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Landslides and Rehabilitation of the Highlands Highway, Papua New Guinea

R Goldsmith
MGeoscience, MAusIMM
Principal Engineering Geologist, SMEC International, Australia
M Ernest
BSc
Managing Director, SMEC PNG, Papua New Guinea
S Dorugl
BSc
Engineering Geologist, SMEC PNG, Papua New Guinea

Summary: A study was recently completed for a multi-disciplinary assessment of 600 km of the Highlands Highway that extends from the port city of Lae, through the Highlands to Mendi in Papua New Guinea. The purpose of the study was to investigate and design for the rehabilitation and reconstruction of the Highlands Highway to bring it to a standard where it provides an acceptable level of service.

This paper deals with landslides and sediment run-out affecting the Highway, the process of classification and how the design for rehabilitation was approached. In addition specific case studies are presented to illustrate how the objectives of the study and reporting to the Client were achieved.

The engineering geological studies involved air photo and satellite imagery review, detailed mapping of the geomorphology at over 120 landslides along the Highway, test pits, drilling and laboratory testing. Assessment for design of rehabilitation ranged from the appreciation of geological hazards contained within the hinterlands of large drainage catchments, landslides both within the road corridor and at quite remote locations, drainage and erosion issues in combination with many environmental and social aspects.

INTRODUCTION

The Highlands Highway in Papua New Guinea is a critical transport link between the coastal port of Lae and five highlands provinces where almost 2 million people live. The road has been progressively upgraded from a cart track over the past 40 years to its present configuration as a National Highway. Improved road geometry in mountainside sections has enabled better passage for heavy vehicles but at the same time has made the road more vulnerable to slope instability, due to the deeper cuttings, filling across gullies and straightening of previously contour graded re-entrants. In addition there has not been the required maintenance for many years and the road has now deteriorated to a condition where it is often impassable in many sections. Geological hazards are significant in this steep mountainous terrain with high rainfall. The situation has become exacerbated as many different government, private and commercial users now share the road. These include mining and petroleum based developments and coffee and other cash crop producers.

In order to improve the present situation a study was recently completed for a multi-disciplinary assessment of 600 km of the Highlands Highway that extends from Lae, through Goroka and Mount Hagen and beyond to Mendi. This involved geologists, geotechnical and civil engineers, river morphologists, environmental and social scientists, economists and planners.

The purpose of the study, funded by the World bank and implemented by the Department of Works, was to investigate and design for the rehabilitation of this highway to bring it to a standard where it provides an acceptable level of service (SMEC, 2002).

ENGINEERING GEOLOGICAL STUDIES

The engineering geology component was critical to the project, carried out in 2001-2002 as it defined the problem, the locations of hazards and the approach to rehabilitation designs. In view of the large scope of this work a special approach was needed to define, collate and classify the areas for attention. Historically there were critical sections where specific geotechnical and hydrological conditions were largely responsible for the poor and worsening condition of the Highway (Figure 1). These formed the initial focus of attention, but it was soon found that the entire length of Highway required a comprehensive review.

This paper deals with the nature and extent of landslides and sediment runout affecting the Highway and the process of classification and design for rehabilitation. In addition specific case studies are presented to illustrate how the objectives of the study and the reporting to the Government of PNG was achieved.

Initially 16 Critical Sections (CS) were studied as these were the locations of major problems relating to unfavourable conditions. CS 1 to CS 6 are located along the first section of the road within the Markham valley. CS7 to CS11 are localised instability problems that affect only a few hundred metres of highway at any particular location within the Eastern Highlands Province. CS12, west of Goroka is a section of landsliding over the Daulo Pass, covering 16km. CS13 is by far the biggest section through all of Simbu Province where 50km of the Highway is affected by earth flow type movements developed within a weak rock formation. The remaining three sections CS14 to CS16 related to more specific instability issues in the western part of the Highlands.

