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NEW ZEALAND

PROJECT REPORT

A MODEL OF SLIP EROSION RISK, CENTRAL HAWKE'S BAY COASTAL HILL COUNTRY

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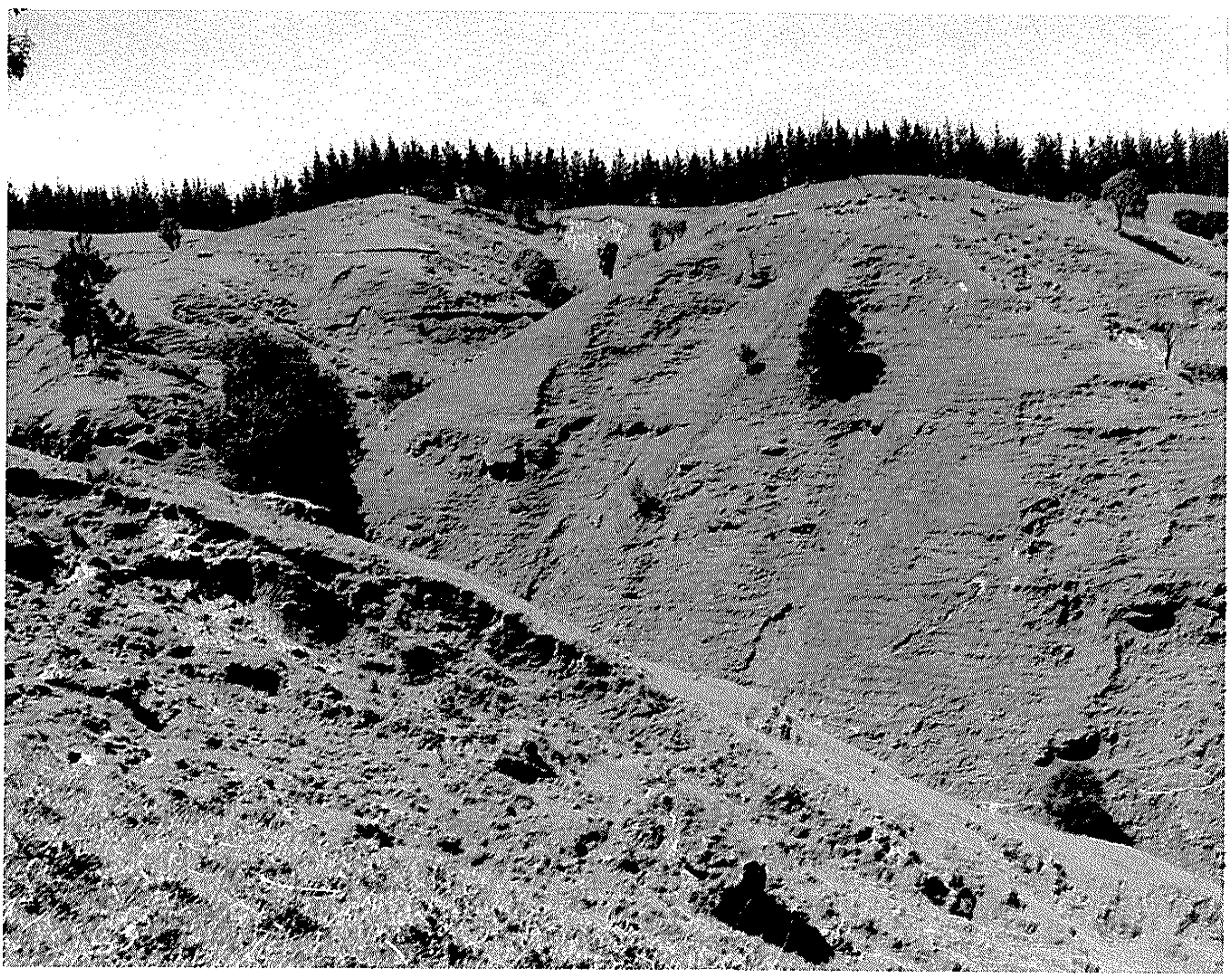

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P.R.59

Cover photo - High erosion risk slopes in the Tamingimingi catchment showing old and fresh slip scars. Pakuratahi catchment is beyond the ridge.

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Research Organisation
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ABSTRACT

The forest operations planner may require slip erosion risk maps particularly when there is no sign of potential slope instability. A slip erosion risk map was generated for a pasture catchment and a forest catchment near Tangoio, Hawkes Bay. Maps of geology, soil and associated landform, slope steepness and aspect, were cross referenced with maps of historical slip coverage in a Geographic Information System (GIS). Erosion risk was divided into five categories based on the proportion of slips in erosion classes:

- *Very high slip erosion risk occupies 2% to 6% of the catchments' area; occurring on upper ridge areas mantled by Recent Tephric and Orthic soil, Ohakean gravel; and 20° to 25° slopes facing east or west.*

- *High erosion risk occupies 8% to 10% of the catchments' area defined by; Ohakean gravel, Kaiwaka Formation, Recent Tephric and Orthic soil on steep slopes and upper ridges, north, east or west aspects, and 20° to 35° slopes.*

- *Moderate levels of slip erosion risk occupy about 14% of the catchments' area. They have similar features to the higher risk categories but included are slopes 15° to 25° over all aspects.*

- *Low and very low risk areas take up more than 70% of the catchment area, occurring on gentle to rolling relief, on alluvial soils, on escarpments with thin soils and on thick mudstone formations.*

INTRODUCTION

Soil erosion and flooding has long been a land management issue in the Hawke's Bay region. Afforestation projects since the 1940s have proved an effective soil conservation technique to control slip erosion in the steep hill country (Campbell, 1964). Now there is concern that logging will lead to renewed erosion, threatening the sustainability of local soil and water resources.

