled.

A further set of analyses has been carried out for a block size of 400mm, which is in the mid-range of the sizes specified. The analyses have been performed for different starting velocities of 0.1 and 1 m/s. These would be typical of the situations where blocks ravel during rainfall or are more forcibly ejected by ice wedging or earthquake. The full set of results is included in Appendix B with a summary given below in Table 1.

For the analyses performed, all the boulders are shown to be rolling across the highway rather than bouncing or impacting on the full. This is a function of the slope geometry, which is at a moderate angle such that rocks do not gain free flight at any stage. It is also related to the simplified geometry that has been used for the analyses. Although the modelling includes simulation of local variations in slope profile where the blocks impact, there is no large-scale slope roughness on the main slopes adjacent to the highway. If the site inspections show that rocks are impacting on the carriageway, further analyses could be carried out if a more detailed section were provided or at least some indication was given as to local "ski-jumps" on the cross sections.

Table 1 provides the data on rock velocities and travel distances which can be used to calculate the probabilities of rocks hitting road traffic. The method of doing these calculations is given in the Canadian Geotechnical Journal article by Morgernstern and Bunce of which you have a copy and also in the review article by Robin Fell in the recent volume on landslide risk assessment which I have lent to you. (I have not yet had a chance to look through this in detail and doubt that I will have time to call in for it before I leave. Could you please post it back as soon as you have finished copying relevant papers as I would like to take it with me).

Please let me know if you have any queries. As discussed with you, I will be away from 12 May to 21 June and will look forward to reviewing your draft on my return. If there are any immediate queries, I can be contacted by email during this time.

Best regards

Laurie Richards

TABLE 1: SUMMARY OF ROCKFALL SIMULATIONS

SITE 2: STARTING VELOCITY = 0.1 m/s

	Toe of slope	Inside edge of west lane	Outside edge of east lane
% of boulders reaching point	31	28	0
Mean velocity m/s	10	6	-
Mean height m	0	0	-
Mean energy kN*m	33	12	-

SITE 2: STARTING VELOCITY = 1 m/s

	Toe of slope	Inside edge of west lane	Outside edge of east lane
% of boulders reaching point	95	73	3
Mean velocity m/s	8	5	2
Mean height m	0	0	0
Mean energy kN*m	27	10	2

SITE 4: STARTING VELOCITY = 0.1 m/s

	Toe of slope	Inside edge of west lane	Outside edge of east lane
% of boulders reaching point	72	56	19
Mean velocity m/s	8	7	6
Mean height m	0	0	0
Mean energy kN*m	28	18	16

SITE 4: STARTING VELOCITY = 1 m/s

	Toe of slope	Inside edge of west lane	Outside edge of east lane
% of boulders reaching point	94	71	25
Mean velocity m/s	9	7	7
Mean height m	0	0	0
Mean energy kN*m	31	18	18

Appendix A
Rockfall simulations with varying block sizes

TABLE A1: ROCKFALL SIMULATIONS WITH 0.1m/s STARTING VELOCITY

SITE 2	Block size (mm)	Toe of slope	Inside edge of west lane	Outside edge of east lane
Velocity m/s min/mean/max	75	0.57/8.1/15.3	0.37/5.11/8.96	2.57/3.71/4.28
	148.5	0.52/7.49/15.1	0.35/5.0/8.28	0.37/1.25/2.12
	225	0.57/7.59/16.73	0.35/4.93/8.37	0.13/1.12/2.1
	297	0.52/8.75/16.38	0.38/4.64/8.07	0.9/1.05/1.21
	400	0.52/8.21/15.03	1.22/5.37/9.48	1.35/3.62/5.1
	495	0.58/7.97/16.42	0.84/4.91/8.24	1.88/1.88/1.88
	1000	0.52/8.2/16.51	0.76/5.22/8.8	2.17/2.81/3.89
Height m min/mean/max	75	0.0/0.0/0.0	0.0/0.0/0.0	0.0/0.0/0.0
	148.5	0.0/0.0/0.0	0.0/0.0/0.0	0.0/0.0/0.0
	225	0.0/0.0/0.0	0.0/0.0/0.0	0.0/0.0/0.0
	297	0.0/0.0/0.0	0.0/0.0/0.0	0.0/0.0/0.0
	400	0.0/0.0/0.0	0.0/0.0/0.0	0.0/0.0/0.0
	495	0.0/0.0/0.0	0.0/0.0/0.0	0.0/0.0/0.0
	1000	0.0/0.0/0.0	0.0/0.0/0.0	0.0/0.0/0.0
Energy kN*m min/mean/max	75	./0.21/0.58	./0.08/0.2	0.02/0.04/0.05
	148.5	./1.33/3.94	./0.51/1.18	./0.04/0.08
	225	.0.02/4.63/16.6	0.01/1.7/4.16	./0.13/0.26
	297	0.04/13.18/36.49	0.02/3.6/8.85	0.11/0.15/0.2
	400	0.09/29.83/75.34	0.49/11.17/29.97	0.61/4.92/8.69
	495	0.21/52.88/169.88	0.45/18.05/42.81	2.22/2.22/2.22
	1000	1.42/456.57/1414.61	3.0/166.92/401.61	24.49/44.15/78.66

SITE 4	Block size (mm)	Toe of slope	Inside edge of west lane	Outside edge of east lane
Velocity m/s min/mean/max	75	1.43/7.82/19.44	1.45/6.25/14.68	2.02/6.54/12.58
	148.5	1.98/7.94/22.42	1.57/6.18/14.09	1.85/6.04/11.93
	225	0.97/7.99/18.68	1.45/5.87/15.03	0.82/6.56/12.98
	297	0.68/7.71/17.85	2.03/6.03/12.11	0.93/4.75/9.46
	400	1.52/7.7/19.45	0.87/5.66/14.29	1.13/5.5/12.07
	495	1.34/7.95/19.39	0.43/6.26/13.83	0.88/5.52/11.63
	1000	0.82/7.99/22.02	0.31/5.62/19.45	2.61/7.65/17.97
Height m min/mean/max	75	0.0/0.0/0.0	0.0/0.0/0.0	0.0/0.0/0.0
	148.5	0.0/0.0/0.0	0.0/0.0/0.0	0.0/0.0/0.0
	225	0.0/0.0/0.0	0.0/0.0/0.0	0.0/0.0/0.0
	297	0.0/0.0/0.0	0.0/0.0/0.0	0.0/0.0/0.0
	400	0.0/0.0/0.0	0.0/0.0/0.0	0.0/0.0/0.0
	495	0.0/0.0/0.0	0.0/0.0/0.0	0.0/0.0/0.0
	1000	0.0/0.0/0.0	0.0/0.0/0.0	0.0/0.0/0.0
Energy kN*m min/mean/max	75	./0.1/0.47	./0.06/0.27	0.01/0.06/0.2
	148.5	0.07/1.38/8.69	0.04/0.83/3.43	0.06/0.77/2.46
	225	0.06/4.61/20.69	0.12/2.54/13.39	0.04/3.09/10.0
	297	0.06/9.99/43.29	0.56/5.97/19.95	0.12/4.08/12.17
	400	0.77/24.16/126.27	0.25/13.53/68.1	0.42/12.51/48.62
	495	1.13/50.15/236.91	0.12/29.48/120.56	0.49/24.86/85.2
	1000	3.51/407.31/2516.22	0.49/217.64/1962.39	35.32/364.96/1675.52

APPENDIX 5
SUMMARY OF ROCKFALL HAZARD RATINGS
(using Rockfall Hazard Rating System)

ROCKFALL HAZARD RATING SYSTEM

Highway:	**SH 73**	Start MP:		End MP:	
Location:	**SITE 1**	Date Rated:	**2/26/98**	By:	**GGG/PH**
TOTAL SCORE:	**524**				

Slope Height

Slope Height (m):	35	**Score:**	100

Ditch Effectiveness:

Good(G), Moderate(M), Limited(L), Nil(N)	L	**Score:**	27

Average Vehicle Risk:

Average Daily Traffic (veh/day):	900		
Section Length (m):	50		
Posted Speed Limit (km/h):	100		
Average Vehicle Risk (%of time):	1.88	**Score:**	1

Percent Decision Site Distance:

Site Distance (m)	72		
Min Decision Site Distance at Posted Speed Limit (m):	312.99		
Percent Decision Site Distance (%):	23.00	**Score:**	206

Roadway Width

Roadway Width(m):	7.1	**Score:**	52

Structural Condition Category

(Note: fill in case 1 only or case 2 only)
(Place 1 beside chosen option)

Case 1

Discontinuous joints, favourable orientation:			
Discontinuous joints, random orientation:			
Discontinuous joints,adverse orientation:			
Continuous joints,adverse orientation:	1	**Score:**	81
	OK		

Joints rough, irregular			
Joints undulating			
Joints Planar	1		
Clay infilling or slickensided		**Score:**	27
	OK		

OR
Case 2

Structural Condition

Few differential erosion features			
Occasional " "			
Many " "			
Major " "		**Score:**	

Small difference in erosion rates:			
Moderate difference in erosion rates:			
Large, difference, favourable structure:			
Large difference, unfavourable structure:		**Score:**	

OK

Climate and Presence of Water on Slope:

Low/mod precipitation, no freezing periods, no water on slope:			
Mod precip or short freezing periods or intermittent water on slope			
High precip or long freezing periods or continual water on slope			
Hi precip + long freezing pds or continual water + long freezing pds		**Score:**	

OK

Block Size/Volume

1ft/3cubic yards	1		
2ft/6 cubic yards			
3ft/9 cubic yards			
4ft/12 cubic yards		**Score:**	3

OK

Rockfall History

Few Falls:			
Occasional Falls:			
Many Falls:	1		
Constant Falls:		**Score:**	27

OK

Reference: "Rockfall hazard Rating System", US Dept of Transportation
Publicaton No: FHWA SA 93 057, November 1993

ROCKFALL HAZARD RATING SYSTEM

Highway:	**SH 73**	Start MP:		End MP:	
Location:	**SITE 2**	Date Rated:	**2/26/98**	By:	**GGG/PH**
TOTAL SCORE:	**645**				

Slope Height

Slope Height (m):	35	**Score:**	100

Ditch Effectiveness:

Good(G), Moderate(M), Limited(L), Nil(N)	N	**Score:**	81

Average Vehicle Risk:

Average Daily Traffic (veh/day):	900		
Section Length (m):	95		
Posted Speed Limit (km/h):	100		
Average Vehicle Risk (%of time):	3.56	**Score:**	1

Percent Decision Site Distance:

Site Distance (m)	60		
Min Decision Site Distance at Posted Speed Limit (m):	312.99		
Percent Decision Site Distance (%):	19.17	**Score:**	254

Roadway Width

Roadway Width(m):	7.5	**Score:**	43

Structural Condition Category

(Note: fill in case 1 only or case 2 only)
(Place 1 beside chosen option)

Case 1

Discontinuous joints, favourable orientation:			
Discontinuous joints, random orientation:			
Discontinuous joints,adverse orientation:			
Continuous joints,adverse orientation:	1	**Score:**	81
	OK		
Joints rough, irregular			
Joints undulating			
Joints Planar	1		
Clay infilling or slickensided		**Score:**	27
	OK		

OR

Case 2

Few differential erosion features			
Occasional " "			
Many " "			
Major " "		**Score:**	

Small difference in erosion rates:	
Moderate difference in erosion rates:	
Large, difference, favourable structure:	
Large difference, unfavourable structure:	

OK

Score:

Climate and Presence of Water on Slope:

Low/mod precipitation, no freezing periods, no water on slope:	
Mod precip or short freezing periods or intermittent water on slope	
High precip or long freezing periods or continual water on slope	1
Hi precip + long freezing pds or continual water + long freezing pds	

OK

Score: 27

Block Size/Volume

1ft/3cubic yards	1
2ft/6 cubic yards	
3ft/9 cubic yards	
4ft/12 cubic yards	

OK

Score: 3

Rockfall History

Few Falls:	
Occasional Falls:	
Many Falls:	1
Constant Falls:	

OK

Score: 27

Reference: "Rockfall hazard Rating System", US Dept of Transportation
Publicaton No: FHWA SA 93 057, November 1993

ROCKFALL HAZARD RATING SYSTEM

Highway: **SH 73** Start MP: End MP:

Location: **Site 3** Date Rated: **2/26/98** By: **GGG/PH**

TOTAL SCORE: **401**

Slope Height

Slope Height (m): 25 **Score:** 37

Ditch Effectiveness:

Good(G), Moderate(M), Limited(L), Nil(N) N **Score:** 81

Average Vehicle Risk:

Average Daily Traffic (veh/day): 900
Section Length (m): 145
Posted Speed Limit (km/h): 100
Average Vehicle Risk (%of time): 5.44 **Score:** 1

Percent Decision Site Distance:

Site Distance (m) 150
Min Decision Site Distance at Posted Speed Limit (m): 312.99
Percent Decision Site Distance (%): 47.92 **Score:** 52

Roadway Width

Roadway Width(m): 5.9 **Score:** 88

Structural Condition Category (Note: fill in case 1 only or case 2 only)
(Place 1 beside chosen option)

Case 1

Discontinuous joints, favourable orientation:		
Discontinuous joints, random orientation:		
Discontinuous joints,adverse orientation:		
Continuous joints,adverse orientation:	1	**Score:** 81
	OK	

Joints rough, irregular		
Joints undulating		
Joints Planar	1	
Clay infilling or slickensided		**Score:** 27
	OK	

OR

Case 2

Small difference in erosion rates:		
Moderate difference in erosion rates:		
Large, difference, favourable structure:		
Large difference, unfavourable structure:		**Score:**