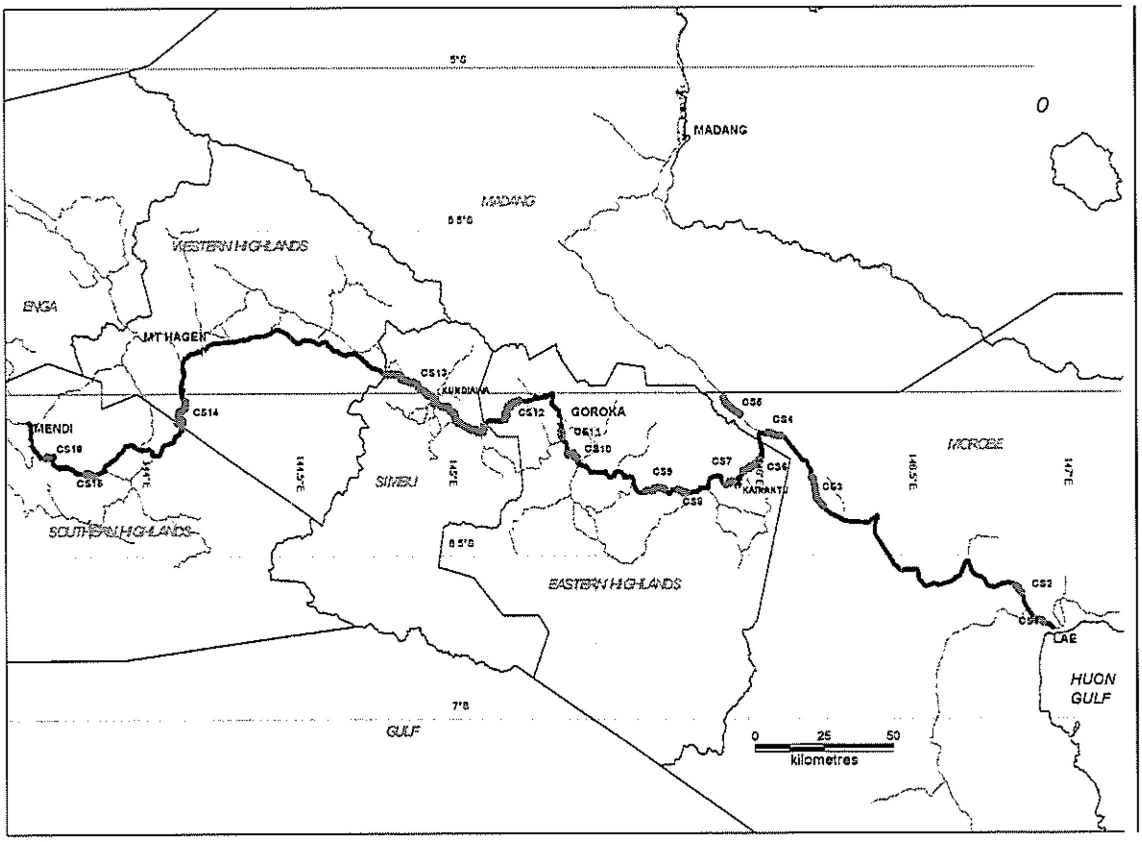

Figure 1. Highlands Highway, showing the critical sections.

DESCRIPTION OF THE HIGHWAY ROUTE

The Highlands Highway is within an area influenced by recent tectonic processes, where seismic activity is an engineering design consideration, the geological materials are highly variable and commonly deeply weathered, slopes are often steep, with a high relief and the annual rainfall is often greater than 3000mm. producing excessive runoff events. The geology is summarised in (Davies, et al, 1997).

For the purposes of this study the Highway has been divided into three main sections based on topography and geological conditions. A detailed description of the geological conditions and state of the highway is given in Tutton & Kuna (1995) and SMEC (2002). Kilometres have been measured from Lae.