Forest and land resource managers continue to explore methods of reducing the potential for soil erosion and sedimentation while ensuring maximum productivity. The New Zealand Land Resource Inventory (NZLRI) worksheets are customarily used by forest planners to identify areas that are sensitive to erosion and requiring resource consents. The NZLRI map units (or land use capability classes) provide basic land inventory information for use at a district or regional scale (1:63,360), (NWASCO, 1979). Only general limitations and suitability for productive land use are stated in the NZLRI, rather than specific management needs.

Forestry operations are usually planned at a scale of 1:10,000 or less. At this level, the harvest planner may require erosion risk information to enable careful management of activities at erosion prone sites. As the NZLRI worksheets do not provide detailed information on erosion risk at the operational scale, there is a need to gather new data so management decisions can be specific to a site or harvest setting.

This report describes a model of slip erosion risk and its potential use as a planning tool in two adjacent catchments in steep hill country; the Tamingimingi pasture catchment and Pakuratahi forest catchment (Figure 1). Landscape components used to develop the erosion risk model were geology, soils and associated landforms, slope steepness and aspect, and historical slip distribution.

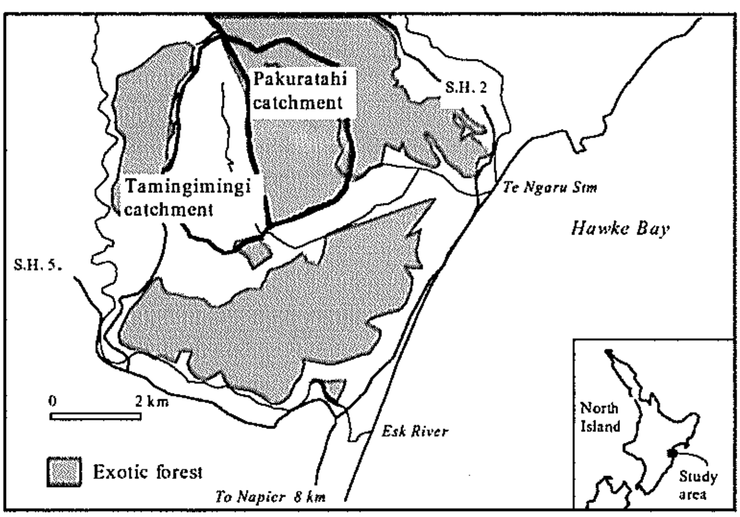

Figure 1 - Location of research catchments

METHODOLOGY

Mapping

Historical slip erosion data were obtained from an archive of aerial photographs held at New Zealand Aerial Mapping, Hastings (Table 1). Only two significant erosion events were recorded by aerial photography in the region. The 1943 and 1988 photos captured widespread slippage associated with storms during ANZAC weekend in 1938 and Cyclone Bola in 1988.

Table 1 - Aerial photography used for mapping soil slips and land use

Date of photographs	Photo scale	Reason for selection
Mar 1943	1:17000	Erosion after April 1938 storm
Nov 1970	1:25000	Conditions prior to forest planting
Oct 1981	1:25000	Forest cover in Pakuratahi catchment
Dec 1988	1:25000	Erosion after Cyclone Bola in March
Jan 1994	1:29000	Present conditions and geographic controls

Slip scars were mapped from photo diapositives using a Carto Instruments AP190 analytical stereo-plotter linked to TerraSoft GIS software[1]. The Department of Survey and Land Information provided photo and diapositive control points and their New Zealand Map Grid coordinates. The photos were then orientated and registered by digitizer to the GIS. Photo registration statistics showed coordinates were accurate to within one metre.

All visible slip scars were mapped from the photographs listed in Table 1. Slip debris (debris tail) was not mapped, as most were invisible due to vegetation growth (Figure 2).

Field mapping using 5 m interval contour maps (at 1:10000 scale) aimed to determine the influence of geology and soil on slips. Soil types were associated with specific landform units, and are referred to for convenience as soil-landforms.