Few differential erosion features		
Occasional " "		
Many " "		
Major " "		**Score:**

OK

Climate and Presence of Water on Slope:

Low/mod precipitation, no freezing periods, no water on slope:		
Mod precip or short freezing periods or intermittent water on slope		
High precip or long freezing periods or continual water on slope	1	
Hi precip + long freezing pds or continual water + long freezing pds		**Score:** 27

OK

Block Size/Volume

1ft/3cubic yards	1	
2ft/6 cubic yards		
3ft/9 cubic yards		
4ft/12 cubic yards		**Score:** 3

OK

Rockfall History

Few Falls:	1	
Occasional Falls:		
Many Falls:		
Constant Falls:		**Score:** 3

OK

Reference: "Rockfall hazard Rating System", US Dept of Transportation
Publicaton No: FHWA SA 93 057, November 1993

ROCKFALL HAZARD RATING SYSTEM

Highway:	**SH 73**	Start MP:		End MP:	
Location:	**Site 4**	Date Rated:	**2/26/98**	By:	**GGG/PH**
TOTAL SCORE:	**566**				

Slope Height

Slope Height (m):	32	**Score:**	100

Ditch Effectiveness:

Good(G), Moderate(M), Limited(L), Nil(N)	L	**Score:**	27

Average Vehicle Risk:

Average Daily Traffic (veh/day):	900		
Section Length (m):	86		
Posted Speed Limit (km/h):	100		
Average Vehicle Risk (%of time):	3.225	**Score:**	1

Percent Decision Site Distance:

Site Distance (m)	70		
Min Decision Site Distance at Posted Speed Limit (m):	312.99		
Percent Decision Site Distance (%):	22.364932	**Score:**	213

Roadway Width

Roadway Width(m):	6.8	**Score:**	59

Structural Condition Category

(Note: fill in case 1 only or case 2 only)
(Place 1 beside chosen option)

Case 1

Discontinuous joints, favourable orientation:			
Discontinuous joints, random orientation:			
Discontinuous joints,adverse orientation:			
Continuous joints,adverse orientation:	1	**Score:**	81
	OK		
Joints rough, irregular			
Joints undulating			
Joints Planar	1		
Clay infilling or slickensided		**Score:**	27
	OK		

OR

Case 2

Small difference in erosion rates:			
Moderate difference in erosion rates:			
Large, difference, favourable structure:			
Large difference, unfavourable structure:		**Score:**	

Few differential erosion features			
Occasional " "			
Many " "			
Major " "		**Score:**	

OK

Climate and Presence of Water on Slope:

Low/mod precipitation, no freezing periods, no water on slope:			
Mod precip or short freezing periods or intermittent water on slope			
High precip or long freezing periods or continual water on sl	1		
Hi precip + long freezing pds or continual water + long freezing pds		**Score:**	27

OK

Block Size/Volume

1ft/3cubic yards	1		
2ft/6 cubic yards			
3ft/9 cubic yards			
4ft/12 cubic yards		**Score:**	3

OK

Rockfall History

Few Falls:			
Occasional Falls:			
Many Falls:	1		
Constant Falls:		**Score:**	27

OK

Reference: "Rockfall hazard Rating System", US Dept of Transportation
Publicaton No: FHWA SA 93 057, November 1993

ROCKFALL HAZARD RATING SYSTEM

Highway:	**SH 73**	Start MP:		End MP:	
Location:	**Site 5**	Date Rated:	**2/26/98**	By:	**GGG/PH**
TOTAL SCORE:	**377**				

Slope Height

Slope Height (m):	50	**Score:**	100

Ditch Effectiveness:

Good(G), Moderate(M), Limited(L), Nil(N)	L	**Score:**	27

Average Vehicle Risk:

Average Daily Traffic (veh/day):	900		
Section Length (m):	150		
Posted Speed Limit (km/h):	100		
Average Vehicle Risk (%of time):	5.625	**Score:**	1

Percent Decision Site Distance:

Site Distance (m)	150		
Min Decision Site Distance at Posted Speed Limit (m):	312.99		
Percent Decision Site Distance (%):	47.924854	**Score:**	52

Roadway Width

Roadway Width(m):	8.2	**Score:**	31

Structural Condition Category (Note: fill in case 1 only or case 2 only)
(Place 1 beside chosen option)

Case 1

Discontinuous joints, favourable orientation:			
Discontinuous joints, random orientation:			
Discontinuous joints,adverse orientation:			
Continuous joints,adverse orientation:	1	**Score:**	81
	OK		
Joints rough, irregular			
Joints undulating			
Joints Planar	1		
Clay infilling or slickensided		**Score:**	27
	OK		

OR

Case 2

Small difference in erosion rates:			
Moderate difference in erosion rates:			
Large, difference, favourable structure:			
Large difference, unfavourable structure:		**Score:**	

Few differential erosion features			
Occasional " "			
Many " "			
Major " "		**Score:**	

OK

Climate and Presence of Water on Slope:

Low/mod precipitation, no freezing periods, no water on slope:			
Mod precip or short freezing periods or intermittent water on slope			
High precip or long freezing periods or continual water on slope	1		
Hi precip + long freezing pds or continual water + long freezing pds		**Score:**	27

OK

Block Size/Volume

1ft/3cubic yards	1		
2ft/6 cubic yards			
3ft/9 cubic yards			
4ft/12 cubic yards		**Score:**	3

OK

Rockfall History

Few Falls:			
Occasional Falls:			
Many Falls:	1		
Constant Falls:		**Score:**	27

OK

Reference: "Rockfall hazard Rating System", US Dept of Transportation
Publicaton No: FHWA SA 93 057, November 1993

APPENDIX 6

SUMMARY OF COST OF MITIGATION OPTIONS

Maintenance Option Cost Summary, Paddys Bend, SH74

Site: 2 Option: M1

Description:

Monitoring: Implement a video surveillance programme

No.	Description	Unit	Quant	Rate			Amount
				Min	ML	Max	
1	**Annual Cost** **Start life: year 1** **End life: year 25**						
1.1	Rockfall callout costs (costs due to extra visits to clear road each time there is a warning from the video (say 10/yr)	*annual cost*		3500	4800	6000	$ 4,766.67
1.2	Disruption Costs Allow for disruption/delay to traffic due to false alarms, say 2 hours at $74628 / day	*annual cost*		4000	5000	6000	$ 5,000.00
1.3	Maintenance of video unit	*annual cost*		4000	5000	6000	$ 5,000.00
	Subtotal						$ 14,766.67
	Initial set up cost incurred at end of year 1.						
2	Set up cost	LS		20000	30000	40000	$ 30,000.00
	Subtotal						$ 30,000.00

Calculation of Present Value (PV) of Cost of Maintenance Option

Option:	2	
Description:	Monitoring: Implement a video surveillance programme	
Discount Rate:	0.10	
Design Life:	25.00	years

Initial Cost:	$ 30,000.00	
Incurred at end of year:	1.00	
SPPWF	0.9091	
PV	$ 27,272.73	$ 27,272.73

Annual Maintenance Cost:	$ 14,766.67	(Incurred at end of each year)
Start Life (end of year ?)	1.00	
End Life (end of year ?)	25.00	
USPWF (start)	0.9538	
USPWF (end)	9.5237	
PV	$ 126,548.27	$ 126,548.27

One Off Maintenance/Repair 1		
Item:		
Cost:	$ -	
Incurred at end of year:	5.00	
SPPWF	0.6209	
PV	$ -	$ -
One Off Maintenance/Repair 2:		
Item:		
Cost:	$ -	
Incurred at end of year:	5.00	
SPPWF	0.6209	
PV	$ -	$ -
One Off Maintenance/Repair 3:		
Item:		
Cost:	$ -	
Incurred at end of year:	5.00	
SPPWF	0.6209	
PV	$ -	$ -

Total PV

Following Monte-Carlo simulation, 1000 iterations:

Min	**$ 130,012.00**
ML	**$ 153,821.00**
Max	**$ 180,379.00**

Maintenance Option Cost Summary, Paddys Bend, SH74

Site: 2 Option: M2

Description:

Scaling, scale loose rock from existing cut batter

No.	Description	Unit	Quant	Rate			Amount
				Min	ML	Max	
	Initial set up cost incurred at end of year 1.						
2.1	Scaling						
2.1.1	Establishment	LS		6480	7200	7920	7,200
2.1.2	Traffic management	day	20	450	600	750	12,000
2.1.3	Scaling 3 men @ 160 hours	day	20	1440	1920	2400	38,400
2.1.4	Plant hire front end loader for rock removal	day	2	500	1000	1500	2,000
	Subtotal						59,600

Calculation of Present Value (PV) of Cost of Maintenance Option

Option:	2	
Description:	Scaling, scale loose rock from existing cut batter	
Discount Rate:	0.10	
Design Life:	25.00	years

Initial Cost:	$ 59,600.00	
Incurred at end of year:	1.00	
SPPWF	0.9091	
PV	$ 54,181.82	$ 54,181.82

Annual Maintenance Cost:	$ -	(Incurred at end of each year)
Start Life (end of year ?)	1.00	
End Life (end of year ?)	25.00	
USPWF (start)	0.9538	
USPWF (end)	9.5237	
PV	$ -	$ -

One Off Maintenance/Repair 1		
Item:		
Cost:	$ -	
Incurred at end of year:	5.00	
SPPWF	0.6209	
PV	$ -	$ -
One Off Maintenance/Repair 2:		
Item:		
Cost:	$ -	
Incurred at end of year:	5.00	
SPPWF	0.6209	
PV	$ -	$ -
One Off Maintenance/Repair 3:		
Item:		
Cost:	$ -	
Incurred at end of year:	5.00	
SPPWF	0.6209	
PV	$ -	$ -

Total PV

Following Monte-Carlo simulation, 1000 iterations:

Min	$	**44,255.00**
ML	$	**54,181.82**
Max	$	**64,532.00**

Maintenance Option Cost Summary, Paddys Bend, SH74

Site: 2 Option: M3

Description:

Scaling, spot rock bolting and wire mesh protection over entire face

No.	Description	Unit	Quant	Rate			Amount
				Min	ML	Max	
1	**Annual Cost** **Start life: year 1** **End life: year 25**						
1.1	Traffic management	*Annual Cost*		900	1200	1800	1,300
1.2	Clean out behind wire mesh	*Annual Cost*		1920	2560	3840	2,773
1.3	Plant hire - front end loader for rock removal	*Annual Cost*		1500	2000	3000	2,167
	Subtotal						6,240
	Initial set up cost incurred at end of year 1.						
2.1	Scaling						
2.1.1	Establishment - including accommodation, meals etc	LS		6480	7200	7920	7,200
2.1.2	Traffic management	day	20	450	600	750	12,000
2.1.3	Rock fall scaling 3 men @ 160 hours	day	20	1440	1920	2400	38,400
2.1.4	Plant hire - front end loader for rock removal	day	2	500	1000	1500	2,000
2.2	Spot rock bolting						
2.2.1	establishment	LS		1920	2400	2880	2,400
2.2.2	3m long rock bolts	no	50	180	200	220	10,000
2.2.3	Installation - 2 men @10 days	LS		10240	12800	15360	12,800
2.4	Wire Mesh						
2.4.1	Establishment - including accommodation, meals etc	LS		1920	2400	2880	2,400
2.4.2	Wire mesh supply	m2	4000	8	10	12	40,000
2.4.3	2 m long hook dowells	ea	200	40	50	60	10,000
2.4.4	Installation - 3 men @ 20 days	Day	20	1440	1920	2400	1,920
2.5	Crane hire	Day	10	800	1000	1200	10,000
	Subtotal						149,120

Calculation of Present Value (PV) of Cost of Maintenance Option

Option:	M3	
Description:	Scaling, spot rock bolting and wire mesh protection over entire face	
Discount Rate:	0.10	
Design Life:	25.00	years

Initial Cost:	$ 149,120.00		
Incurred at end of year:	1.00		
SPPWF	0.9091		
PV	$ 135,563.64	$	135,563.64

Annual Maintenance Cost:	$ 6,240.00	(Incurred at end of each year)	
Start Life (end of year ?)	1.00		
End Life (end of year ?)	25.00		
USPWF (start)	0.9538		
USPWF (end)	9.5237		
PV	$ 53,475.93	$	53,475.93

One Off Maintenance/Repair 1			
Item:			
Cost:	$ -		
Incurred at end of year:	5.00		
SPPWF	0.6209		
PV	$ -	$	-
One Off Maintenance/Repair 2:			
Item:			
Cost:	$ -		
Incurred at end of year:	5.00		
SPPWF	0.6209		
PV	$ -	$	-
One Off Maintenance/Repair 3:			
Item:			
Cost:	$ -		
Incurred at end of year:	5.00		
SPPWF	0.6209		
PV	$ -	$	-

Total PV

Following Monte-Carlo simulation, 1000 iterations:

Min	$	**168,205.00**
ML	$	**189,039.56**
Max	$	**211,617.00**

Maintenance Option Cost Summary, Paddys Bend, SH74

Site: 2 Option: M4

Description:

Road realignment - realign road towards river, scaling and spot rock bolting, construct rock fall protection fence at toe of existing cut slope