1. 0 to 175km: Markham Valley section, following the tectonic structural rift in which the Markham and Ramu Rivers flow. The fault zone following this valley is considered to have once been the boundary between the Pacific and Australian tectonic plates and thus the area remains highly seismically active. The mountain ranges facing the valley are underlain by late Tertiary age sedimentary and volcanic units. Rapid and continuing elevation changes contribute to the geological hazards that include – hinterland instability that contributes excessive sediment to alluvial fans and braided river channels; changes in river courses, flooding and debris torrents and progressively worsening erosion and sedimentation

(Buleka, el al, 1999). The materials involved are mostly moist to wet granular residual soils that are highly erodible.

2. 175 to 345km: Eastern Highlands Section underlain by a series of Tertiary age volcanics and sedimentary units that progress to the Recent period. The section commences with a steep climb through the Kassam Pass (Figure 2) and then into a variable section of ranges and intermontane valley. West of Goroka the road then progresses over the 2.600m high Daulo Pass. Conditions that contribute to the slope instability are mainly poor drainage and extensive weathering on weak basement that produce unconsolidated and saturated soils.

3. 345 to 606km: Highlands Section affected by the Chim Formation. This section commences at the Chimbu gap with a 50km section of the Highway that is extensively affected mostly by slow-moving earthflow type movements. The underlying rock is Upper Cretaceous age mudstone, that behaves similarly to an overconsolidated clay when weathered, and is subject to failure on slopes as shallow as about 10 degrees. This condition is also encountered in three areas in the Southern Highlands towards Mendi at the end of the study area.

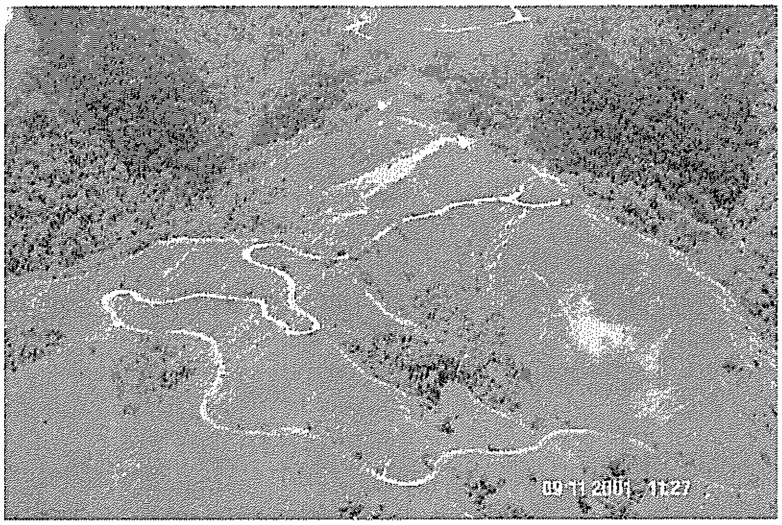

Figure 2. Kassam Pass section of the Highway that climbs through interbedded sedimentary rocks.

METHODS OF INVESTIGATION

The Engineering Geological Studies involved air photo and satellite imagery review, detailed geomorphological mapping of over 120 landslides, test pits, drilling and laboratory testing. This work extended over three months using a team of four geologists. The work was assisted by many local people who provided a valuable history of events and led the team to many locations that could have been missed in the dense vegetation that engulfs much of the ground near the road.

The process involved initial identification to defme a landslide "Feature" at a particular distance in kilometres from Lae and GPS located co-ordinates. A proforma was used to describe the site (Appendix 1) that was developed from other work carried out by the authors and with reference to extensive work done in Malaysia, (including Hurley et al, 1995). Information recorded at each site included location, road geometry, site geology, vegetation type and cover, drainage and erosion conditions, existing and recent slope stability and evidence of recent works. This was accompanied by individual geomorphological maps at 1:1,000 scale, measured up using a combination of hand held GPS (accurate to 5-7m), compass, clinometer and hip-chain. Figure 3 is one such map at a landslide on Daulo Pass. At none of the sites was there an existing detailed topographic plan, and although aerial photography was conducted and proved to be most informative, the detailed maps depended upon the ground work. This was particularly the case where dense vegetation encroached along the road side.