Field notebook entries were marked on the map and labelled. These reference sites and the contacts of geological strata were digitised into the GIS. Field data for each

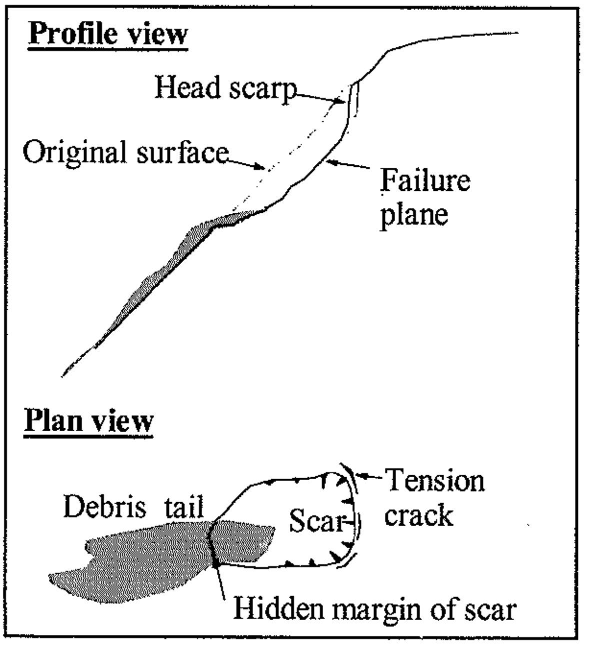

Figure 2 - Slip features

[1] Essential Planning Systems Limited, Victoria, British Columbia.

reference site were entered into a database management system to assist with map construction in the GIS.

GIS Analyses

The GIS enabled calculation of the planimetric areas of geological formations, soil-landforms, and slips in the research area. The proportion of slips within specific geological formations and soil-landform groups was then estimated by overlaying all the mapped slips (Figure 3).

Raster (grid based) maps of slope steepness and aspect were generated from the detailed (5 m) elevation contour map stored in the GIS. Classification of slope steepness followed the Land Resource Inventory criteria (NWASCO, 1979). Slope aspect was divided into four quadrants. All slips were combined and converted into a raster map, and then cross tabulated with slope steepness and aspect classes. The percentage area of slips within each slope and aspect class was then calculated in a spreadsheet.

Erosion Risk Modelling

The range of slip erosion risk was determined within the catchments. Rock type, soil-landform type, and slope are important landscape features controlling slip location. Each one of these features has an unknown greater or lesser effect on slippage.

Development of a model of slip erosion risk entailed assigning and summing numerical ratings.

Risk ratings were assigned by assessing the percentage area of slips within sub-classes of each landscape feature. The higher the percentage area of slips, the higher the rating. Some classes were assigned equal risk where the percentages were of similar value or magnitude, and to simplify further data analysis.

Raster layers were then created for the four landscape features with their assigned risk values. These layers could then be cross-tabulated to produce a report of areas containing 185 combinations of risk (Table 2).

Ratings were then summed to obtain Erosion risk = geology risk + soil-landform risk + steepness risk + aspect risk. Summation in a spreadsheet, yielded ratings ranging from four to 17. A composite risk map was produced using the erosion risk ratings as classes and geology, soil, aspect and steepness risk values as filters.

Finally, generalisation of the 14 risk classes (four to 17) resulted in five erosion risk categories; very high, high, moderate, low, and very low. These categories enabled generation of a simplified risk map.

Table 2 - Example of erosion risk ratings and summation

Area (ha)	Geology risk	Soil risk	Aspect risk	Steepness risk	Erosion risk
12.4	1	5	3	5	15
75.9	3	4	3	5	15
3.6	3	2	3	5	13
64.9	4	1	1	1	7

A limitation of the ordinal summation approach is the " double counting " of the landscape attributes (geology, soils, etc) where they may not be independent, or where the ratings are not scaled equally (Hopkins (1977). The assignment of ratings is usually subjective, but in this study the use of quantitative slip data enabled ratings to be assigned objectively. However, to account for the potential effects of summation of ordinal data, the composite risk map was verified by cross tabulation with the all-slips layer. The percentage area of slips was re-calculated for the 14 risk classes.

RESULTS AND DISCUSSION

All Slips

The result of combining all slip records is shown in Figure 3. The total area of slips was 34.2 ha. When converted to raster thematic maps with resolution of 10 m, the area increased to 38.4 ha. This conversion resulted in a 0.4% increase in slip area relative to the total ccatchment area. This increase was not expected to bias estimates of the proportion of slips within each landscape feature.

Eighty six percent of the slips represented in Figure 3, were triggered by the 1938 ANZAC storm and Cyclone Bola in 1988 (Fransen and Brownlie, 1996). The highest concentrations of slips were in the north and western sides with lower concentrations occuring in the eastern quadrants of both catchments.

In 1943, both catchments were in pasture, with scrub cover protecting 9% and 18% of the Tamingimingi and Pakuratahi catchments, respectively. In 1988, 73% of the Pakuratahi catchment was protected against slippage by 17 year old pine forest.

