▪ report

Slope Instability Hazard: Samoa Islands

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Prepared for

Ministry of Natural Resources, Environment & Meteorology

By

Beca International Consultants Ltd

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Ministry of Natural Resources, Environment & Meteorology
Private Bag
Apia
SAMOA

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Attention: Vitaua Peleiupu Fuatai

Dear Sir

Slope Instability Hazard: Samoa Islands

The attached report is a partial delivery for the additional hazard layer for the MNREM GIS system. This concerns the slope instability hazard, and the associated GIS data layers will be separately delivered by the Beca GIS team on their forthcoming visit in early April 2006. The balance of this deliverable on a flood hazard assessment will be delivered as a separate report. We are still working on this as the absence of rainfall data across the country is necessitating some additional interpretation of catchment data.

Yours faithfully
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Revision History

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Document Acceptance

Action	Name	Signed	Date
Prepared by	Ann Williams		
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Approved by	Graeme Roberts		27 Mar 06
on behalf of	**Beca International Consultants Ltd**		

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1 Introduction

This report provides a preliminary assessment of the relative risk of movement of natural slopes on the Samoan islands of Upolu and Savai'i, in response to heavy rainfall or earthquake shaking. The principal conditions controlling slope stability are considered (soil/rock type, slope height and angle, and evidence of past instability), with each attribute being weighted and summed to identify the relative risk. This relative risk has been calibrated with anecdotal evidence provided in discussion with local government representatives and road maintenance contractors.

The objective of the assessment is to identify the relative susceptibility of natural slopes to slope movement for consideration in development of Coastal Infrastructure Management plans.

2 Geological Setting

The west-northwest to east-southeast aligned Samoan islands are located at the northern end of the north-south aligned Tonga Trench. The islands comprise a chain of predominantly basaltic volcanic domes and cones forming a central ridge along the island.

2.1 Soils and Rocks

The oldest rocks generally occur on Upolu and the youngest on Savai'i, although simultaneous volcanism has occurred over much of the Quaternary (the last 2 million years through to historic times). The depth of soil developed from weathering of the basalts increases with the age of the volcanics, so that the deepest soils are found overlying the Fagaloa (Upolu) and Vanu (Fagaloa equivalents outcropping on Savai'i) volcanics. These thicker soils are more likely to be susceptible to slope movement.

Non-volcanic deposits include coral and tuff rich sands deposited in response to sea-level rise and alluvium-filled vallies blocked by lava flows. Swamp deposits, coral reef and cemented beach sands also occur. In places the younger volcanics overlie beach and reef deposits.

A summary of the soils and rocks mapped is given in Table 1 (Kear & Wood 1959, Kear et al 1979, Turner 1985).

Table 1: Soil and Rock Groups

Name	Description
Aopo Volcanics	▪ Basalt produced by historic eruptions (within the last 200 years; latest eruption ceasing 1911); ▪ Little vegetation; ▪ Unweathered, bouldery surface; ▪ No surface water; ▪ In places covered Puapua basalt and reef at coast; fills lagoons.
Tafagamanu Sand, Nu'utele Sand, Lalomauga Alluvium	▪ Sand comprising shell, coral and rock fragments; ▪ Little vegetation; ▪ No surface water.
Puapua Volcanics	▪ Slightly weathered to fresh basalt; ▪ Thin soil cover; ▪ Unweathered boulders common on uneven surface (10° to 15°); ▪ Basalt filled lagoons leaving almost no reef offshore; lavas flowed over reefs to form rocky coastline.
Lefaga Volcanics	▪ Olivine basalt weathered to a depth of 5 m to 10 m; ▪ Thin soil cover; ▪ Unweathered boulders common on uneven surface (10° to 15°); ▪ Almost no surface water or evidence of erosion by surface water; ▪ Reef close inshore.
Mulifanua Volcanics	▪ Olivine basalt weathered to a depth of 10 m to 20 m; ▪ Thin soil cover; ▪ Unweathered boulders common on uneven surface (10° to 15°); ▪ Almost no surface water; ▪ Shallow stream channels eroded; ▪ May overlie wave-cut benches and coral reefs at depths of 30+ m; ▪ Reef far offshore.
Salani Volcanics	▪ Thick olivine basalt weathered to a depth of about 35 m; ▪ Soil cover more than 0.3 m thick; ▪ Weathered rounded boulders on surface sloping ~15°; ▪ Gorges cut in flanks; ▪ Surface water sometimes present; ▪ Reef far offshore.
Fagaloa Volcanics and Vanu Volcanics	▪ Basaltic lava flows with associated dykes, tuffs and cones; ▪ Form steep (25° to 50°) high slopes (original slope of the lavas 5 - 20°); ▪ Younger basalts sit unconformably on, and fill valleys eroded in, Fagaloa rocks ▪ Weathered to a depth of ~ 75 m; covered by thick clayey soils; ▪ Individual flows 0.3 to 30 m thick, but typically 2 m to 4 m separated by rubbly basalt partly filled by clays; ▪ Vegetation cover can be poor because soils are leached; ▪ Reef absent or close inshore; ▪ Surface water retained.