A second stage of investigation was performed at selected landslides, comprising test pits, drilling and laboratory testing, after a team review to assess the need for certain information in order to design remedial works. The process of geological and geotechnical investigations, followed by several group assessments both on the road and in the office involving the geologist, civil engineer, surveyor and other inputs, was necessary to develop an appropriate set of designs and specifications to match the project's objectives and to be within budget.

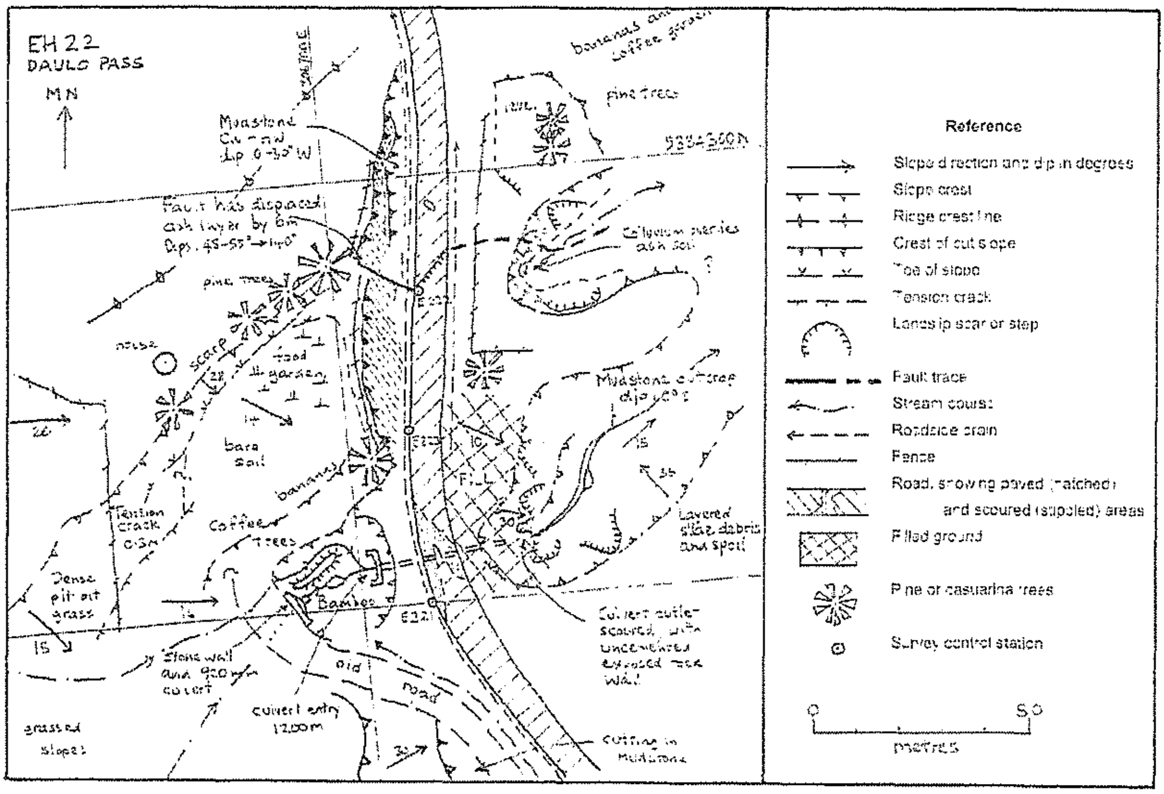

Figure 3. Geomorphologicalmapping at landslide site on Daulo Pass

HAZARD AND RISK ASSESSMENT

Each feature was categorized using a hazard and risk rating system developed by the Roads and Traffic Authority of NSW (2000). This system proved useful for a quick analysis of defined locations in order to set priorities for more detailed investigation and for justifications of inclusions within the Critical Sections. The magnitude and expected frequency of occurrence of failures provided a Hazards rating and the consequence rating then was used to apply a risk class from 1 to 5 (Appendix 1).