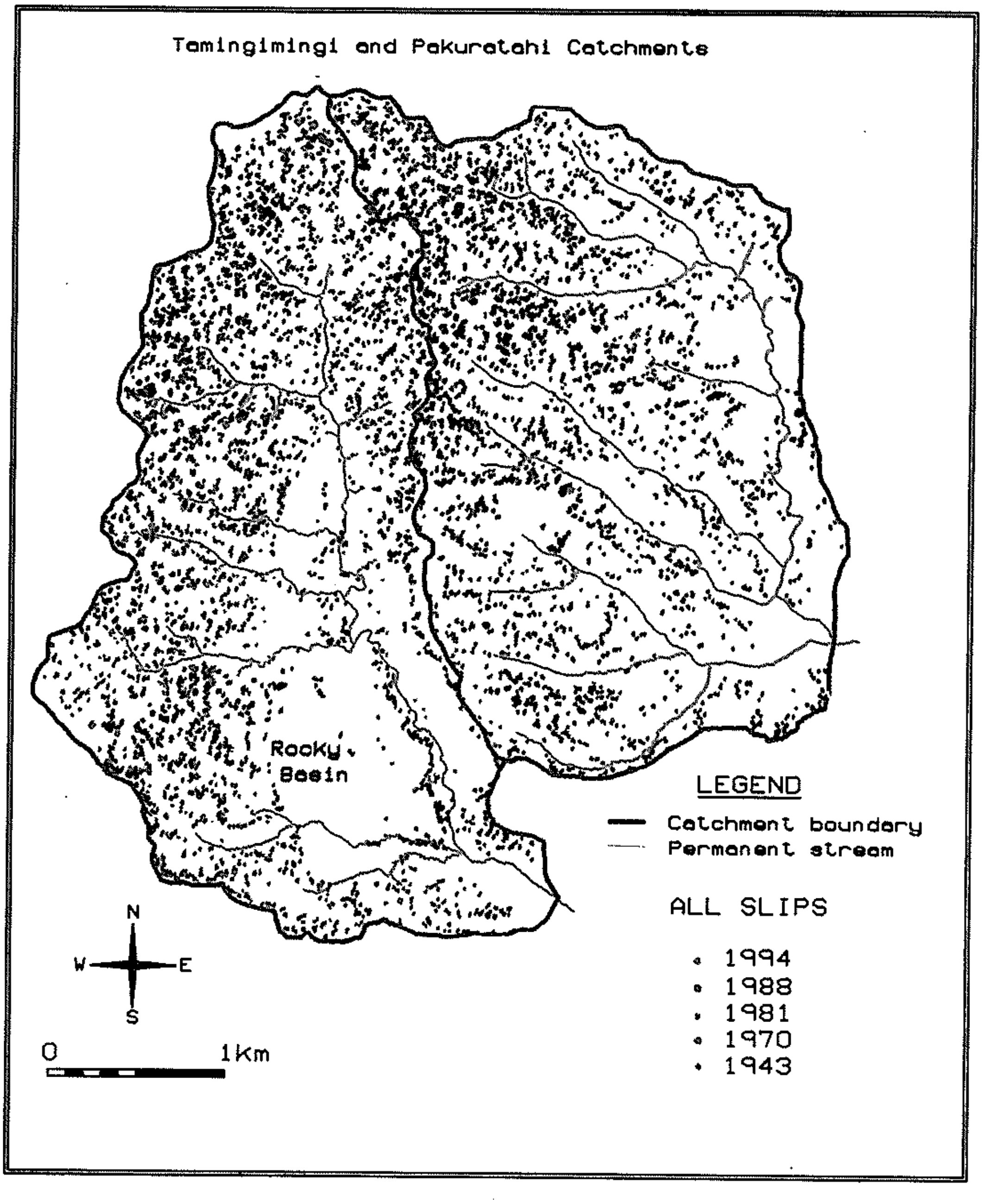

Figure 3 - Slips used in GIS cross tabulation analyses represent 2% of the research catchment area

Geological Influences

Assignment of slip erosion risk ratings reflects the percentage area of geological formation occupied by slips (Table 3).

The Kaiwaka Formation is an important influence on erosion. Occupying the largest area in both catchments, the formation comprises a 100-150 m thick sequence of marine sands, mudstones and limestones (Haywick *et al.*, 1991). Inspection of more than 100 slip scars revealed that the slips ruptured at or near the contact of two lithologies within the Kaiwaka Formation; the friable red-weathered slightly clayey fine sand; and the 5 to 10 m thick indurated mudstone layer that occurs at three or more distinct levels on the slopes.

The clayey sands exhibit a blocky structure that provides good permeability and drainage. Near the contact zone with the mudstone layers the sands appear to have a greater clay content, and are very greasy when wet. Seepage is common from this zone, as the mudstone layers impede the downward flow of groundwater (Figure 4). A combination of geo-hydrological processes and ground conditions at these sites appear to predispose the slopes to slip failure.

Ohakean gravels (>22,000 years old) overlie the Kaiwaka Formation, and are most evident in the Pakuratahi catchment. These gravel deposits vary in extent and thickness. Road cuttings in the Pakuratahi catchment reveal volcanic ash and loess deposits overlying, and older ash beds within, the gravels. The paucity of this lithology in the Tamingimingi catchment indicates substantial removal from the hill tops by erosion.