No.	Description	Unit	Quant	Rate				Amount
				Min	ML	Max	Dist	
1	**Annual Cost** **Start life: year 1** **End life: year 25**							
1.1	Maintain wire mesh involving clean out behind mesh							
1.2	Establishment	annual cost		360	480	720	520	520
1.3	Clean out behind wire mesh: 2 men @ 2 days	annual cost		1920	2560	3840	2,773	2,773
1.4	Plant hire - front end loader for rock removal	annual cost		1500	2000	3000	2,167	2,167
1.5	Repairs to rock fall catch fence: 2 men @ 2 days	annual cost		1920	2560	3840	2,773	2,773
	Subtotal						8,233	8,233
	Initial set up cost incurred at end of year 1.							
2.1	Road realignment							
2.1.1	Establishment	LS		12000	15000	20000	15,667	15,667
2.1.1	Earthworks - placement of fill material	m3	15400	5	7.5	9	7	110,367
2.1.2	Subbase supply and construct 200 mm thick	m3	165	30	37.5	45	38	6,188
2.1.3	Basecourse, supply and construct	m3	135	45	48	55	49	6,660
2.1.4	Running course, supply and construct	m3	15	40	50	60	50	750
2.1.5	Tie into existing seal	ea	2	250	400	500	383	767
2.1.6	Two coat first coat sealing	m2	800	4.5	5	6	5	4,133
2.1.7	Edge marker posts supply and install	ea	12	20	25	30	25	300
2.1.8	Guard railing supply and install	LM	100	150	180	200	177	17,667
2.1.9	Pavement marking	LS		400	500	600	500	500
2.1.10	Testing of materials	LS		800	1000	1200	1,000	1,000
2.2	Scaling							
2.2.1	Establishment - including accommodation, meals etc	LS		6480	7200	7920	7,200	7,200
2.2.2	Traffic management	day	20	450	600	750	600	12,000
2.2.3	Rock fall scaling 3 men	man hr	480	60	80	100	80	38,400
2.2.4	Plant hire - front end loader for rock removal	day	1000	1	2	3	2	2,000
2.3	Spot rock bolting							
2.3.1	Establishment	LS		1920	2400	2880	2,400	2,400
2.2.2	3 m long bolts	ea	200	45	50	55	50	10,000
2.2.3	Installation - 2 men @ 10 days	day	10	1024	1280	1536	1,280	12,800
2.4	Crane hire	day	1000	8	10	12	10	10,000
2.5	Rock fall catch fence							
2.5.1	Establishment	LS		1920	2400	2880	2,400	2,400
2.5.2	Mesh, supply: 100m x 3 m high	m2	300	8.5	10	12	10	3,050
2.5.3	Cables	LM	300	8	10	12	10	3,000
2.5.4	Post, RSJ supply and install	ea	500	45	50	60	52	25,833
2.5.5	Installation: 2 men @ 10 days	day	10	1024	1280	1536	1,280	12,800
	Subtotal						33,275	305,881

Maintenance Option Cost Summary, Paddys Bend, SH74

Site: 2

Option: M4 (Cont)

No.	Description	Unit	Quant	Rate				Amount
				Min	ML	Max	Dist	
3	**One off Maintenance /repair**							
	Incurred during: year 15							
3.1	Replace rock fall catch net							
3.1.1	Establishment	LS		1920	2400	2880	2,400	2,400
3.1.2	Mesh, supply: 100 m x 3 m high	m2	300	8.5	10	12	10	3,050
3.1.3	Cables	LM	300	8	10	12	10	3,000
3.1.4	Post, RSJ supply and install	ea	500	45	50	60	52	25,833
3.1.5	Installation: 2 men @ 10 days	man dy	20	512	640	768	640	12,800
	Subtotal							47,083

Calculation of Present Value (PV) of Cost of Maintenance Option

Option:	M4	
Description:	Road realignment - realign road towards river, scaling and spot rock bolting, construct rock fall protection fence at toe of existing cut slope	
Discount Rate:	0.10	
Design Life:	25.00	years

Initial Cost:	$ 305,880.83			
Incurred at end of year:	1.00			
SPPWF	0.9091			
PV	$ 278,073.48		$	278,073.48

Annual Maintenance Cost:	$ 8,233.33	(Incurred at end of each year)		
Start Life (end of year ?)	1.00			
End Life (end of year ?)	25.00			
USPWF (start)	0.9538			
USPWF (end)	9.5237			
PV	$ 70,558.52		$	70,558.52

One Off Maintenance/Repair 1			
Item:	Replace rockfall catch net		
Cost:	$ 47,083.33		
Incurred at end of year:	15.00		
SPPWF	0.2394		
PV	$ 11,271.38	$	11,271.38
One Off Maintenance/Repair 2:			
Item:			
Cost:	$ -		
Incurred at end of year:	5.00		
SPPWF	0.6209		
PV	$ -	$	-
One Off Maintenance/Repair 3:			
Item:			
Cost:	$ -		
Incurred at end of year:	5.00		
SPPWF	0.6209		
PV	$ -	$	-

Total PV

Following Monte-Carlo simulation, 1000 iterations:

Min	$	**315,875.00**
ML	$	**359,903.38**
Max	$	**397,432.00**

Maintenance Option Cost Summary, Paddys Bend, SH74

Site: 2 Option: M5

Description:

Earthworks option - excavate existing cutting to a new profile as indicaded on the cross section.

No.	Description	Unit	Quant	Rate			Amount
				Min	ML	Max	
1	**Annual Cost** **Start life: year 1** **End life: year 25**						
1.1	Maintain wire mesh involving clean out behind mesh						
1.2	Establishment	*annual cost*		360	480	720	520
1.3	Clean out behind wire mesh	*annual cost*		1920	2560	3840	2,773
1.4	Plant hire - front end loader for rock removal	*annual cost*		1500	2000	3000	2,167
1.5	Repairs to rock fall catch fence, 2 men at 2 days	*annual cost*		3840	5120	7680	5,547
	Subtotal						11,007
	Initial set up cost incurred at end of year 1.						
2.1	Earthworks						
2.1.1	Rock excavation and cart to dump below SH73	m3	28000	30	40	50	1,120,000
2.2	Scaling @ 50% of M4						
2.2.1	Establishment - including accommodation, meals etc	LS		3240	3600	3960	3,600
2.2.2	Traffic management	day	600	7.5	10	12.5	6,000
2.2.3	Rock fall scaling 3 men @ 80 hours	day	1920	7.5	10	12.5	19,200
2.2.4	Plant hire - front end loader for rock removal	day	1000	0.5	1	1.5	1,000
2.3	Spot rock bolting @ 50% of M4						
2.3.1	Establishment	LS	240	4	5	6	1,200
2.2.2	50x3 m long bolts	ea	200	22.5	25	27.5	5,000
2.2.3	Installation - 2 men @ 10 days	day	1280	4	5	6	6,400
2.4	Crane hire @ 50% of M4	day	1000	4	5	6	5,000
2.5	Rock fall catch fence						
2.5.1	Establishment	LS		1920	2400	2880	2,400
2.5.2	Mesh, supply: 100m x 3 m high	m2	300	4.2	5	12	2,120
2.5.3	Cables	LM	300	8	10	12	3,000
2.5.4	Post, RSJ supply and install	ea	500	45	50	60	25,833
2.5.5	Installation: 2 men @ 10 days	Day	10	1024	1280	1536	12,800
	Subtotal						1,213,553

Maintenance Option Cost Summary, Paddys Bend, SH74

Site: 2 Option: M5

Description:

Earthworks option - excavate existing cutting to a new profile as indicaded on the cross section.

No.	Description	Unit	Quant	Rate			Amount
				Min	ML	Max	
3	**One off Maintenance /repair** **Incurred during: year 15**						
3.1	Replace rock fall catch net						
3.1.1	Establishment	LS		1920	2400	2880	2,400
3.1.2	Mesh, supply	LM	300	8.5	10	12	3,050
3.1.3	Cables	LM	300	8	10	12	3,000
3.1.4	Post, RSJ supply and install	ea	50	450	500	600	25,833
3.1.5	Installation: 2 men @ 10 days	Day	1280	8	10	12	12,800
	Subtotal						47,083

Calculation of Present Value (PV) of Cost of Maintenance Option

Option:	M5	
Description:	Earthworks option - excavate existing cutting to a new profile as indicaded on the cross section.	
Discount Rate:	0.10	
Design Life:	25.00	years

Initial Cost:	$ 1,213,553.33		
Incurred at end of year:	1.00		
SPPWF	0.9091		
PV	$ 1,103,230.30	$	1,103,230.30

Annual Maintenance Cost:	$ 11,006.67	(Incurred at end of each year)	
Start Life (end of year ?)	1.00		
End Life (end of year ?)	25.00		
USPWF (start)	0.9538		
USPWF (end)	9.5237		
PV	$ 94,325.59	$	94,325.59

One Off Maintenance/Repair 1			
Item:	Replace catch fence		
Cost:	$ 47,083.33		
Incurred at end of year:	15.00		
SPPWF	0.2394		
PV	$ 11,271.38	$	11,271.38
One Off Maintenance/Repair 2:			
Item:			
Cost:	$ -		
Incurred at end of year:	5.00		
SPPWF	0.6209		
PV	$ -	$	-
One Off Maintenance/Repair 3:			
Item:			
Cost:	$ -		
Incurred at end of year:	5.00		
SPPWF	0.6209		
PV	$ -	$	-

Total PV

Following Monte-Carlo simulation, 1000 iterations:

Min	**$**	**961,680.00**
ML	**$**	**1,208,827.27**
Max	**$**	**1,471,553.00**

Maintenance Option Cost Summary, Paddys Bend, SH74

Site: 4 Option: M1

Description:

Monitoring: Impliment a video surveillance programme

No.	Description	Unit	Quant	Rate				Amount
				Min	ML	Max	Dist	
1	**Annual Cost** **Start life: year 1** **End life: year 25**							
1.1	Rockfall callout costs (costs due to extra visits to clear road each time there is a warning from the video (say 10/yr)	*annual cost*		20000	24000	30000	$ 24,666.67	$ 24,666.67
1.2	Disruption Costs Allow for disruption/delay to traffic due to false alarms, say 2 at $74628 / day	*annual cost*		20000	24876	30000	$ 24,958.67	$ 24,958.67
1.3	Maintenance of video unit	*annual cost*		4000	5000	6000	$ 5,000.00	$ 5,000.00
	Subtotal Annual costs							$ 54,625.33
	Initial set up cost incurred at end of year 1.							
2	Set up cost	ls		20000	30000	40000	$ 30,000.00	$ 30,000.00
	Subtotal Initial costs							$ 30,000.00

Calculation of Present Value (PV) of Cost of Maintenance Option

Option:	M1	
Description:	Monitoring: Impliment a video surveillance programme	
Discount Rate:	0.10	
Design Life:	25.00	years

Initial Cost:	$ 30,000.00		
Incurred at end of year:	1.00		
SPPWF	0.9091		
PV	$ 27,272.73	$	27,272.73

Annual Maintenance Cost:	$ 54,625.33	(Incurred at end of each year)	
Start Life (end of year ?)	1.00		
End Life (end of year ?)	25.00		
USPWF (start)	0.9538		
USPWF (end)	9.5237		
PV	$ 468,131.47	$	468,131.47

One Off Maintenance/Repair 1			
Item:			
Cost:	$ -		
Incurred at end of year:	5.00		
SPPWF	0.6209		
PV	$ -	$	-
One Off Maintenance/Repair 2:			
Item:			
Cost:	$ -		
Incurred at end of year:	5.00		
SPPWF	0.6209		
PV	$ -	$	-
One Off Maintenance/Repair 3:			
Item:			
Cost:	$ -		
Incurred at end of year:	5.00		
SPPWF	0.6209		
PV	$ -	$	-

Total PV

Following Monte-Carlo simulation, 1000 iterations:

Min	**$**	**426,565.00**
ML	**$**	**495,404.19**
Max	**$**	**578,830.00**

Maintenance Option Cost Summary, Paddys Bend, SH74

Site: 4 Option: M2

Description:

Construct 2m high rock gabion at toe of slope for rockfall protection

No.	Description	Unit	Quant	Rate				Amount
				Min	ML	Max	Dist	
1	**Annual Cost** **Start life: year 1** **End life: year 25**							
1.3	Gabion wall maintenance							
1.3.1	Traffic management	day	2	450	600	900	650	1,300
1.3.2	Establishment	LS		360	480	720	520	520
1.3.3	Clean out behind wire mesh: 2 men @ 2 days	day	2	960	1280	1920	1,387	2,773
1.3.4	Plant hire - front end loader for rock removal	day	2	750	1000	1500	1,083	2,167
	Subtotal							6,760
	Initial set up cost incurred at end of year 1.							
2.1	Rock Gabion wall							
2.1.1	Establishment - including accommodation, meals etc	LS		4320	4800	5280	4,800	4,800
2.1.2	Traffic management	day	20	450	600	750	600	12,000.00
2.1.3	Gabion netting 100 m long x 2 m high	LM	45	88.88	100	111.11	100	4,499.85
2.1.4	Rock fill @ 100 m long x 1 m wide x 2 m high = 200 m3	m3	8	125	200	275	200	1,600.00
2.1.5	Installation say 2 men for 20 days	day	20	1152	1280	1408	1,280	25,600.00
2.2	Road realignment; 100 m of new highway							
2.2.1	Establishment	LS		12000	15000	20000	15,667	15,667
2.2.2	Subbase supply and construct 200 mm thick	m3	35	141.9	165	212.14	173	6,055.47
2.2.3	Basecourse, supply and construct	m3	48	126.56	135	154.68	139	6,659.84
2.2.4	Running course, supply and construct	m3	50	12	15	18	15	750.00
2.2.5	Tie into existing seal	ea	800	1.6	2	2.2	2	1,546.67
2.2.6	Two coat first coat sealing	m2	5	720	800	960	827	4,133.33
2.2.7	Edge marker posts supply and install	ea	25	11	12	13	12	300.00
2.2.8	Guard railing supply and install	LM	180	83.3	100	111	98	17,658.00
2.2.9	Pavement marking	LS		400	500	600	500	500
.2.1	Testing of materials	LS		800	1000	1200	1,000	1,000
	Subtotal						25,412	102,770