The purpose of the landslide hazard assessment was to define the likelihood of landslides over selected sections of the Highway. This assisted those responsible for Highway management in developing levels of preparedness and contingency plans in the event of landslides/drainage problems blocking or disrupting the Highway.

Another method employed for mapping of large sections of the Highlands Highway was a factor overlay evaluation modified from Anbalagan (1991). This method was initially evolved in India for development planning in hilly landslide prone terrain. The system has focussed on specific rock types, structures, landforms and land use activities and uses a landslide hazard evaluation factor (LHEF). This rating system depends on the major contributory factors of slope instability such as geology, slope morphometry, relief, land use, land cover and finally, groundwater conditions. The maximum LHEF for different categories are determined on the basis of their estimated significance in causing the instability.

A series of 1:10,000 scale hazard maps was also prepared for each of the Critical Sections (SMEC, 2002).

CASE STUDIES

Maniang Fan in the Markham Valley

The Maniang Alluvial Fan affecting 14.5km of Highway is the most problematic section along the Markham Valley. Here flooding, changing river courses and scour have affected the road. Within the upper catchments of the Maniang and Yafatz Rivers the catastrophic Kaiapit Landslide occurred. This slide involving the displacement of about 1.8 billion m^3 of weathered rock and non-cohesive soils and caused a massive mnout of sediment into the two rivers which have consequently changed course across the fans. In addition two large earthquakes in the area in 1993 also contributed to massive landsliding in the catchment areas that added to the stream sediment load (Tutton & Kuna, 1995). One result has been an increased flow into Garia Creek, a distributary from the Maniang River. The lower reaches of the Garia Creek aggraded by 2001 to the extent whereby the flow has been blocked and the creek then broke out of its channel and cut back to the western side of the Highway where it now follows it for about 1.2km. The creek banks have locally scoured out 50% of the carriageway (Figure 4). Recent rock fill placement has temporarily protected this section of the road.

Most of the streams on the Fan are sediment choked braided channels that flow at a gradient of about 1%. This is far steeper than the lower Markham River, at about 0.1% gradient. The system is very dynamic due to the recent tectonic movements, landslides and the highly erodible sediments that form the catchment areas. This is a priority section for rehabilitation works in order to reduce the risk of Highway closures.

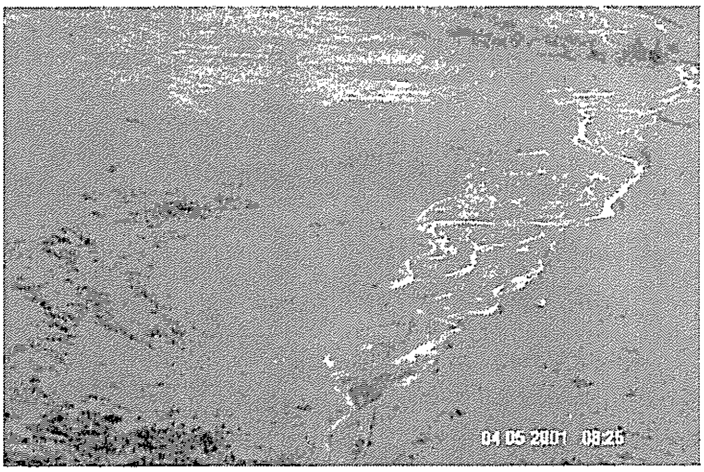

Figure 4. Garia Creek cutting the western edge of the Highway in the Markham Valley.

Daulo Pass.

This steep mountain pass has been affected by debris slides, rotational slumps and general creep ever since it was first upgraded from a simple track to an engineered road in the 1960's. The geology is dominated by folded and faulted acid volcanics, with interbedded volcanolithic sediments that are characteristically deeply weathered. Where they occur on steep slopes they produce a wide range of landslide types that require rehabilitation in the form of drainage improvements, reinforced fill, strategic cutting and possible structural slope stabilisation such as a bored pile retaining wall.