Table 3 - Assignment of erosion risk for geological formations

Geological Formation	Area of all-slips (ha)	Area of formation (ha)	% of formation in slips	Erosion risk rating
Alluvial fans and terraces	0.2	63	0.3	1
Large-scale landslides	1.7	215	0.8	2
Ohakean gravels	7.6	231	3.3	4
Kaiwaka Formation	23.3	886	2.6	3
Mudstone formations	1.4	178	0.8	2
Total (vector)	34.2	1573		

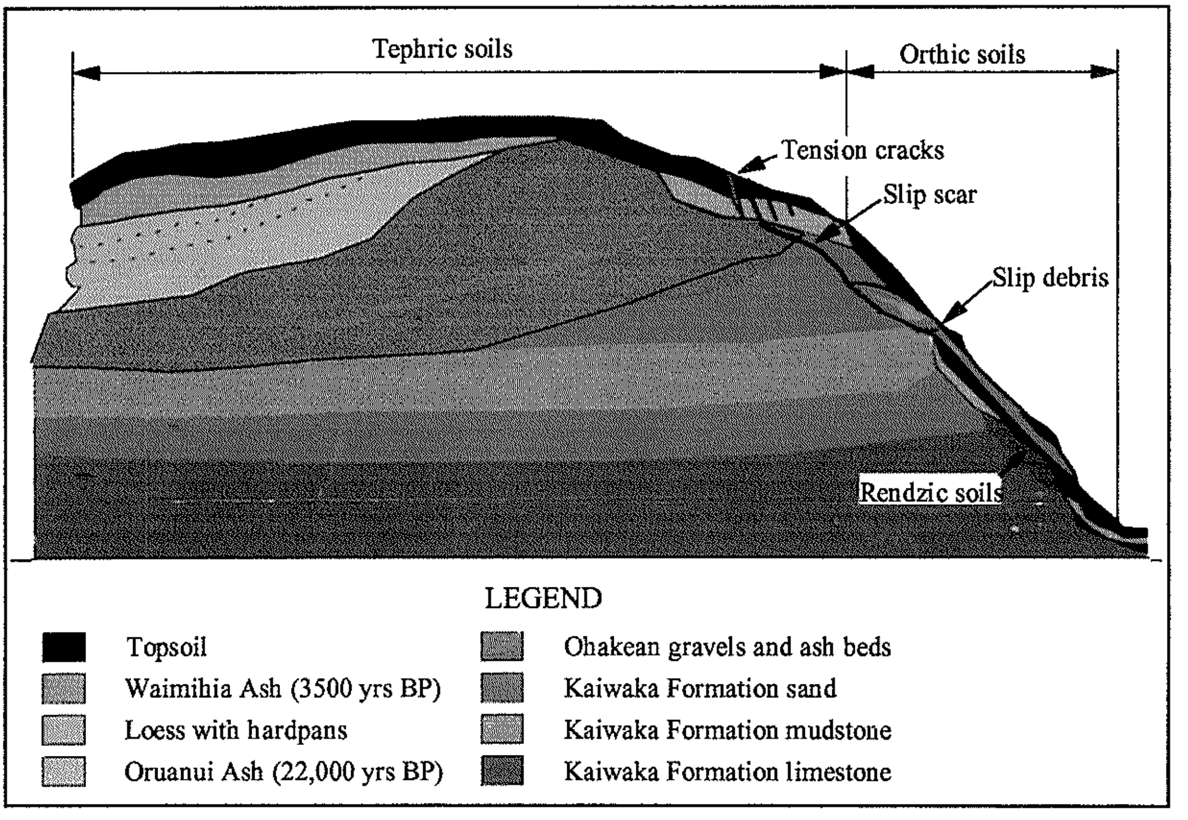

Figure 4 - General association of soils and geology in Pakuratahi and Tamingimingi catchments

The weakly consolidated Ohakean gravels, loess and interbedded ash are important influences on slope stability; having the highest geological erosion risk rating (Table 3). In particular, the fine grained loess deposits (0.5 to 3 m thick) comprise hard layers with blocky or platey structure. Eyles (1971) indicated that slip failure occurred along the interface of soft loose silt (loess) overlying the impervious hard layers. Consequently, poor drainage, saturation and weakening of the soft loess may induce slope failure.

Slips are less concentrated in areas occupied by a the large-scale pre-historic landslide and thick mudstone formations (underlying the Kaiwaka Formation). The rolling topography of Rocky Basin (Figure 3), in the Tamingimingi catchment, represents a large-scale pre-historic landslide occupying 160 ha (20% of the catchment area). This feature comprises large blocks of mudstone, Kaiwaka Formation, and Ohakean gravels.

Soil and Landform Influences

Pohlen, Harris, Gibbs, Raeside (1947) described the soils of the study area as yellow grey sandy loams of the Crownthorpe, Tangoio and Matapiro series. This study uses the revised New Zealand Soil Classification (Hewitt, 1993), to describe the soils in the catchments.