Calculation of Present Value (PV) of Cost of Maintenance Option

Option:	M2		
Description:	Construct 2m high rock gabion at toe of slope for rockfall protection		
Discount Rate:	0.10		
Design Life:	25.00	years	

Initial Cost:	$ 102,769.82		
Incurred at end of year:	1.00		
SPPWF	0.9091		
PV	$ 93,427.11	$	93,427.11

Annual Maintenance Cost:	$ 6,760.00	(Incurred at end of each year)	
Start Life (end of year ?)	1.00		
End Life (end of year ?)	25.00		
USPWF (start)	0.9538		
USPWF (end)	9.5237		
PV	$ 57,932.25	$	57,932.25

One Off Maintenance/Repair 1			
Item:			
Cost:	$ -		
Incurred at end of year:	5.00		
SPPWF	0.6209		
PV	$ -	$	-
One Off Maintenance/Repair 2:			
Item:			
Cost:	$ -		
Incurred at end of year:	5.00		
SPPWF	0.6209		
PV	$ -	$	-
One Off Maintenance/Repair 3:			
Item:			
Cost:	$ -		
Incurred at end of year:	5.00		
SPPWF	0.6209		
PV	$ -	$	-

Total PV

Following Monte-Carlo simulation, 1000 iterations:

Min	**$ 136,412.00**
ML	**$ 151,359.37**
Max	**$ 165,624.00**

Maintenance Option Cost Summary, Paddys Bend, SH74

Site: 4 Option: M3

Description:

Scaling, spot rock bolting and wire mesh protection over entire face area

No.	Description	Unit	Quant	Rate			Amount
				Min	ML	Max	
1	**Annual Cost** **Start life: year 1** **End life: year 25**						
1.1	Maintain wire mesh involving clean out behind mesh						
1.2	Traffic management: 2 man days	*annual cost*		900	1200	1800	1,300
1.3	Clean out behind wire mesh	*annual cost*		1920	2560	3840	2,773
1.4	Plant hire - front end loader for rock removal	*annual cost*		1500	2000	3000	2,167
	Subtotal						6,240
	Initial set up cost incurred at end of year 1.						
2.1	Scaling						
2.1.1	Establishment - including accommodation, meals etc	LS		6480	7200	7920	7,200
2.1.2	Traffic management	day	20	450	600	750	12,000
2.1.3	Rock fall scaling 3 men @ 160 hours	day	20	1440	1920	2400	38,400
2.1.4	Plant hire - front end loader for rock removal	day	2	500	1000	1500	2,000
2.2	Spot rock bolting						
2.2.1	Establishment - as per item 2.2.1	LS		1920	2400	2880	2,400
2.2.2	50x3 m long bolts	ea	50	180	200	220	10,000
2.2.3	Installation - 2 men @ 10 days	day	10	1024	1280	1536	12,800
2.3	Wire Mesh						
2.3.1	Establishment - including accommodation, meals etc			1920	2400	2880	2,400
2.2.2	Wire mesh supply	m2	10	7650	9000	10350	90,000
2.3.3	50x2 m long hook dowells	ea	50	160	200	240	10,000
2.3.4	Installation - 3 men @ 20 days	Day	20	1536	1920	2304	38,400
2.3	Crane hire	day	10	1000	1200	1500	12,333
	Subtotal						237,933

Calculation of Present Value (PV) of Cost of Maintenance Option

Option:	M3	
Description:	Scaling, spot rock bolting and wire mesh protection over entire face area	
Discount Rate:	0.10	
Design Life:	25.00	years

Initial Cost:	$ 237,933.33	
Incurred at end of year:	1.00	
SPPWF	0.9091	
PV	$ 216,303.03	$ 216,303.03

Annual Maintenance Cost:	$ 6,240.00	(Incurred at end of each year)
Start Life (end of year ?)	1.00	
End Life (end of year ?)	25.00	
USPWF (start)	0.9538	
USPWF (end)	9.5237	
PV	$ 53,475.93	$ 53,475.93

One Off Maintenance/Repair 1		
Item:		
Cost:	$ -	
Incurred at end of year:	5.00	
	0.6209	
	$ -	$ -
One Off Maintenance/Repair 2:		
Item:		
Cost:	$ -	
Incurred at end of year:	5.00	
SPPWF	0.6209	
PV	$ -	$ -
Item:		
Cost:	$ -	
Incurred at end of year:	5.00	
SPPWF	0.6209	
PV	$ -	$ -

Total PV

Following Monte-Carlo simulation, 1000 iterations:

Min	$ **246,939.60**
ML	$ **269,778.96**
Max	$ **293,947.60**

Maintenance Option Cost Summary, Paddys Bend, SH74

Site: 4 Option: M4

Description:

Rock fall catch fence on inside of road, scaling and local spot bolting.

No.	Description	Unit	Quant	Rate			Amount
				Min	ML	Max	
1	**Annual Cost** **Start life: year 1** **End life: year 25**						
1.1	Maintain wire mesh involving clean out behind mesh	*annual cost*		900	1200	1800	1,300
1.2	Traffic management	*annual cost*		1920	2560	3840	2,773
1.3	Clean out behind wire mesh	*annual cost*		1500	2000	3000	2,167
1.4	Plant hire - front end loader for rock removal	*annual cost*		3840	5120	7680	5,547
1.5	Repairs to rock fall catch fence	*annual cost*		8160	10880	16320	11,787
	Subtotal						23,573
	Initial set up cost incurred at end of year 1.						
2.1	Scaling						
2.1.1	Establishment - including accommodation, meals etc	LS		6480	7200	7920	7,200
2.1.2	Traffic management	day	20	450	600	750	12,000
2.1.3	Rock fall scaling 3 men @ 160 hours	day	20	1440	1920	2400	38,400
2.1.4	Plant hire - front end loader for rock removal	day	2	500	1000	1500	2,000
2.2	Spot rock bolting						
2.2.1	Establishment - as per item 2.2.1	LS		1920	2400	2880	2,400
2.2.2	50x3 m long bolts	ea	50	180	200	220	10,000
2.2.3	Installation - 2 men @ 10 days	day	10	1024	1280	1536	12,800
2.3	Crane hire	day	10	800	1000	1200	10,000
2.4	Rock fall catch fence						
2.4.1	Establishment	LS		1920	2400	2880	2,400
2.4.2	Mesh, supply	m2	10	255	300	360	3,050
2.4.3	Cables	LM	10	240	300	360	3,000
2.4.4	Post, RSJ supply and install	ea	500	45	50	60	25,833
2.4.5	Installation	Day	10	1024	1280	1536	12,800
	Subtotal						141883.3333
3	**One off Maintenance /repair** **Incurred during: year 15**						
3.1	Replace rock fall catch net						
3.1.1	Establishment	LS		1920	2400	2880	2,400
3.1.2	Mesh, supply	LM	10	255	300	360	3,050
3.1.3	Cables	LM	10	240	300	360	3,000
3.1.4	Post, RSJ supply and install	ea	500	45	50	60	25,833
3.1.5	Installation: 2 men @ 10 days	day	10	1024	1280	1536	12,800
	Subtotal						47,083

Calculation of Present Value (PV) of Cost of Maintenance Option

Option:	M4	
Description:	Rock fall catch fence on inside of road, scaling and local spot bolting.	
Discount Rate:	0.10	
Design Life:	25.00	years

Initial Cost:	$ 141,883.33	
Incurred at end of year:	1.00	
SPPWF	0.9091	
PV	$ 128,984.85	$ 128,984.85

Annual Maintenance Cost:	$ 23,573.33	(Incurred at end of each year)
Start Life (end of year ?)	1.00	
End Life (end of year ?)	25.00	
USPWF (start)	0.9538	
USPWF (end)	9.5237	
PV	$ 202,020.17	$ 202,020.17

One Off Maintenance/Repair 1		
Item:	Replace rockfall catch fence	
Cost:	$ 47,083.33	
Incurred at end of year:	5.00	
SPPWF	0.6209	
PV	$ 29,235.05	$ 29,235.05
One Off Maintenance/Repair 2:		
Item:		
Cost:	$ -	
Incurred at end of year:	5.00	
SPPWF	0.6209	
PV	$ -	$ -
One Off Maintenance/Repair 3:		
Item:		
Cost:	$ -	
Incurred at end of year:	5.00	
SPPWF	0.6209	
PV	$ -	$ -

Total PV

Following Monte-Carlo simulation, 1000 iterations:

Min	**$ 316,870.00**
ML	**$ 360,240.06**
Max	**$ 416,808.70**

Maintenance Option Cost Summary, Paddys Bend, SH74

Site: 4 Option: M5

Description:

Construct concrete rock fall avalanche shed, and reconstruct highway surface

No.	Description	Unit	Quant	Rate			Amount
				Min	ML	Max	
	Initial set up cost incurred at end of year 1.						
	Incurred during: year 1						
1.1	Construct rock fall avalanche shed						
1.1.1	Establishment	LS		40000	50000	60000	50,000
1.1.2	Traffic control	day	100	540	600	720	62,000
1.1.3	Two lane rock fall shed (ref Opus Intl. Scheme assessment report on Candy's Bend highway)	LM	110	10000	15000	20000	1,650,000
2.2	Road realignment; 100 m of new highway						
2.2.1	Establishment	LS		12000	15000	20000	15,667
2.2.2	Subbase supply and construct 200 mm thick	m3	35	141.9	165	212.14	6,055.47
2.2.3	Basecourse, supply and construct	m3	48	126.56	135	154.68	6,659.84
2.2.4	Running course, supply and construct	m3	50	12	15	18	750.00
2.2.5	Tie into existing seal	ea	800	1.6	2	2.2	1,546.67
2.2.6	Two coat first coat sealing	m2	5	720	800	960	4,133.33
2.2.7	Edge marker posts supply and install	ea	25	11	12	13	300.00
2.2.8	Guard railing supply and install	LM	180	83.3	100	111	17,658.00
2.2.9	Pavement marking	LS		400	500	600	500
.2.1	Testing of materials	LS		800	1000	1200	1,000
	Subtotal						1,816,270

Calculation of Present Value (PV) of Cost of Maintenance Option

Option: M5

Description: Construct concrete rock fall avalanche shed, and reconstruct highway surface

Discount Rate: 0.10

Design Life: 25.00 years

Initial Cost:	$ 1,816,269.97	
Incurred at end of year:	1.00	
SPPWF	0.9091	
PV	$ 1,651,154.52	$ 1,651,154.52

Annual Maintenance Cost:	$ -	(Incurred at end of each year)
Start Life (end of year ?)	1.00	
End Life (end of year ?)	25.00	
USPWF (start)	0.9538	
USPWF (end)	9.5237	
PV	$ -	$ -

One Off Maintenance/Repair 1		
Item:		
Cost:	$ -	
Incurred at end of year:	5.00	
SPPWF	0.6209	
PV	$ -	$ -
One Off Maintenance/Repair 2:		
Item:		
Cost:	$ -	
Incurred at end of year:	5.00	
SPPWF	0.6209	
PV	$ -	$ -
One Off Maintenance/Repair 3:		
Item:		
Cost:	$ -	
Incurred at end of year:	5.00	
SPPWF	0.6209	
PV	$ -	$ -

Total PV

Following Monte-Carlo simulation, 1000 iterations:

Min	$	**1,163,962.00**
ML	$	**1,651,154.52**
Max	$	**2,141,026.00**

APPENDIX 7
ANALYSIS WORKSHEETS FOR SITE 2

Riddolls & Grocott Ltd

Probabilistic Optimisation of Slope Stability Management Stategy

transfund NEW ZEALAND

Analysis Summary

Highway: SH 74, Christchurch to Arthurs Pass

Transit NZ Region: Canterbury

Location: Paddy's Bend

Site: 2

Kilometre Reference: **From:** RP121/5.100 **To:** RP121/5.200

Length (m): 100

Speed Limit (km/hr): 100 **Avg Speed (km/hr):** 70

Analyst: PH **Date:** Jul-98

Instability Modes :

F1 Rockfall, 0-150 mm
F2 Rockfall,150-300 mm
F3 Rockfall,300-500 mm
F4 Rockfall,500-1000 mm

Consequences of Instability:

C1 Detritus Clearance ($)
C2 Service Disruption (hours/yr)
C3 Fatal Accidents (No/yr)
C4 Serious Accidents (No/yr)
C5 Minor Accidents (No/yr)
C6 Non-injury Accidents (No/yr)

Maintenance Options:

	Lowest Total Equivalent Cost	*Greatest Probability of Being Cheapest*
M0,Unmitigated Case		
M1, Instability Monitoring		
M2, Scaling		
M3, Scaling, Bolting and Wire Mesh	✓	✓
M4, Realignment Scaling, Bolting and Catch Fence		
M5, Earthworks, Scaling, Bolting and Catch Fence		

Contents.