In late 2000 the Highway at Nambawaniku Creek (Figure 5) was cut for several days following a debris torrent 700m in length and involving 80,000m^3 of saturated weathered volcanic rocks and soil. This event demonstrated that geological studies along the Highway need to include all the catchment areas and not just an assessment of the immediate road corridor area. Clean up of the debris proved to be difficult due to the step gradients downstream and the need to avoid damage to dwellings and cultivation on the lower slopes. Rehabilitation involves better drainage control and a multi-plate culvert with a facility to remove debris as it accumulates.

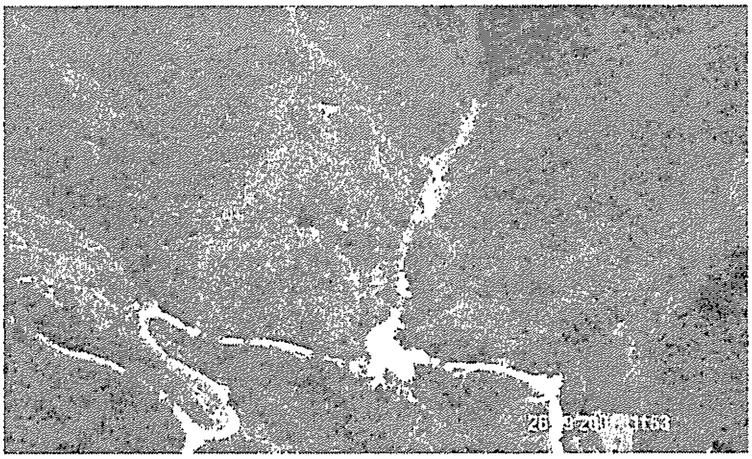

Figure 5. Major debris torrent that blocked the Highway at the Daulo Pass in 2000.

Simbu Province Earth Flows

Over 50km of the Highway, where it passes through this province, has been subjected to the alternate creeping and slow surging movements of earth flows (Hungr, el al, 2001) that have developed in weak mudstones. This member of the Chim Formation weathers and breaks down rapidly in combination with undrained loading from debris slides and rock falls off the scarps of Chimbu Limestone (Blong, 1987).

Many sections of the Highway are affected by displacement downslope, disruption of drainage and overriding from debris coming from the upper valley slopes (see Figure 6). Evidence of such landslides is sharp lateral shears and steps in the road profile up to 1m in size. Surging movements have been known to displace the road by 20-30m in one year. The engineering approach to rehabilitation is restricted by budget and thus it has been necessary to accept the process and effectively manage it by drainage improvements, pavement edge reinforcement to delay the inevitable deformation and minor diversions. The earthflows are well defmed and are mostly separated by stable ridges, thus if funds are available in the future more sophisticated stabilisation techniques may be employed such as tie-back walls, debris bridges and larger road diversions.

Figure 6. Overriding earthflow partly blocks the highway in eastern Simbu Province. Note also the lateral shear that displaces the road pavement.

RESULTS OF THE INVESTIGATIONS

The site investigation data is an extensive catalogue of the condition of the Highway in 2001 and has been utilised to design detailed remedial works at more than 50 landslides. The work, including the Feature catalogues, forms, maps, photos and larger scale hazard maps should also be a valuable reference for the future.

Detailed designs and tender documents were prepared by 2002 and to date only maintenance works have been performed on the Highway. In addition, in April 2003 the Highway was closed for two weeks due to the Garia Creek bridge abutment being washed out and debris from an earthflow overriding the road in Simbu. Thus the fate of the Highway now rests upon funding for the works. It is intended that a Highlands Highway Authority be set up to co-ordinate this work.

CONCLUSIONS & RECOMMENDATIONS

A detailed engineering geological investigation was conducted for over 600km of the Highlands Highway. To obtain the most beneficial information for rehabilitation works to proceed the road was initially inspected to define the main Critical Sections. These were designated by assessing the risk of road closure from landslides and where concentrations of such features along sections of similar geological terrain.