Slips occurred in two main classes of soil within the catchments. Recent soils (weakly developed soils) and the Melanic soils (well structured, dark soils associated with limestones). Grouping of the Recent soils are: 1) Tephric soils - developed on sandy volcanic airfall deposits that drape the ridge tops and upper parts of the steep side slopes; and, 2) Orthic soils - developed on mixed tephric and bedrock materials (Ohakean gravels and colluvium, Figure 4). Tephric soils comprise indistinct Taupo Tephra Formation on thick ash (about 500 mm thick on average) constituting the Waimihia Tephra Formation (Eyles, 1971; Froggart and Lowe, 1990). The A-B soil horizon is 200 to 400 mm thick with a distinct but slightly irregular lower boundary marked by worm casts. The weakly developed crumb to fine nutty structured soil has a friable consistency and is hard to dig when dry.

Recent soils have the highest proportion of slips per area for both catchments (Table 3). These soils occur mainly on the upper

Table 3 - Assignment of erosion risk for soil-landform type

Landform	Soils	Area of all-slips (ha)	Area of landform (ha)	% landform in slips	Erosion risk rating
Ridge (n =25)	RT (68%) , RO (20%)	2.7	79	3.4	5
Ridge (n = 14*)	RT (43%), RO (21%), ER(14%)	11.0	358	3.1	5
Steep slopes (n = 73)	RO (40%) , ER (26%) RT (7%)	18.6	821	2.3	4
Narrow valley floor	RF	0.4	47	0.8	2
Wide flood plains	RF	0.0	45	0.0	1
Escarpment	Rock	0.1	5	1.9	3
Large-scale landslide					
Alluvial fan	RF	0.1	40	0.3	1
Talus slope	RO, ER	0.4	47	0.9	2
Rolling to steep	Various	0.9	131	0.7	2
Total (vector)		34.2	1573		

*Soil codes depicted are: RT - Tephric Recent , RF - Fluvial Recent , RO - Orthic Recent, ER - Rendzic Melanic. Soils were tentatively classified using the NZ Soil Classification in Hewitt (1993). n - number of soil sites examined, * - Pakuratahi catchment only.*

ridges and occupies 22% of the Tamingimingi catchment and 34% of the Pakuratahi catchment. The western side of the Tamingimingi catchment has predominantly Tephric Recent soils; whereas the eastern side - and the Pakuratahi catchment - comprise mainly Orthic Recent soils developed on Ohakean gravels (Table 3). In the northern parts of the catchments, the Tephric soils mantle loess deposits with duripans (hard resistant horizons).

Orthic Recent (colluvial slip debris) and Rendzic Melanic soils occur on steep slopes. Melanic soils commonly occur on the lower slopes where Kaiwaka Formation limestones are thickest. In some locations these soils were thinly covered by Waimihia Ash (c. 3280 years old; Froggart and Lowe, 1990), indicating a long period of soil development and hill slope stability. The Orthic and Rendzic soils occupy approximately 52% of the research area, but the proportion of slips is lower than in the Tephric soils (Table 3).

Table 4 - Assignment of erosion risk for slope steepness classes

Slope class (degrees)	Area of all-slips (ha)	Area of slope class (ha)	% of class in slips	Risk erosion rating
0°-7°	0.1	156	0.1	1
7°-15°	1.8	300	0.6	1
15°-20°	6.7	264	2.5	3
20°-25°	13.3	283	4.7	5
25°-35°	14.1	423	3.3	4
>35°	2.4	147	1.6	2
Total (raster)	38.4	1573		

Slope Steepness

Erosion risk ratings for slope classes are shown in Table 4. Tamingimingi and Pakuratahi catchments have 60% to 64% of their respective areas comprising slopes between 15° to 35°. Less than 11% of their catchment areas comprise slopes over 35°. Slopes between 20°- 25° have the highest risk rating. Slopes over 35° have a low erosion risk rating because of the thin soil cover or presence of rock outcrop.

Slips commonly occur at or below the point of slope inflexion; from gently sloping ridge to steeper slopes (front cover).

Slope Aspect

East and west facing slopes have similar erosion risk ratings, while north facing slopes have a slightly lower risk rating (Table 5). These slopes are probably subject to greater climatic extremes than

Table 5 - Assignment of erosion risk for slope aspect

Aspect class	Area of all-slips (ha)	Area of class (ha)	% of class in slips	Erosion risk rating
North	10.0	407	2.5	2
South	7.4	439	1.7	1
East	14.1	485	2.9	3
West	6.9	242	2.9	3
Total (raster)	38.4	1573		

southern slopes. In Hawke's Bay, droughts are most frequent when westerly winds predominate and reach their maximum intensity in early summer (Salinger, 1995). At the other extreme, heavy downpours originating from the north of New Zealand may end the droughts in autumn. This pattern of weather occurred in 1938 with the ANZAC weekend storm and in 1988 with Cyclone Bola. On both occasions, the impact of the storm was from the north east (SCRCC, 1957; R. Black, Hawke's Bay Regional Council Scientist, pers. comm.).

The higher proportion of slipping in the subhumid regions of Hawke's Bay has been attributed to extra drying and fissuring of the surface soil under pasture (Campbell, 1945; Eyles, 1971; Gibbs, 1980). The fissures intercept and direct rainwater into the subsoil leading to variations in water pressure and seepage that act to destabilise the slope resulting in slippage.