Existing Failure Probabilities and Consequences, (M0)

Highway:	SH 74, Christchurch to Arthurs Pass
Region:	Canterbury
Location:	Paddy's Bend
Site:	2
Maintenance Option:	M0,Unmitigated Case

1. Determine probability of failure

	Failure Mode	PDF Input Parameters																					E	events/ year	Checksums	
		Min	ML	Max																						
Discrete PDFs	F1 Rockfall, 0-150 mm	220	293	366																			1.00	293		
	F2 Rockfall,150-300 mm	100	150	200																			1.00	150		
	No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20				
Triangular PDFs	F3 Rockfall,300-500 mm	0.00	0.0250	#####	0.050	0.200	0.400	0.200	0.050	0.0250	0.0250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	5.00	*1.00*	*OK*
	F4 Rockfall,500-1000 mm	0.05	0.200	0.500	0.200	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	2.00	*1.00*	*OK*

*/factor 10.000

2. Determine Consequences given Failure

		Consequence																							
		C1 Detritus Clearance ($)				C2 Service Disruption (hours/yr)				C3 Fatal Accidents (No/yr)				C4 Serious Accidents (No/yr)				C5 Minor Accidents (No/yr)				C6 Non-injury Accidents (No/yr)			
		Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist
	Failure Mode:	E=	*1.00*			E=	*1.00*			E=	*1.00*			E=	*1.00*			E=	*1.00*			E=	*1.00*		
Triangular PDFs	F1 Rockfall, 0-150 mm	2.13	26.8	44	24.3	0	0	0.005	0.0017	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.94E-07	4.94E-06	4.94E-05	1.83E-05	4.94E-06	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02
	F2 Rockfall,150-300 mm	2.13	26.8	44	24.3	0	0	0.005	0.0017	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.94E-07	4.94E-06	4.94E-05	1.83E-05	4.94E-06	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02
	F3 Rockfall,300-500 mm	2.13	26.8	44	24.3	0	0	0.005	0.0017	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.94E-07	4.94E-06	4.94E-05	1.83E-05	4.94E-06	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02
	F4 Rockfall,500-1000 mm	2.13	26.8	44	24.3	0	0	0.005	0.0017	2.75E-07	2.75E-06	2.75E-06	1.02E-05	4.94E-07	4.94E-06	4.94E-05	1.83E-05	4.94E-06	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02

P(C)	Expected Mean Consequences /yr	*10939.5*	*0.750*	*0.005*	*0.008*	*0.082*	*9.058*

Worksheet 2

Estimated Effectiveness of Maintenance Options

Highway: SH 74, Christchurch to Arthurs Pass
Region: Canterbury
Location: Paddy's Bend
Site: 2

Mean fractional reduction in P(F) and P(C|F) for implementation of each maintenance
Truncated normal distributions assumed for effectiveness estimates
Mean as shown in table below
Standard deviation: 0.2

		Maintenance Options											
		M0,Unmitigated Case		M1, Instability Monitoring		M2, Scaling		M3, Scaling, Bolting and Wire Mesh		M4, Realignment Scaling, Bolting and Catch Fence		M5, Earthworks, Scaling, Bolting and Catch Fence	
		Effectiveness, E											
		mean	dist	mean	dist	mean	dist	mean	dist	mean	dist	mean	dist
Failure Modes	F1 Rockfall, 0-150 mm	0.00	0.00	0.00	0.00	0.25	0.29	0.95	0.82	0.60	0.59	0.60	0.59
	F2 Rockfall,150-300 mm	0.00	0.00	0.00	0.00	0.40	0.41	0.99	0.84	0.70	0.67	0.70	0.67
	F3 Rockfall,300-500 mm	0.00	0.00	0.00	0.00	0.60	0.59	0.99	0.84	0.75	0.71	0.75	0.71
	F4 Rockfall,500-1000 mm	0.00	0.00	0.00	0.00	0.80	0.74	0.99	0.84	0.85	0.77	0.85	0.77
Consequences	C1 Detritus Clearance ($)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.82	0.95	0.82
	C2 Service Disruption (hours/yr)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.82	0.95	0.82
	C3 Fatal Accidents (No/yr)	0.00	0.00	0.85	0.77	0.00	0.00	0.00	0.00	0.96	0.83	0.99	0.84
	C4 Serious Accidents (No/yr)	0.00	0.00	0.75	0.71	0.00	0.00	0.00	0.00	0.96	0.83	0.98	0.83
	C5 Minor Accidents (No/yr)	0.00	0.00	0.60	0.59	0.00	0.00	0.00	0.00	0.93	0.81	0.98	0.83
	C6 Non-injury Accidents (No/yr)	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.90	0.80	0.95	0.82

Adjusted Failure Probabilities and Consequences, M1

Highway:	SH 74, Christchurch to Arthurs Pass
Region:	Canterbury
Location:	Paddy's Bend
Site:	2
Maintenance Option:	M1, Instability Monitoring

1. Determine reduced probability of failure

	Failure Mode	**PDF Input Parameters**			E	events/ year
		Min	ML	Max		
Triangular PDFs	F1 Rockfall, 0-150 mm	220	293	366	1.00	293
	F2 Rockfall,150-300 mm	100	150	200	1.00	150

	No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			Checksums	
Discrete PDFs	F3 Rockfall,300-500 mm	0.00	0.025	0.025	0.050	0.200	0.400	0.200	0.050	0.025	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	5.00	1.00	OK
	F4 Rockfall,500-1000 mm	0.05	0.200	0.500	0.200	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	2.00	1.00	OK

2. Determine Mitigated Consequences

		Consequence																							
		C1 Detritus Clearance ($)				C2 Service Disruption (hours/yr)				C3 Fatal Accidents (No/yr)				C4 Serious Accidents (No/yr)				C5 Minor Accidents (No/yr)				C6 Non-injury Accidents (No/yr)			
		Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist
	Failure Mode:	E=	1.00			E=	1.00			E=	0.23			E=	0.29			E=	0.41			E=	0.50		
Triangular PDFs	F1 Rockfall, 0-150 mm	2.13	26.8	44	24.3	0	0	0.005	1.67E-03	2.75E-07	2.75E-06	2.75E-05	2.32E-06	4.94E-07	4.94E-06	4.94E-05	5.31E-06	4.94E-06	4.94E-05	4.94E-04	7.50E-05	5.44E-04	5.44E-03	5.44E-02	1.01E-02
	F2 Rockfall,150-300 mm	2.13	26.8	44	24.3	0	0	0.005	1.67E-03	2.75E-07	2.75E-06	2.75E-05	2.32E-06	4.94E-07	4.94E-06	4.94E-05	5.31E-06	4.94E-06	4.94E-05	4.94E-04	7.50E-05	5.44E-04	5.44E-03	5.44E-02	1.01E-02
	F3 Rockfall,300-500 mm	2.13	26.8	44	24.3	0	0	0.005	1.67E-03	2.75E-07	2.75E-06	2.75E-05	2.32E-06	4.94E-07	4.94E-06	4.94E-05	5.31E-06	4.94E-06	4.94E-05	4.94E-04	7.50E-05	5.44E-04	5.44E-03	5.44E-02	1.01E-02
	F4 Rockfall,500-1000 mm	2.13	26.8	44	24.3	0	0	0.005	1.67E-03	2.75E-07	2.75E-06	2.75E-05	2.32E-06	4.94E-07	4.94E-06	4.94E-05	5.31E-06	4.94E-06	4.94E-05	4.94E-04	7.50E-05	5.44E-04	5.44E-03	5.44E-02	1.01E-02

P(C)	Consequences/yr given mitigation	10939.50	0.75	0.00104	0.00239	0.03373	4.52880

Adjusted Failure Probabilities and Consequences, M2

Highway:	SH 74, Christchurch to Arthurs Pass
Region:	Canterbury
Location:	Paddy's Bend
Site:	2
Maintenance Option:	M2, Scaling

1. Determine mitigated probability of failure

	Failure Mode	**PDF Input Parameters**																					F	events/ year		
		Min	ML	Max																						
Failure Modes	F1 Rockfall, 0-150 mm	*220*	*293*	*366*																			0.71	208		
	F2 Rockfall,150-300 mm	*100*	*150*	*200*																			0.59	88		
	No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			Checksums	
	F3 Rockfall,300-500 mm	*0.59*	*0.010*	*0.010*	*0.021*	*0.082*	*0.164*	*0.082*	*0.021*	*0.010*	*0.010*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	0.41	2.00	*1.00*	*OK*
	F4 Rockfall,500-1000 mm	*0.61*	*0.082*	*0.205*	*0.082*	*0.021*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	0.26	1.00	*1.00*	*OK*

2. Determine Mitigated Consequences

		Consequence																							
		C1 Detritus Clearance ($)				C2 Service Disruption (hours/yr)				C3 Fatal Accidents (No/yr)				C4 Serious Accidents (No/yr)				C5 Minor Accidents (No/yr)				C6 Non-injury Accidents (No/yr)			
		Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist
	Failure Mode:	F=	*1.00*			F=	*1.00*			F=	*1.00*			F=	*1.00*			F=	*1.00*			F=	*1.00*		
Consequences	F1 Rockfall, 0-150 mm	2.13	26.8	44	24.3	0	0	0.005	0.0017	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.94E-07	4.94E-06	4.94E-05	1.83E-05	4.94E-06	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02
	F2 Rockfall,150-300 mm	2.13	26.8	44	24.3	0	0	0.005	0.0017	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.94E-07	4.94E-06	4.94E-05	1.83E-05	4.94E-06	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02
	F3 Rockfall,300-500 mm	2.13	26.8	44	24.3	0	0	0.005	0.0017	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.94E-07	4.94E-06	4.94E-05	1.83E-05	4.94E-06	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02
	F4 Rockfall,500-1000 mm	2.13	26.8	44	24.3	0	0	0.005	0.0017	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.94E-07	4.94E-06	4.94E-05	1.83E-05	4.94E-06	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02

P(C)	Consequences/yr given mitigation	*7277.17*	*0.50*	*0.00305*	*0.00547*	*0.05471*	*6.02529*

Adjusted Failure Probabilities and Consequences, M3

Highway:	SH 74, Christchurch to Arthurs Pass
Region:	Canterbury
Location:	Paddy's Bend
Site:	2
Maintenance Option:	M3, Scaling, Bolting and Wire Mesh

1. Determine mitigated probability of failure

	Failure Mode	**PDF Input Parameters**																					F	events/ year		
		Min	ML	Max																						
Failure Modes	F1 Rockfall, 0-150 mm	220	293	366																			0.18	52		
	F2 Rockfall,150-300 mm	100	150	200																			0.16	24		
	No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			Checksums	
	F3 Rockfall,300-500 mm	0.84	0.004	0.004	0.008	0.033	0.065	0.033	0.008	0.004	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.16	1.00	1.00	OK
	F4 Rockfall,500-1000 mm	0.85	0.033	0.082	0.033	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.16	0.00	1.00	OK

2. Determine Mitigated Consequences

		Consequence																							
		C1 Detritus Clearance ($)				C2 Service Disruption (hours/yr)				C3 Fatal Accidents (No/yr)				C4 Serious Accidents (No/yr)				C5 Minor Accidents (No/yr)				C6 Non-injury Accidents (No/yr)			
		Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist
	Failure Mode:	F=	1.00			F=	1.00			F=	1.00			F=	1.00			F=	1.00			F=	1.00		
Consequences	F1 Rockfall, 0-150 mm	2.13	26.8	44	24.3	0	0	0.005	0.0017	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.94E-07	4.94E-06	4.94E-05	1.83E-05	4.94E-06	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02
	F2 Rockfall,150-300 mm	2.13	26.8	44	24.3	0	0	0.005	0.0017	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.94E-07	4.94E-06	4.94E-05	1.83E-05	4.94E-06	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02
	F3 Rockfall,300-500 mm	2.13	26.8	44	24.3	0	0	0.005	0.0017	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.94E-07	4.94E-06	4.94E-05	1.83E-05	4.94E-08	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02
	F4 Rockfall,500-1000 mm	2.13	26.8	44	24.3	0	0	0.005	0.0017	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.94E-07	4.94E-06	4.94E-05	1.83E-05	4.94E-05	4.94E-06	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02

P(C)	Consequences/yr given mitigation	1893.68	0.13	0.00079	0.00142	0.01424	1.56791

Adjusted Failure Probabilities and Consequences, M4

Highway:	SH 74, Christchurch to Arthurs Pass
Region:	Canterbury
Location:	Paddy's Bend
Site:	2
Maintenance Option:	M4, Realignment Scaling, Bolting and Catch Fence

1. Determine mitigated probability of failure

	Failure Mode	**PDF Input Parameters**																					F	events/ year	Checksums	
		Min	ML	Max																						
Failure Modes	F1 Rockfall, 0-150 mm	220	293	366																			0.41	120		
	F2 Rockfall,150-300 mm	100	150	200																			0.33	49		
	No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20				
	F3 Rockfall,300-500 mm	0.71	0.007	0.007	0.015	0.058	0.116	0.058	0.015	0.007	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.29	1.00	1.00	OK
	F4 Rockfall,500-1000 mm	0.72	0.058	0.145	0.058	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.23	1.00	1.00	OK