3 Conditions that Affect Slope Stability

The principal conditions that contribute to instability are discussed below.

3.1 Soil and Rock Type

The majority of the soils and rocks on Samoa have a similar volcanic origin. Their behaviour is mostly distinguished by:

- The depth of weathering products developed, which is a function of age (failure within the soil mass or at the interface between the soil and rock);
- The form (eg columnar, blocky, scoriaceous) and degree of fracturing of the flows (fall of rock blocks isolated by fractures); and
- The thickness of flows and nature of the material between flows (sliding on the clayey zone developed between flow).

3.2 Slope Height and Angle

The steepness and height of a slope in relation to the properties of the soil and rock slopes may be critical to slope stability. Most of the younger lavas have surface slopes of up to 10° to 15° controlled by lava flow viscosity. However steeper slopes (up to 50°) have formed by stream erosion down-cutting along fractures in the older volcanic rocks.

Where the basalt is massive and sound, the slopes are expected to be stable at slopes of 45° or steeper, however weathering and/or dipping fractures reduce the stable height and angle of the slopes.

3.3 Past Movement

Evidence of past instability indicates a potential for failure of geologically similar slopes of similar slope grade in the same area, providing a guide to the likely future behaviour of similar slopes in other areas.

Discussions with government officials and those responsible for road maintenance identified the following areas as being particularly susceptible to ongoing slope movement affecting roads on Upolu:

- Much of the east coast road of Upolu from Lauili'i to Saluafata; road blocked on an annual basis;
- Richardson Track between Falevao and Vaipu; and
- Debris slides at Lalomanu, Fagaloa and Lefaga Bays.

4 Hazard Contributions

4.1 Soil/Rock Type

Although the soil/rock units exposed on Samoa are predominantly basaltic volcanics, their geomorphic expression and properties differ. An attempt has been made to correlate this observed behaviour with the mapped basalt type. Soil and rock categories developed to group the materials described in Table 1 according to their known or expected geotechnical characteristics are given in Table 2. Soil and rock type distribution are shown on Maps 1A (Savai'i) and 1B (Upolu), appended.

Table 2: Soil/ Rock Categories

Class	Soil/ Rock Group	Characteristic Instability
A	Tafagamanu Sand, Nu'utele Sand	■ Loss by erosion or washout.
B	Lalomauga Alluvium and talus derived from Fagaloa Volcanics	■ Failure by sliding or flow where the slope is saturated, cut, or undermined by stream erosion.
C	Aopo/ Puapua/ Lefaga/ Mulifanua Volcanics	■ Failure by individual rock falls; ■ Collapse of rock into cavities, in particular in the coastal area where waves exploit fractures in the rock venting as blow holes
D	Salani Volcanics	■ Shallow sliding within weathered soils and rock; ■ Failure by planar sliding on an interface with the underlying rock; ■ Rock block and debris fall.
E	Fagaloa and Vanu Volcanics	■ Failure by sliding along a circular failure surface within the deep weathered soil or soil and rock mass; ■ Rock block and debris fall.

4.2 Slope Grade

Slope grade information was developed from a terrain model built from the 20 m contours, spot heights and coastline, sourced from the Samoan 1:50,000 scale maps. Slope grades were grouped into the four classes defined in Table 3 and illustrated in Maps 2A and 2B (Savai'i and Upolu respectively). Relative scores were assigned to each slope category based on observed or inferred behaviour of each rock type class within each slope angle range.