South facing slopes have a lower erosion risk, being shaded and perhaps having higher soil moisture contents and smaller fluctuations in soil moisture. This may limit the development of fissures and reduce the infiltration capacity of the soil on these slopes.

Erosion Risk Model

Figure 5 validates the summation of the individual risk ratings for geology, soil-landform, aspect and slope. Results showed that percentage of slips and risk classes increased together (with the exception of risk class 9).

Figure 5 also defines general erosion risk categories used to simplify the risk map (Figure 7). The risk classes were nominally categorised by dividing the 7.6% (of class 17 in slips) by five.

Areas of very high risk occupy 6% of the Pakuratahi catchment and 2% of the Tamingimingi catchment (Table 6). These areas are defined by Ohakean gravels with Recent Tephric and Orthic soils on the

upper ridges, and on east or west facing slopes of 20° to 25°.
High risk areas are similar, but include areas comprising Kaiwaka Formation, Recent Orthic soil on steep side-slopes, slopes facing north, and slopes from 25° to 35°.

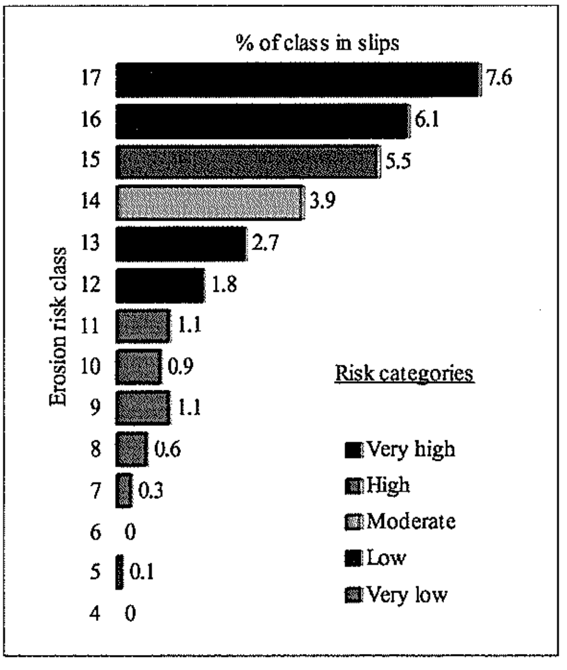

Figure 5 - General risk categories from composite slip erosion classes

Table 6 - Proportion of catchments affected by erosion risk categories

	Tamingimingi catchment (799 ha)	Pakuratahi catchment (774 ha)
Risk	**% area of risk category**	
Very high	2	6
High	8	10
Moderate	13	14
Low	32	41
Very low	45	29

Moderate erosion risk areas differ in that they include 15° to 25° slopes facing north, south, and east or west; ridge and steep slope soils on Ohakean gravels and Kaiwaka Formation.

Both catchments have similar areas at high and moderate risk.

Low and very low risk areas occupy 77% of the Tamingimingi catchment, compared to 70% of the Pakuratahi catchment. Low risk areas occured on:

- subdued relief on the large-scale landslide formation in the Rocky Basin
- flat ridge-tops, alluvial terraces, fans, valley floors and flood plains
- escarpment areas with thin soils
- thick mudstone formations

Erosion Risk Management

An erosion risk map can be used to plan and improve management of steep hill country. The map highlights the size and location of areas at risk, even at sites where there is little sign of slippage, and particularly under a forest cover. The risk map allows appropriate land use decisions to be made.

Site disturbance should be kept to a minimum in areas most susceptible to erosion.

During forest growth, trees protect slopes by intercepting rainfall, using soil water, and reinforcing the soils through development of an extensive root system. However, slips do occur at sites where trees become too heavy to be supported. This is evident on some lower slopes in the Pakuratahi catchment where tree roots were unable to penetrate mudstones beneath shallow and often wet soils. Ensuring that these areas are kept free of large tree species, may be the best management option.

Storm-induced slippage may be low in the first year after harvesting, as tree root strength is probably sufficient to reinforce the soil. After felling, radiata pine root systems lose half their tensile strength within the first 15 months, and after three