2. Determine Mitigated Consequences

		Consequence																							
		C1 Detritus Clearance ($)				C2 Service Disruption (hours/yr)				C3 Fatal Accidents (No/yr)				C4 Serious Accidents (No/yr)				C5 Minor Accidents (No/yr)				C6 Non-injury Accidents (No/yr)			
		Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist
	Failure Mode:	F=	0.18			F=	0.18			F=	0.17			F=	0.17			F=	0.19			F=	0.20		
Consequences	F1 Rockfall, 0-150 mm	2.13	26.8	44	4.4	0	0	0.005	2.98E-04	2.75E-07	2.75E-06	2.75E-05	1.78E-06	4.94E-07	4.94E-06	4.94E-05	3.20E-06	4.94E-06	4.94E-05	4.94E-04	3.43E-05	5.44E-04	5.44E-03	5.44E-02	4.06E-03
	F2 Rockfall,150-300 mm	2.13	26.8	44	4.4	0	0	0.005	2.98E-04	2.75E-07	2.75E-06	2.75E-05	1.78E-06	4.94E-07	4.94E-06	4.94E-05	3.20E-06	4.94E-06	4.94E-05	4.94E-04	3.43E-05	5.44E-04	5.44E-03	5.44E-02	4.06E-03
	F3 Rockfall,300-500 mm	2.13	26.8	44	4.4	0	0	0.005	2.98E-04	2.75E-07	2.75E-06	2.75E-05	1.78E-05	4.94E-07	4.94E-06	4.94E-06	3.20E-06	4.94E-06	4.94E-05	4.94E-04	3.43E-05	5.44E-04	5.44E-03	5.44E-02	4.06E-03
	F4 Rockfall,500-1000 mm	2.13	26.8	44	4.4	0	0	0.005	2.98E-04	2.75E-07	2.75E-06	4.69E-03	2.73E-04	4.94E-07	4.94E-05	4.94E-05	3.20E-06	4.94E-05	4.94E-05	4.94E-04	3.43E-06	5.44E-04	5.44E-03	5.44E-02	4.06E-03
P(C)	Consequences/yr given mitigation	745.10				0.05				0.00058				0.00055				0.00587				0.69504			

Adjusted Failure Probabilities and Consequences, M5

Highway:	SH 74, Christchurch to Arthurs Pass
Region:	Canterbury
Location:	Paddy's Bend
Site:	2
Maintenance Option:	M5, Earthworks, Scaling, Bolting and Catch Fence

1. Determine mitigated probability of failure

	Failure Mode	**PDF Input Parameters**																					F	events/ year		
		Min	ML	Max																						
Failure Modes	F1 Rockfall, 0-150 mm	*220*	*293*	*366*																			0.41	120		
	F2 Rockfall,150-300 mm	*100*	*150*	*200*																			0.33	49		
	No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			Checksums	
	F3 Rockfall,300-500 mm	*0.71*	*0.007*	*0.007*	*0.015*	*0.058*	*0.116*	*0.058*	*0.015*	*0.007*	*0.007*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	0.29	1.00	*1.00*	*OK*
	F4 Rockfall,500-1000 mm	*0.72*	*0.058*	*0.145*	*0.058*	*0.015*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	0.23	1.00	*1.00*	*OK*

2. Determine Mitigated Consequences

		Consequence																							
		C1 Detritus Clearance ($)				C2 Service Disruption (hours/yr)				C3 Fatal Accidents (No/yr)				C4 Serious Accidents (No/yr)				C5 Minor Accidents (No/yr)				C6 Non-injury Accidents (No/yr)			
		Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist
	Failure Mode:	F=	*0.18*			F=	*0.18*			F=	*0.16*			F=	*0.17*			F=	*0.17*			F=	*0.18*		
Consequences	F1 Rockfall, 0-150 mm	2.13	28.8	44	4.4	0	0	0.005	0.0003	2.75E-07	2.75E-08	2.75E-05	1.66E-05	4.94E-07	4.94E-06	4.94E-05	3.05E-06	4.94E-06	4.94E-05	4.94E-04	3.05E-05	5.44E-04	5.44E-03	5.44E-02	3.60E-03
	F2 Rockfall,150-300 mm	2.13	28.8	44	4.4	0	0	0.005	0.0003	2.75E-07	2.75E-09	2.75E-05	1.66E-06	4.94E-07	4.94E-06	4.94E-05	3.05E-06	4.94E-06	4.94E-05	4.94E-04	3.05E-05	5.44E-04	5.44E-03	5.44E-02	3.60E-03
	F3 Rockfall,300-500 mm	2.13	28.8	44	4.4	0	0	0.005	0.0003	2.75E-07	2.75E-08	2.75E-05	1.66E-06	4.94E-07	4.94E-05	4.94E-05	3.05E-06	4.94E-06	4.94E-05	4.94E-04	3.05E-05	5.44E-04	5.44E-03	5.44E-02	3.60E-03
	F4 Rockfall,500-1000 mm	2.13	26.8	44	4.4	0	0	0.005	0.0003	2.75E-07	2.75E-05	2.75E-05	1.66E-05	4.94E-07	4.94E-08	4.94E-05	3.05E-06	4.94E-06	4.94E-05	4.94E-04	3.05E-06	5.44E-04	5.44E-03	5.44E-02	3.60E-03

P(C)	Consequences/yr given mitigation	*745.10*	*0.05*	*0.00028*	*0.00052*	*0.00522*	*0.61692*

Worksheet 8

Determination of Lowest Total Equivalent Cost

Highway:	SH 74, Christchurch to Arthurs Pass
Region:	Canterbury
Location:	Paddy's Bend
Site:	2

Costs of Consequences:

Detritus Removal	*Already in $*
Service Disruption (per hr)	$ 3,109.00
Fatal Accident (ea)	$ 2,570,000.00
Serious Accident (ea)	$ 236,000.00
Minor Accident (ea)	$ 21,400.00
Non-injury accident (ea)	$ 2,400.00

Cost of Maintenance Prgrmme
(in excess of M0, baseline option)

	Maintenance Activity					
	M0	**M1**	**M2**	**M3**	**M4**	**M5**
Implimentation cost as Present Value($)	M0,Unmitigated Case	M1, Instability Monitoring	M2, Scaling	M3, Scaling, Bolting and Wire Mesh	M4, Realignment Scaling, Bolting and Catch Fence	M5, Earthworks, Scaling, Bolting and Catch Fence
Min	0	130012	44255	168205	315875	961680
ML	0	153821	54181	189039	359903	1208827
Max	0	180379	64532	211617	397432	1471553
Dist	0	154737	54323	189620	357737	1214020

Summary of Annual Consequences

C1 Detritus Clearance ($)	*10940*	*10940*	*7277*	*1894*	*745*	*745*
C2 Service Disruption (hours/yr)	*0.750*	*0.750*	*0.499*	*0.130*	*0.051*	*0.051*
C3 Fatal Accidents (No/yr)	*0.005*	*0.001*	*0.003*	*0.001*	*0.001*	*0.000*
C4 Serious Accidents (No/yr)	*0.008*	*0.002*	*0.005*	*0.001*	*0.001*	*0.001*
C5 Minor Accidents (No/yr)	*0.082*	*0.034*	*0.055*	*0.014*	*0.006*	*0.005*
C6 Non-injury Accidents (No/yr)	*9.058*	*4.529*	*6.025*	*1.568*	*0.695*	*0.617*
Total Annual Cost of Consequences($)	*50478*	*28105*	*33579*	*8738*	*4308*	*3350*
Discount to Present Value(discount rate 0.1 over 25 years)($)	*432588*	*240856*	*287766*	*74883*	*36919*	*28708*
Add cost of Maintenance Option to get Total Equivalent Cost ($)	***432588***	***395594***	***342088***	***264503***	***394655***	***1242728***
Benefit Cost Ratio	***1.00***	***1.24***	***2.67***	***1.89***	***1.11***	***0.33***

Expected Value of Benefit Cost Ratio from Simulation	**1.00**	**1.25**	**2.69**	**1.89**	**1.12**	**0.33**
			Highest B:C			

Expected Value of Total Equivalent Cost from Simulation	**433007**	**395563**	**341870**	**264306**	**392210**	**1245586**
				Lowest TEC		

Worksheet 9

Determination of Greatest Probability of Being Cheapest

Degree of Preference Among Alternative Maintenance Programmes

	M1	M2	M3	M4	M5
over M0	*-36994*	*-90499*	*-168085*	*-37933*	*810140*
over M1		*-53505*	*-131090*	*-938*	*847134*
over M2			*-77585*	*52567*	*900639*
over M3				*130152*	*978224*
over M4					*848072*

Absolute Preference (1=yes, 0=no)

	M1	M2	M3	M4	M5
over M0	*1*	*1*	*1*	*1*	*0*
over M1		*1*	*1*	*1*	*0*
over M2			*1*	*0*	*0*
over M3				*0*	*0*
over M4					*0*
Over all others					
0	0	0	1	0	0

Probability that maintenance programme is the cheapest, % (after simulation)

M0	M1	M2	M3	M4	M5
4.20	**2.40**	**20.40**	**72.60**	**0.40**	**0.00**
			Greatest Prob		

APPENDIX 8
ANALYSIS WORKSHEETS FOR SITE 4

Riddolls & Grocott Ltd

Probabilistic Optimisation of Slope Stability Management Stategy

transfund NEW ZEALAND

Analysis Summary

Highway: SH 74, Christchurch to Arthurs Pass

Transit NZ Region: Canterbury

Location: Paddy's Bend

Site: 4

Kilometre Reference: **From:** RP121/6.123 **To:** RP121/6.213

Length (m): 100

Speed Limit (km/hr): 100 **Avg Speed (km/hr):** 70

Analyst: PH **Date:** Jul-98

Instability Modes :

F1 Rockfall, 0-150 mm
F2 Rockfall,150-300 mm
F3 Rockfall,300-500 mm
F4 Rockfall,500-1000 mm
F5 Rockslide

Consequences of Instability:

C1 Detritus Clearance ($)
C2 Service Disruption (hours/yr)
C3 Fatal Accidents (No/yr)
C4 Serious Accidents (No/yr)
C5 Minor Accidents (No/yr)
C6 Non-injury Accidents (No/yr)

Maintenance Options:

	Lowest Total Equivalent Cost	*Greatest Probability of Being Cheapest*
M0,Unmitigated Case		
M1, Instability Monitoring		
M2, Toe Gabion Wall, Minor Realignment	✓	✓
M3, Scaling, Bolting and Wire Mesh		
M4, Rock Catch Fence		
M5, Avalanche Shed		

Contents.

Existing Failure Probabilities and Consequences, (M0)

Highway:	SH 74, Christchurch to Arthurs Pass
Region:	Canterbury
Location:	Paddy's Bend
Site:	4
Maintenance Option:	M0,Unmitigated Case

1. Determine probability of failure

	Failure Mode	**PDF Input Parameters**																					E	Dist		
		Min	ML	Max																						
Triangular PDFs	F1 Rockfall, 0-150 mm	1350	2025	2700																			1.00	2025		
	F2 Rockfall,150-300 mm	380	570	760																			1.00	570		
	F3 Rockfall,300-500 mm	20	30	44																			1.00	31		
	No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			Checksums	
Discrete PDFs	F4 Rockfall,500-1000 mm	0.040	0.040	0.080	0.090	0.200	0.300	0.200	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	4.00	*1.0000*	*OK*
	F5 Rockslide	0.800	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	0.0	*1.00*	*OK*

*/factor 10.000

2. Determine Consequences given Failure

		Consequence																							
		C1 Detritus Clearance ($)				C2 Service Disruption (hours/yr)				C3 Fatal Accidents (No/yr)				C4 Serious Accidents (No/yr)				C5 Minor Accidents (No/yr)				C6 Non-injury Accidents (No/yr)			
		Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist
	Failure Mode:	E=	*1.00*			E=	*1.00*			E=	*1.00*			E=	*1.00*			E=	*1.00*			E=	*1.00*		
Triangular PDFs	F1 Rockfall, 0-150 mm	2.13	26.80	44.00	24.31	0.00	0.00	0.01	1.667E-03	2.8E-07	2.8E-06	2.8E-05	1.0E-05	4.9E-07	4.9E-06	4.9E-05	1.8E-05	4.9E-06	4.9E-05	4.9E-04	1.8E-04	5.4E-04	5.4E-03	5.4E-02	2.0E-02
	F2 Rockfall,150-300 mm	2.13	26.80	44.00	24.31	0.00	0.00	0.01	1.667E-03	2.8E-07	2.8E-06	2.8E-05	1.0E-05	4.9E-07	4.9E-06	4.9E-05	1.8E-05	4.9E-06	4.9E-05	4.9E-04	1.8E-04	5.4E-04	5.4E-03	5.4E-02	2.0E-02
	F3 Rockfall,300-500 mm	2.13	26.80	44.00	24.31	0.00	0.00	0.01	1.667E-03	2.8E-07	2.8E-06	2.8E-05	1.0E-05	4.9E-07	4.9E-06	4.9E-05	1.8E-05	4.9E-06	4.9E-05	4.9E-04	1.8E-04	5.4E-04	5.4E-03	5.4E-02	2.0E-02
	F4 Rockfall,500-1000 mm	2.13	26.80	44.00	24.31	0.00	0.00	0.01	1.667E-03	2.8E-07	2.8E-06	2.8E-05	1.0E-05	4.9E-07	4.9E-06	4.9E-05	1.8E-05	4.9E-06	4.9E-05	4.9E-04	1.8E-04	5.4E-04	5.4E-03	5.4E-02	2.0E-02
	F5 Rockslide	100.00	500.00	1000.00	533.33	0.00	1.00	4.00	1.667E+00	2.8E-07	2.8E-06	2.8E-05	1.0E-05	4.9E-07	4.9E-06	4.9E-05	1.8E-05	4.9E-06	4.9E-05	4.9E-04	1.8E-04	5.4E-04	5.4E-03	5.4E-02	2.0E-02
P(C)	Consequences /yr				*63943.4*				*4.384*				*0.027*				*0.048*				*0.481*				*52.94*

Estimated Effectiveness of Maintenance Options

Highway: SH 74, Christchurch to Arthurs Pass
Region: Canterbury
Location: Paddy's Bend
Site: 4

Mean fractional reduction in P(F) and P(C|F) for implementation of each maintenance
Truncated normal distributions assumed for effectiveness estimates
Mean as shown in table below
Standard deviation: **0.2**