Engineering geological data for each feature was obtained from detailed site mapping, photography and completion of standard proforma. This was utilized by a team approach to assess the most appropriate rehabilitation works. The works were designed to provide improved drainage, pavement and fill foundations and stabilized slopes to mitigate the impacts from site instability. By understanding the geomorphological processes on the slopes affecting the highway the proposed civil works can improve the road condition over a longer period than is presently the case. The geological setting cannot be changed, but a sensible engineering approach, combined with an appreciation for the need for a combined effort for funding maintenance and continued remedial works must be achieved. Similar projects can benefit from utilising a standard system of obtaining information, cataloguing the features and involving a multi-disciplined team at several stages in a project in order to achieve a satisfactory outcome.

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APPENDIX A: FEATURE SUMMARY PROFORMA

HIGHLANDS HIGHWAY REHABILITATION PROJECT

FEATURE SUMMARY PROFORMA

					FEATURE	SB24	
LOCATION:	Co-ordinates (Lae end)	E:	55 262739		N:	9328744	
	Km	From:	363.0		To:	363.3	
GEOMETRY:	L / R	both	Aspect:	westward	Road Length:	200m	
Slope height	50m	Slope angle	<15 deg	Slope length	>3000m		
Description:	The road crossing the Wara Tamba has been displaced in the past by over 30m, in addition a surge in landslide movement in 1994 caused lateral shear scarps of about 1m. Ground deformation and sediment carried by the stream have blocked the 2m culvert in the past resulting in a pond over 20m across and flooding of the road. This is a major slide complex (see Notes below).						
GEOLOGY		Formation:	Chim Formation				
Bedrock:	Lithology:	Mudstone		Weathering	variably weathered, saturated, reduced state		
	Strength:	Very low to medium		Structures:	Bedding dips 40-025, poor exposures		
Soil:	Type:	Colluvium, alluvium in channels					
	Texture:	Coll: soft wet silty clay/ clayey silt, zones of mdst gravel. Alluv. silty to gravelly sand.					
	Stratification:	none observed					
General description:	The bedrock of dark grey mudstone dips northward beneath an escarpment of limestone Scree from the limestone has combined with the underlying mudstone to form large creeping masses of colluvium that converge on the stream courses and develop into major landslide complexes.						
VEGETATION		Dense grasses and stands of tall yar trees with local garden areas, roadside planting.					
DRAINAGE	Unlined drains where road forms an embankment over Wara Tamba. Culvert at main stream is partly blocked, 3 pipes in main stream. Poor drainage ove the body of the slip area.						
Seepages:	Many observed upslope of the road			Ponded water:		Periodic pond forms	
EROSION	Sheet: no		Rill: no	Gully: no		Depth: n/a	
INSTABILITY:	Classification		Major slip	Mode of failure		Earth flow/creep zone	
Size	Height >200m?		Width 250 m	Depth >20m?		***Vol:*** > 5 mill m^3	
Extent of Debris	Creeping mass has displaced road, etc by >30m					***Rate:*** very slow	
Displaced begetation	yes		Drainage disrupted	yes stream courses periodically alter			
Description	The Wara Tamba flow is part of a large slide complex It was active in 1979 about 1km down stream when a surge of 40 hectares cut Elcom power lines. The earth flow affecting the road is a headward extension of that slide The surge in 1994 cut the road with I m scarps and the road had to be regraded This type of failure moves on defined shear surfaces and is slow moung						
RECENT WORKS			Age of Feature	>2yrs	1-2yrs	6-12mths	0-6mths
Eudence of recent works	Culvert extension works cleared blocked culvert, pond drained						
RISK ASSESSMENT:	worst					least	
Event Magnitude	M1	M2	M3	M4	M5		
Likelihood Analysis:	L1	L2	L3	L4	L5	L6	
Hazard Class:	H1	H2	H3	H4	H5	H6	
Consequence Rating	C1	C2	C3	C4	C5		
RISK RATING	1	2	3	4	5		

Notes:	Although the existing road and passage of vehicles is currently acceptable the pavement is deteriorating on the northern flank due to poor drainage and the culvert is periodically blocked. The condition of the road and the rehabilitation requires an assessment of the whole river catchment and other integrated landslides.