Table 3: Slope Grade Classes

Class	Slope Grade	Slope Angle (°)	Slope Type
A	Gentle	0 – 7	Alluvial and debris slopes
B	Moderately steep	8 – 15	Unweathered lava flows
C	Steep	16 – 25	Lava flows modified by erosion and weathering
D	Very steep	25+	Lava flows modified by stream downcutting and weathering; fault scarps; vent slopes

4.3 Evidence of Past Slope Movement

Aerial photographs, discussion with parties responsible for road maintenance and a drive-over of the islands have been used to provide a preliminary assessment of areas that have been affected by slope movement in the past. These are more difficult to distinguish in the Samoan landscape because of the predominance of lava and debris flows derived from volcanic activity, modified by stream down-cutting, which may have a similar appearance to landslides and flows. Areas considered to have been subject to slope movement in the past are shown on Maps 3A and 3B. These have been correlated with anecdotal evidence provided from discussions with local government representatives and road maintenance contractors and with preliminary work in the coastal domain presented by Gibb 2001.

5 Hazard Assessment

Regional scale assessment of slope instability hazard (1:100,000) has been carried out by allocating weighted scores to each of the key attributes contributing to slope movement described above, and combining these to produce regional slope instability hazard maps, Map 4A, Savai'i and Map 4B, Upolu.

5.1 Hazard Scores

Weightings are attributed to each contributing factor according to Table 4. Classes are as identified in Section 4.

Table 4: Weighted Scores

Class	Soil/Rock Type Score	Slope Grade Score	Past Instability Score
A	1	1	2
B	3	2	-
C	2	3	-
D	3	5	-
E	6	-	-

5.2 Hazard Assessment

The soil/rock type and slope grade scores from Table 4 have been combined using GIS and are presented in Table 5. Where a locality has been subject to past instability, a Past Instability Score (Table 4) is added to the tabulated score.

Table 5: Hazard Assessment

Soil/ Rock Class	Slope Class A	Slope Class B	Slope Class C	Slope Class D
A	1+1 = 2	1+2 = 3	1+3 = 4	1+5 = 6
B	3+1 = 4	3+2 = 5	3+3 = 6	3+5 = 8
C	2+1 = 3	2+2 = 4	2+3 = 5	2+5 = 7
D	3+1 = 4	3+2 = 5	3+3 = 6	3+5 = 8
E	6+1 = 7	6+2 = 8	6+3 = 9	6+5 = 11
F	2+1 = 3	2+2 = 4	2+3 = 5	2+5 = 7

The total scores are interpreted in terms of slope instability hazard in Table 6 and shown on the Slope Instability Hazard Maps (Maps 4A and 4B) as Hazard Zones.

Table 6: Hazard Assessment

Total Score	Class	Hazard Risk
0 – 4	A	Very low slope instability hazard
5 – 7	B	Low slope instability hazard: stability will be dependent on local factors such as depth of weathering and degree of saturation
8 – 9	C	Moderate slope instability hazard: slopes unstable; ongoing movement anticipated
10 – 13	D	High slope instability hazard

6 Discussion

Details of the methods used to produce the accompanying preliminary slope instability hazard maps are presented. The slope instability hazard maps have been compiled at a broad scale (1:100,000) to identify areas of relative risk based on available information on rock type and slope angle and on observed behaviour of accessible outcrops of the different soil and rock types.

The maps indicate:

- The risk of slope movement on the island of Savai'i is for the most part, very low to low. A moderate to high risk of slope movement occurs only locally in coastal areas or away from population centres;
- There are also large areas of Upolu, in particular in the more densely populated coastal zone, where the risk of slope movement is judged to be low or very low. The risk is higher where steep slopes occur in proximity to the coast and adjacent to streams and rivers. (Note: The risk of slope movement associated with smaller streams and short slopes in the coastal domain may be localised and not identified at the scale of mapping carried out as part of this project to date).
- There are a number of significant areas judged to be at moderate to high risk of slope movement on Upolu:
  - i. The area bound by the coast from Letogo to Cape Utusi'a, extending inland to Mt Fito and across to Mt Le Pu'e;
  - ii. The area east of the Le Mafa Pass Road and north of Richardson Road, extending to the coast; and
  - iii. Steep land between the Faleaseela River, the Falevai River and the coast.
  - iv. Steep ground inland of Apia, elevated but more marginal land, becoming increasingly developed: such development will need to be carefully managed to limit instability.

7 References

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