		Maintenance Options											
		M0,Unmitigated Case		M1, Instability Monitoring		M2, Toe Gabion Wall, Minor Realignment		M3, Scaling, Bolting and Wire Mesh		M4, Rock Catch Fence		M5, Avalanche Shed	
		Effectiveness, E											
		mean	dist	mean	dist	mean	dist	mean	dist	mean	dist	mean	dist
Failure Modes	F1 Rockfall, 0-150 mm	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.82	0.00	0.00	0.00	0.00
	F2 Rockfall,150-300 mm	0.00	0.00	0.00	0.00	0.00	0.00	0.99	0.84	0.00	0.00	0.00	0.00
	F3 Rockfall,300-500 mm	0.00	0.00	0.00	0.00	0.00	0.00	0.99	0.84	0.00	0.00	0.00	0.00
	F4 Rockfall,500-1000 mm	0.00	0.00	0.00	0.00	0.00	0.00	0.99	0.84	0.00	0.00	0.00	0.00
	F5 Rockslide	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.20	0.00	0.00	0.00	0.00
Consequences	C1 Detritus Clearance ($)	0.00	0.00	0.00	0.00	0.90	0.80	0.00	0.00	0.95	0.82	1.00	1.00
	C2 Service Disruption (hours/yr)	0.00	0.00	0.00	0.00	0.90	0.80	0.00	0.00	0.95	0.82	1.00	1.00
	C3 Fatal Accidents (No/yr)	0.00	0.00	0.85	0.77	0.95	0.82	0.00	0.00	0.96	0.83	1.00	1.00
	C4 Serious Accidents (No/yr)	0.00	0.00	0.75	0.71	0.95	0.82	0.00	0.00	0.96	0.83	1.00	1.00
	C5 Minor Accidents (No/yr)	0.00	0.00	0.60	0.59	0.90	0.80	0.00	0.00	0.93	0.81	1.00	1.00
	C6 Non-injury Accidents (No/yr)	0.00	0.00	0.50	0.50	0.88	0.79	0.00	0.00	0.90	0.80	1.00	1.00

Adjusted Failure Probabilities and Consequences, M1

Highway:	SH 74, Christchurch to Arthurs Pass
Region:	Canterbury
Location:	Paddy's Bend
Site:	4
Maintenance Option:	M1, Instability Monitoring

1. Determine reduced probability of failure

	Failure Mode	**PDF Input Parameters**																					E	events/ year		
		Min	ML	Max																						
Triangular PDFs	F1 Rockfall, 0-150 mm	1350	2025	2700																			1.00	2025		
	F2 Rockfall,150-300 mm	380	570	760																			1.00	570		
	F3 Rockfall,300-500 mm	20	30	44																			1.00	31		
	No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			Checksums	
Discrete PDFs	F4 Rockfall,500-1000 mm	*0.04*	*0.040*	*0.080*	*0.090*	*0.200*	*0.300*	*0.200*	*0.050*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	1.00	4.00	*1.00*	*OK*
	F5 Rockslide	*0.80*	*0.200*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	1.00	0.00	*1.00*	*OK*

2. Determine Mitigated Consequences

		Consequence																							
		C1 Detritus Clearance ($)				C2 Service Disruption (hours/yr)				C3 Fatal Accidents (No/yr)				C4 Serious Accidents (No/yr)				C5 Minor Accidents (No/yr)				C6 Non-injury Accidents (No/yr)			
		Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist
	Failure Mode:	E=	*1.00*			E=	*1.00*			E=	*0.23*			E=	*0.29*			E=	*0.41*			E=	*0.50*		
	F1 Rockfall, 0-150 mm	2.13	26.8	44	24.3	0	0	0.005	1.667E-03	2.75E-07	2.75E-06	2.75E-05	2.32E-06	4.94E-07	4.94E-06	4.94E-05	5.31E-06	4.94E-06	4.94E-05	4.94E-04	7.50E-05	5.44E-04	5.44E-03	5.44E-02	1.01E-02
	F2 Rockfall,150-300 mm	2.13	26.8	44	24.3	0	0	0.005	1.667E-03	2.75E-07	2.75E-06	2.75E-05	2.32E-06	4.94E-07	4.94E-06	4.94E-05	5.31E-06	4.94E-06	4.94E-05	4.94E-04	7.50E-05	5.44E-04	5.44E-03	5.44E-02	1.01E-02
	F3 Rockfall,300-500 mm	2.13	26.8	44	24.3	0	0	0.005	1.667E-03	2.75E-07	2.75E-06	2.75E-05	2.32E-05	4.94E-07	4.94E-06	4.94E-05	5.31E-06	4.94E-06	4.94E-05	4.94E-04	7.50E-05	5.44E-04	5.44E-03	5.44E-02	1.01E-02
	F4 Rockfall,500-1000 mm	2.13	26.8	44	24.3	0	0	0.005	1.667E-03	2.75E-07	2.75E-06	2.75E-05	2.32E-06	4.94E-07	4.94E-06	4.94E-05	5.31E-06	4.94E-06	4.94E-05	4.94E-04	7.50E-05	5.44E-04	5.44E-03	5.44E-02	1.01E-02
	F5 Rockslide	100	500	1000	533.3	0	1	4	1.67E+00	2.75E-07	2.75E-06	2.75E-05	2.32E-06	4.94E-07	4.94E-06	4.94E-05	5.31E-06	4.94E-06	4.94E-05	4.94E-04	7.50E-05	5.44E-04	5.44E-03	5.44E-02	1.01E-02
P(C)	Consequences/yr given mitigation				*63943*				*4.38*				*0.0061*				*0.0140*				*0.1971*				*26.4717*

Adjusted Failure Probabilities and Consequences, M2

Highway:	SH 74, Christchurch to Arthurs Pass
Region:	Canterbury
Location:	Paddy's Bend
Site:	4
Maintenance Option:	M2, Toe Gabion Wall, Minor Realignment

1. Determine mitigated probability of failure

	Failure Mode	**PDF Input Parameters**																					F	events/ year		
		Min	ML	Max																						
Triangular PDFs	F1 Rockfall, 0-150 mm	1350	2025	2700																			1.00	2025		
	F2 Rockfall,150-300 mm	380	570	760																			1.00	570		
	F3 Rockfall,300-500 mm	20	30	44																			1.00	31		
	No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			Checksums	
Discrete PDFs	F4 Rockfall,500-1000 mm	*0.04*	*0.040*	*0.080*	*0.090*	*0.200*	*0.300*	*0.200*	*0.050*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	1.00	4.00	*1.00*	*OK*
	F5 Rockslide	*0.80*	*0.200*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	1.00	0.00	*1.00*	*OK*

2. Determine Mitigated Consequences

		Consequence																							
		C1 Detritus Clearance ($)				C2 Service Disruption (hours/yr)				C3 Fatal Accidents (No/yr)				C4 Serious Accidents (No/yr)				C5 Minor Accidents (No/yr)				C6 Non-injury Accidents (No/yr)			
		Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist
	Failure Mode:	E=	*0.20*			E=	*0.20*			E=	*0.18*			E=	*0.18*			E=	*0.20*			E=	*0.21*		
Triangular PDFs	F1 Rockfall, 0-150 mm	2.13	26.8	44	4.9	0	0	0.005	3.36E-04	2.75E-07	2.75E-06	2.75E-05	1.82E-06	4.94E-07	4.94E-06	4.94E-05	3.27E-06	4.94E-06	4.94E-05	4.94E-04	3.69E-05	5.44E-04	5.44E-03	5.44E-02	4.26E-03
	F2 Rockfall,150-300 mm	2.13	26.8	44	4.9	0	0	0.005	3.36E-04	2.75E-07	2.75E-06	2.75E-05	1.82E-06	4.94E-07	4.94E-06	4.94E-05	3.27E-06	4.94E-06	4.94E-05	4.94E-04	3.69E-05	5.44E-04	5.44E-03	5.44E-02	4.26E-03
	F3 Rockfall,300-500 mm	2.13	26.8	44	4.9	0	0	0.005	3.36E-04	2.75E-07	2.75E-06	2.75E-05	1.82E-06	4.94E-07	4.94E-06	4.94E-05	3.27E-06	4.94E-06	4.94E-05	4.94E-04	3.69E-05	5.44E-04	5.44E-03	5.44E-02	4.26E-03
	F4 Rockfall,500-1000 mm	2.13	26.8	44	4.9	0	0	0.005	3.36E-04	2.75E-07	2.75E-06	2.75E-05	1.82E-06	4.94E-07	4.94E-06	4.94E-05	3.27E-06	4.94E-06	4.94E-05	4.94E-04	3.69E-05	5.44E-04	5.44E-03	5.44E-02	4.26E-03
	F5 Rockslide	100	500	1000	107.5	0	1	4	3.36E-01	2.75E-07	2.75E-06	2.75E-05	1.82E-06	4.94E-07	4.94E-06	4.94E-05	3.27E-06	4.94E-06	4.94E-05	4.94E-04	3.69E-05	5.44E-04	5.44E-03	5.44E-02	4.26E-03
P(C)	Consequences/yr given mitigation				*12892.76*				*0.8839*				*0.00479*				*0.00860*				*0.09694*				*11.20398*

Adjusted Failure Probabilities and Consequences, M3

Highway:	SH 74, Christchurch to Arthurs Pass
Region:	Canterbury
Location:	Paddy's Bend
Site:	4
Maintenance Option:	M3, Scaling, Bolting and Wire Mesh

1. Determine mitigated probability of failure

	Failure Mode	PDF Input Parameters																					F	events/ year		
		Min	ML	Max																						
Triangular PDFs	F1 Rockfall, 0-150 mm	1350	2025	2700																			0.18	362		
Triangular PDFs	F2 Rockfall,150-300 mm	380	570	760																			0.16	93		
Triangular PDFs	F3 Rockfall,300-500 mm	20	30	44																			0.16	5		
Discrete PDFs	No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			Checksums	
Discrete PDFs	F4 Rockfall,500-1000 mm	0.84	0.007	0.013	0.015	0.033	0.049	0.033	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.16	1.00	1.00	OK
Discrete PDFs	F5 Rockslide	0.97	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.80	0.00	1.00	OK

2. Determine Mitigated Consequences

	Consequence																							
	C1 Detritus Clearance ($)				C2 Service Disruption (hours/yr)				C3 Fatal Accidents (No/yr)				C4 Serious Accidents (No/yr)				C5 Minor Accidents (No/yr)				C6 Non-injury Accidents (No/yr)			
	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist
Failure Mode:	E=	1.00			E=	1.00			E=	1.00			E=	1.00			E=	1.00			E=	1.00		
F1 Rockfall, 0-150 mm	2.13	26.8	44	24.3	0	0	0.005	1.667E-03	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.94E-07	4.94E-05	4.94E-05	1.83E-05	4.94E-06	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02
F2 Rockfall,150-300 mm	2.13	26.8	44	24.3	0	0	0.005	1.667E-03	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.94E-07	4.94E-06	4.94E-05	1.83E-05	4.94E-06	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02
F3 Rockfall,300-500 mm	2.13	26.8	44	24.3	0	0	0.005	1.667E-03	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.94E-07	4.94E-06	4.94E-05	1.83E-05	4.94E-05	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02
F4 Rockfall,500-1000 mm	2.13	26.8	44	24.3	0	0	0.005	1.667E-03	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.84E-07	4.84E-06	4.84E-05	1.83E-05	4.94E-06	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02
F5 Rockslide	100	500	1000	533.3	0	1	4	1.667E+00	2.75E-07	2.75E-06	2.75E-05	1.02E-05	4.84E-07	4.84E-06	4.94E-05	1.83E-05	4.94E-06	4.94E-05	4.94E-04	1.83E-04	5.44E-04	5.44E-03	5.44E-02	2.01E-02

P(C)	Consequences/yr given mitigation	11218.20	0.7691	0.00470	0.00843	0.08435	9.28835

Adjusted Failure Probabilities and Consequences, M4

Highway:	SH 74, Christchurch to Arthurs Pass
Region:	Canterbury
Location:	Paddy's Bend
Site:	4
Maintenance Option:	M4, Rock Catch Fence

1. Determine mitigated probability of failure

	Failure Mode	PDF Input Parameters																					F	events/ year	Checksums	
		Min	ML	Max																						
Triangular PDFs	F1 Rockfall, 0-150 mm	1350	2025	2700																			1.00	2025		
	F2 Rockfall,150-300 mm	380	570	760																			1.00	570		
	F3 Rockfall,300-500 mm	20	30	44																			1.00	31		
	No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			Checksums	
Discrete PDFs	F4 Rockfall,500-1000 mm	0.04	0.040	0.080	0.090	0.200	0.300	0.200	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	4.00	1.00	OK
	F5 Rockslide	0.80	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	0.00	1.00	OK