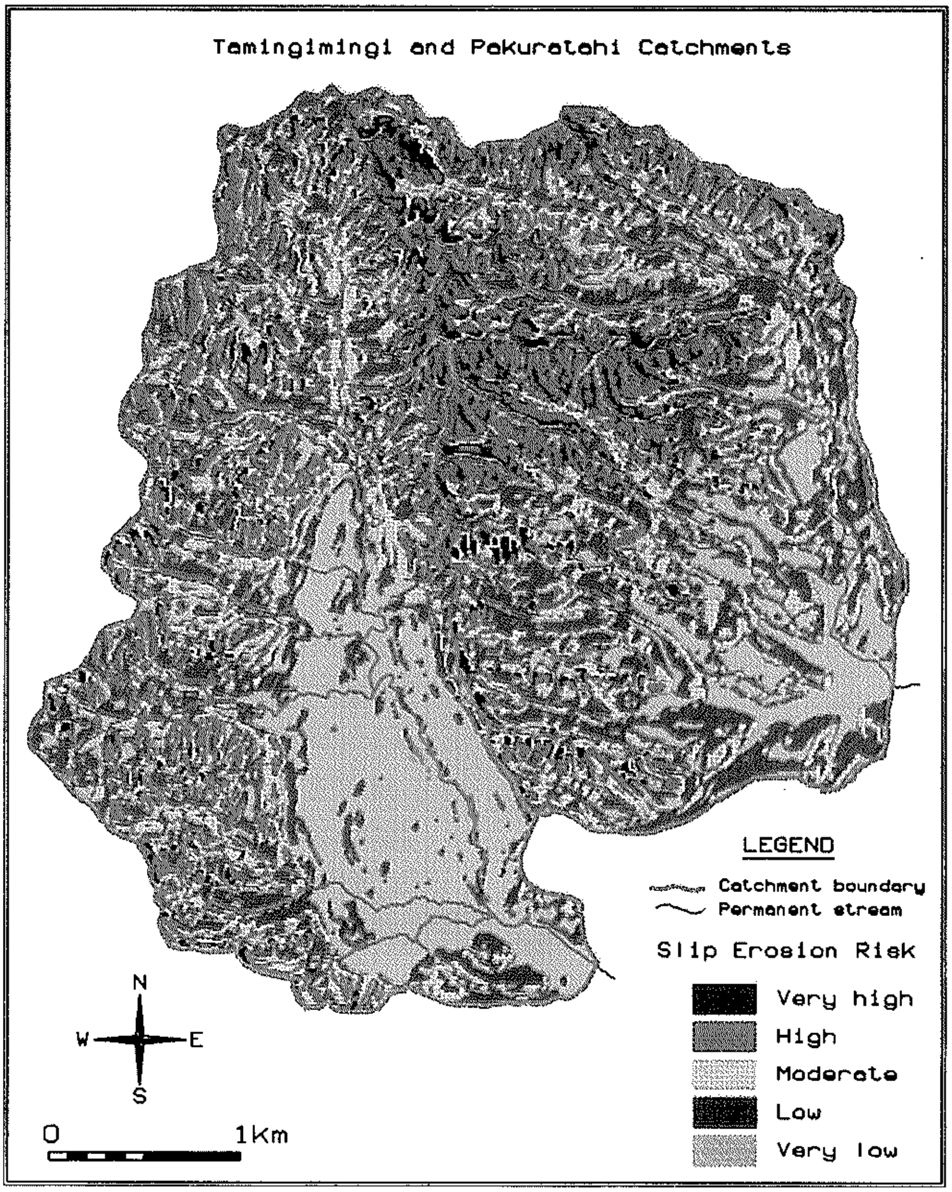

Figure 6 - Erosion risk map

years the large structural roots (> 5 cm diameter) are in an advanced state of decay (O'Loughlin and Watson, 1979). Replanting within a year of felling is commonplace in New Zealand forestry. However, trees make little contribution to slope stability for the first six years after establishment (Phillips, Marden and Pearce, *et al.*, 1990; Marden and Rowan, 1993). Thus, slopes are more vulnerable to erosion when the next crop of trees are three to six years old. Beyond this time the root systems of the re-establishing crop start to reinforce the soil.

In the Pakuratahi catchment, where 64% of slopes are over 20°, cable logging will likely be the preferred harvesting system, while ground-based harvesting systems may be employed on the flat to easy slopes. Access to harvest settings will be along existing ridge top roads. Minimising deep site disturbance, careful siting and formation of landings and roads, and controlling drainage in areas of high risk are primary considerations for preventing erosion. The erosion risk map will be of value in determining the areas needing special attention.

CONCLUSIONS

A model of slip erosion risk for the Tamingimingi pasture and Pakuratahi forest catchments, Hawke's Bay, was produced in a GIS by cross tabulating feature maps of historical storm induced slip erosion with geology, soil-landforms, slope steepness and aspect. Risk ratings were assigned to classes for each feature which were then added to derive a composite risk map.

Five general categories of slip erosion risk defined were:

- Very high levels of risk occurring on upper ridges mantled by Recent Tephric and Orthic soils and Ohakean gravels, and on 20° to 25° slopes facing east or west.
- High levels of risk include the above factors but with more combinations comprising Kaiwaka Formation, Recent Orthic soils on steep slopes, north aspects and slopes 25° to 35°.
- Moderate risk areas include the above but with slopes 15° to 25° and all aspects.
- Low and very low risk areas represent predominantly subdued relief on the large-scale landslide formation in the Rocky Basin (Tamingimingi catchment), flat alluvial terraces, fans, valley floors and flood plains, flat ridge-tops, escarpment areas with thin soils, and thick mudstone formations.

The Pakuratahi catchment has a greater proportion of its area affected by very high to low erosion risk categories than the Tamingimingi catchment. Very high to high risk areas occupy 10% to 16% of the

Tamingimingi and Pakuratahi catchment, respectively.

Resource and operations planners should find erosion risk maps useful when considering activities in areas that may not be showing signs of slip erosion. Decisions can be made about the type and intensity of the activity required to avoid undue soil disturbance in areas of high erosion risk.

ACKNOWLEDGEMENT

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