2. Determine Mitigated Consequences

		Consequence																							
		C1 Detritus Clearance ($)				C2 Service Disruption (hours/yr)				C3 Fatal Accidents (No/yr)				C4 Serious Accidents (No/yr)				C5 Minor Accidents (No/yr)				C6 Non-injury Accidents (No/yr)			
		Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist
	Failure Mode:	E=	0.18			E=	0.18			E=	0.17			E=	0.17			E=	0.19			E=	0.20		
Tralangular PDFs	F1 Rockfall, 0-150 mm	2.13	26.8	44	4.4	0	0	0.005	2.983E-04	2.75E-07	2.75E-06	2.75E-05	1.78E-06	4.94E-07	4.94E-06	4.94E-05	3.20E-06	4.94E-06	4.94E-05	4.94E-04	3.43E-05	5.44E-04	5.44E-03	5.44E-02	4.06E-03
	F2 Rockfall,150-300 mm	2.13	26.8	44	4.4	0	0	0.005	2.983E-04	2.75E-07	2.75E-06	2.75E-05	1.78E-06	4.94E-07	4.94E-06	4.94E-05	3.20E-06	4.94E-05	4.94E-05	4.94E-04	3.43E-05	5.44E-04	5.44E-03	5.44E-02	4.06E-03
	F3 Rockfall,300-500 mm	2.13	26.8	44	4.4	0	0	0.005	2.983E-04	2.75E-07	2.75E-06	2.75E-05	1.78E-06	4.94E-07	4.94E-06	4.94E-05	3.20E-06	4.94E-05	4.94E-05	4.94E-04	3.43E-05	5.44E-04	5.44E-03	5.44E-02	4.06E-03
	F4 Rockfall,500-1000 mm	2.13	26.8	44	4.4	0	0	0.005	2.983E-04	2.75E-07	2.75E-06	2.75E-05	1.78E-05	4.94E-07	4.94E-06	4.94E-05	3.20E-05	4.94E-05	4.94E-05	4.94E-04	3.43E-05	5.44E-04	5.44E-03	5.44E-02	4.06E-03
	F5 Rockslide	100	500	1000	95.4	0	1	4	2.983E-01	2.75E-07	2.75E-05	2.75E-05	1.78E-06	4.94E-07	4.94E-06	4.94E-05	3.20E-06	4.94E-05	4.94E-05	4.94E-04	3.43E-05	5.44E-04	5.44E-03	5.44E-02	4.06E-03
P(C)	Consequences/yr given mitigation				11443.72				0.7846				0.00468				0.00840				0.09021				10.67485

Adjusted Failure Probabilities and Consequences, M5

Highway:	SH 74, Christchurch to Arthurs Pass
Region:	Canterbury
Location:	Paddy's Bend
Site:	4
Maintenance Option:	M5, Avalanche Shed

1. Determine mitigated probability of failure

	Failure Mode	PDF Input Parameters																					F	events/ year		
		Min	ML	Max																						
Triangular PDFs	F1 Rockfall, 0-150 mm	1350	2025	2700																			1.00	2025		
	F2 Rockfall,150-300 mm	380	570	760																			1.00	570		
	F3 Rockfall,300-500 mm	20	30	44																			1.00	31		
	No: Failures	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			Checksums	
Discrete PDFs	F4 Rockfall,500-1000 mm	0.04	0.040	0.080	0.090	0.200	0.300	0.200	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	4.00	1.00	OK
	F5 Rockslide	0.80	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.00	0.00	1.00	OK

2. Determine Mitigated Consequences

		Consequence																							
		C1 Detritus Clearance ($)				C2 Service Disruption (hours/yr)				C3 Fatal Accidents (No/yr)				C4 Serious Accidents (No/yr)				C5 Minor Accidents (No/yr)				C6 Non-injury Accidents (No/yr)			
		Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist	Min	ML	Max	Dist
	Failure Mode:	E=	0.00			E=	0.00			E=	0.00			E=	0.00			E=	0.00			E=	0.00		
Triangular PDFs	F1 Rockfall, 0-150 mm	2.13	26.8	44	0.0	0	0	0.005	0.000E+00	2.75E-07	2.75E-06	2.75E-05	0.00E+00	4.94E-07	4.94E-06	4.94E-05	0.00E+00	4.94E-06	4.94E-05	4.94E-04	0.00E+00	5.44E-04	5.44E-03	5.44E-02	0.00E+00
	F2 Rockfall,150-300 mm	2.13	26.8	44	0.0	0	0	0.005	0.000E+00	2.75E-07	2.75E-06	2.75E-05	0.00E+00	4.94E-07	4.94E-06	4.94E-05	0.00E+00	4.94E-06	4.94E-05	4.94E-04	0.00E+00	5.44E-04	5.44E-03	5.44E-02	0.00E+00
	F3 Rockfall,300-500 mm	2.13	26.8	44	0.0	0	0	0.005	0.000E+00	2.75E-07	2.75E-09	2.75E-05	0.00E+00	4.94E-07	4.94E-06	4.94E-05	0.00E+00	4.94E-06	4.94E-05	4.94E-04	0.00E+00	5.44E-04	5.44E-03	5.44E-02	0.00E+00
	F4 Rockfall,500-1000 mm	2.13	26.8	44	0.0	0	0	0.005	0.000E+00	2.75E-07	2.75E-06	2.75E-05	0.00E+00	4.94E-07	4.94E-06	4.94E-05	0.00E+00	4.94E-06	4.94E-05	4.94E-04	0.00E+00	5.44E-04	5.44E-03	5.44E-02	0.00E+00
	F5 Rockslide	100	500	1000	0.0	0	1	4	0.000E+00	2.75E-07	2.75E-09	2.75E-05	0.00E+00	4.94E-07	4.94E-06	4.94E-05	0.00E+00	4.94E-06	4.94E-05	4.94E-04	0.00E+00	5.44E-04	5.44E-03	5.44E-02	0.00E+00

P(C)	Consequences/yr given mitigation	0.00	0.0000	0.00000	0.00000	0.00000	0.00000

Determination of Lowest Total Equivalent Cost

Highway:	SH 74, Christchurch to Arthurs Pass
Region:	Canterbury
Location:	Paddy's Bend
Site:	4

Costs of Consequences:

Detritus Removal	*Already in $*
Service Disruption (per hr)	$ 3,109.00
Fatal Accident (ea)	$ 2,570,000.00
Serious Accident (ea)	$ 236,000.00
Minor Accident (ea)	$ 21,400.00
Non-injury accident (ea)	$ 2,400.00

Cost of Maintenance Prgrmme
(in excess of M0, baseline option)

	Maintenance Activity					
	M0	**M1**	**M2**	**M3**	**M4**	**M5**
Implimentation cost as Present Value($)	M0,Unmitigated Case	M1, Instability Monitoring	M2, Toe Gabion Wall, Minor Realignment	M3, Scaling, Bolting and Wire Mesh	M4, Rock Catch Fence	M5, Avalanche Shed
Min	0	426565	136412	246939	316870	1163962
ML	0	495404	151359	269778	360240	1651154
Max	0	578830	165624	293947	416808	2141026
Dist	0	500266	151132	270221	364639	1652047

Summary of Annual Consequences

C1 Detritus Clearance ($)	*63943*	*63943*	*12893*	*11218*	*11444*	*0*
C2 Service Disruption (hours/yr)	*4.384*	*4.384*	*0.884*	*0.769*	*0.785*	*0.000*
C3 Fatal Accidents (No/yr)	*0.027*	*0.006*	*0.005*	*0.005*	*0.005*	*0.000*
C4 Serious Accidents (No/yr)	*0.048*	*0.014*	*0.009*	*0.008*	*0.008*	*0.000*
C5 Minor Accidents (No/yr)	*0.481*	*0.197*	*0.097*	*0.084*	*0.090*	*0.000*
C6 Non-injury Accidents (No/yr)	*52.943*	*26.472*	*11.204*	*9.288*	*10.675*	*0.000*
Total Annual Cost of Consequences($)	*295054*	*164280*	*58945*	*51764*	*55441*	*0*
Discount to Present Value(discount rate 0.1 over 25 years)($)	*2528556*	*1407850*	*505149*	*443608*	*475116*	*0*
Add cost of Maintenance Option to get Total Equivalent Cost ($)	***2528556***	***1908116***	***656280***	***713830***	***839756***	***1652047***
Benefit Cost Ratio	***1.00***	***2.24***	***13.39***	***7.72***	***5.63***	***1.53***

Expected Value of Total Equivalent Cost from Simulation	**2539440**	**1914674**	**665825**	**717617**	**846341**	**1652054**
			Lowest TEC			

Expected Value of Benefit Cost Ratio from Simulation	**1.00**	**2.26**	**13.42**	**7.75**	**5.66**	**1.56**
			Highest B:C			

Worksheet 9

Determination of Greatest Probability of Being Cheapest

Degree of Preference Among Alternative Maintenance Programmes

	M1	**M2**	**M3**	**M4**	**M5**
over M0	*-620440*	*-1872276*	*-1814726*	*-1688800*	*-876509*
over M1		*-1251836*	*-1194287*	*-1068361*	*-256069*
over M2			*57549*	*183475*	*995767*
over M3				*125926*	*938218*
over M4					*812292*

Absolute Preference (1=yes, 0=no)

	M1	**M2**	**M3**	**M4**	**M5**
over M0	*1*	*1*	*1*	*1*	*1*
over M1		*1*	*1*	*1*	*1*
over M2			*0*	*0*	*0*
over M3				*0*	*0*
over M4					*0*
Over all others					
0	0	1	0	0	0

Probability that maintenance programme is the cheapest, % (after simulation)

M0	**M1**	**M2**	**M3**	**M4**	**M5**
0.00	**0.00**	**49.20**	**38.20**	**12.60**	**0.00**
		Greatest Prob			

APPENDIX 9

TRANSIT NEW ZEALAND PREVENTIVE MAINTENANCE NATIONAL PRIORITISATION RANKING PROCEDURE

TRANSIT NEW ZEALAND PREVENTIVE MAINTENANCE

NATIONAL PRIORITISATION

The following items are listed as prompts in ensuring consistency in interpretation of the rankings applied to each Assessment Factor to arrive at the final prioritisation score.

RISK OF FAILURE

Prevention of further significant damage to the highway asset.
Probability of consequences if work is not carried out.
Risk and exposure.
Stability.
Return period of next event.
Rate of deterioration.
Distance from edge line to head of scarp.
Condition of existing failures.
Erodibility of the face.
Will next event take out the road.
Frequency of event damage or erosion.
Potential to further deteriorate.
Time of year.
Cycle of repair.

ROAD USER HAZARD

Traffic safety.
Protection and safety of road users.
Road user perception of danger.
Hazard presented should it regress.
Forward visibility to the hazard.

STRATEGIC IMPORTANCE

Class of Highway.
Strategic importance of link.
Traffic volume.
Volume and type of vehicles that would affected.
Severity of road closure.
Alternative routes if closed.
Availability of alternative routes (refer to Emergency Contingency Plans).
Is the road single lane at present.

ECONOMICS

Cost of repair if allowed to degenerate to a candidate for emergency reinstatement funding.
Cost of proposed treatment.
Lowest or least cost.
Other repair options for site.
Ratio of repair cost verse total failure.

User costs of detours.
Short term verse long term repair costs.
Proximity of resources to site.
Cost in Consultant and TNZ time if the work is not carried out.
Have other options been considered.
Is / are treatments part of strategic repair approach.
Economic effects of not repairing and subsequent failure.
What is the previous emergency work expenditure at the site.

LEGAL IMPLICATIONS

Legal responsibility if action not taken.
Risk to adjacent property.
Environmental implications.

PUBLIC / POLITICAL VIEW

Political need to provide a certain level of service.
Public pressure.
Extent of remedial measures and their impact on other parties within the community - cost sharing?

TRANSIT NEW ZEALAND PREVENTIVE MAINTENANCE

NATIONAL PRIORITISATION RANKING TABLE

Assessment Factor	Assessment Measure		Score	Assess Weight
Risk of Failure	The integrity of the highway asset will be endangered if not completed within 6 months.		10	25%
	The integrity of the highway asset will be endangered if not completed within 12 months.		7	
	The integrity of the highway asset will be endangered if not completed within 2 years.		5	
	No risk of further deterioration to the highway asset.		0	
Road User Hazard (Safety)	The safety of the road user may be endangered if not completed within 6 months		10	20%
	The safety of the road user may be endangered if not completed within 12 months		6	
	The work will improve the general safety of the highway network		3	
	No road user hazard		0	
Strategic Importance **(Select highest applicable score)** To calculate Detour Score for a road closure. Multiply the net increase in travel distance (in km) of the detour suitable for all traffic by the AADT.	**Highway Class**	**Detour**		20%
	Motorway	> 250,000 v.kmpd	10	
	Class I Highway > 10,000 vpd	150,000-250,000 v.kmpd	8	
	Class II Highway 4,000 < 10,000 vpd	50,000-150,000 v.kmpd	6	
	Class III Highway 1,000 < 4,000 vpd	5,000-50,000 v.kmpd	4	
	Class IV Highway < 1,000 vpd	<5,000 v.kmpd	2	

Economics	Cost of reinstatement of asset is likely to increase significantly if not completed within 6 to 12 months	10	20%
	Cost of reinstatement of asset is likely to increase significantly if not completed within 2 years	8	
	Cost of reinstatement of asset is unlikely to increase if left untreated	6	
	Reinstatement of the asset will decrease the operating and/or environmental costs of the network	3	
	Completion of the work will improve the value or appearance of the highway network	1	
Legal Implications	Serious legal implications will result if not completed immediately	10	10%
	Legal implications will result if not completed within 12 months	6	
	Legal implications may result if not completed with in 2 years	4	
	No legal implications	0	
Public / Political View	**High**: Matter raised by local MP or at Ministerial level	10	5%
	Medium: Matter raised by Local Authority and/or numerous members of public and/or local community	6	
	Low: Subject of occasional written or verbal complaints	3	
	None	0	

TRANSIT NEW ZEALAND PREVENTIVE MAINTENANCE
NATIONAL PRIORITISATION FIELD SHEET

LOCATION Region ________
SH ________ RP ___/______ Name:

Description of Defect

Description of Proposed Repair

Ranking Assessment

Assesment Factor	Initial Score	Weighting	Adjusted Score
Risk of Failure		25%	
Road User Hazard		20%	
Strategic Importance		20%	
Economics		20%	
Legal Implications		10%	
Public/Political View		5%	
ROC Estimate ($000)		Final Score	

Sketch of Site (as required)