# ENVIRONMENT & SOCIAL TECHNICAL NOTE

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# Testing a Modelling approach to Landslide Erosion in New Zealand


## Summary

In New Zealand, hill country covers 10 million hectares of which 63% occurs in the North Island. Erosion in hill country will lower economic returns, cause environmental damage, and can have serious off-site impacts. The ability to assess and quantify the risk of erosion in detail would assist land mangers to make informed decisions (e.g. roading). Currently an erosion susceptibility surface classifies New Zealand into four broad erosion categories and is used to assess erosion risk nationally, however, there is no fine spatial scale mapping tool available. This addresses the need for improved tools for best land management practices. This research investigates the suitability of SINMAP (Stability INdex MAPping), as a potential tool to identify areas at high risk of landslide erosion in New Zealand. We also quantified the relationship between landslide erosion and the factors that contribute to erosion. Two adjacent research catchments Tamingimingi and Pakurutahi, in Hawke's Bay were selected as the area to test SINMAP and a statistical modelling approach. These catchments are prone to erosion and have detailed erosion data associated with them. SINMAP predicted the erosion susceptibility of these catchments. The best prediction of erosion susceptibility was made using the 5 m DEM (Digital Elevation Model). Rainfall intensity, slope, soil type, vegetation cover and aspect included in the statistical model accurately predict the likelihood of slipping for these catchments. This research will enable landowners, forest managers, regional, local councils and national government to access tools to assess erosion risk at a very detailed resolution. Potential improvements in erosion risk management throughout New Zealand from using this tool could lead to improved location and construction of roads and skid placement. SINMAP is freely available to download and can be run on ArcView® 3.2.


**Authors**: Duncan Harrison, Mark Kimberley and Loretta Garrett (Scion)

## Introduction

Forestry generally mitigates hill country erosion by reinforcing the soil through its network of roots, interception of rainfall and by evaporation from tree canopies. In New Zealand, hill country (slope > 15º) covers 10 million hectares (37% of national land area), the majority (63%) of which occurs in the North Island[1]. Hill country erosion and sedimentation has implications for economic costs through productivity declines and increased downstream flooding damage[2]. Hill country pastoral land can experience significant erosion, which can be greatly reduced by afforestation (Figure 1).

**Figure 1: Hill country erosion (left), comparison of erosion on adjacent pasture and forest (right).**

Planted forests, have an increased erosion risk following harvesting and during earth works (Figure 2). This risk may be heightened in the future as forests are increasingly established on more marginal land, and due to a predicted increase in frequency of extreme rainfall events[3].

**Figure 2: Slips along a forest road (left) and a slope exposed to erosion following harvesting (right).**

The Erosion Susceptibility surface classifies New Zealand into four broad erosion categories and is used to assess erosion risk nationally[4]. The ability to assess and quantify the risk of erosion on a more detailed operational scale would help land mangers to make more informed decisions (e.g. roading).

An ideal erosion susceptibility tool would need to be:

1) Suitable for planning harvest of existing forests on difficult terrain, while meeting resource consent conditions.
2) Capable of predicting at-risk areas useful for operational requirements.
3) Easily implemented and used by forest managers for resource assessment.
4) Support National Environmental Standards.

An investigation into readily available erosion susceptibility tools (based on their ease of use with data available and quality of their predictions) would aid the forestry industry and landowners in decision making processes. Two adjacent research catchments (Tamingimingi and Pakurutahi) in the Hawke's Bay[6], have detailed erosion and terrain data allowing SINMAP to be tested and to investigate development of a statistical model to predict the probability of slipping related to terrain attributes.

This research aims to investigate an alternative to the Erosion Susceptibility surface[4]. The Specific objectives are:

- Evaluate SINMAP for its ability to identify areas at high risk of landslide erosion,
- Relate the probability of slipping to terrain attributes using a statistical modelling approach.

## Methods

SINMAP was evaluated using two adjacent catchments Tamingimingi (pasture) and Pakurutahi (*P. radiata*), in the Hawke's Bay region[6]. These catchments are prone to erosion and have detailed data on past erosion events[7,8] that enables the accuracy of SINMAP to be tested. The detailed erosion data also enables the development of a statistical model to predict erosion.

### SINMAP

SINMAP was run with the default and best available data parameter values using 1, 5, 10, and 20 m terrain DEMs (Digital Elevation Models) for the research catchments. SINMAP was run for two modelled scenarios for these catchments; 1) all pasture and 2) all mature *P. radiata*.

The parameters required for SINMAP are[5]:

- Root cohesion [N/m$^2$],
- Soil cohesion [N/m$^2$],
- Slope angle,
- Soil density [kg/m$^3$],
- Water density [kg/m$^3$],
- Gravitational acceleration (9.81 m/s$^2$),
- Soil depth [m],
- Vertical height of the water table within the soil layer [m],
- Internal friction angle of the soil [-].

The best available parameter values were attained using on-site data or readily available New Zealand data (e.g. DEM or the fundamental soil layer[9]). The variables that were changed in SINMAP when comparing pasture with radiata land use was root cohesion. The root cohesion values were attained from look up tables covering a range of vegetation types[10]. SINMAP specifies a lower and upper threshold for rainfall intensity to predict when erosion will occur. For the catchments the upper threshold was known to be 250 mm/48 hours[8] and the lower threshold used the default value in SINMAP (50 mm/day)[5].

The SINMAP stability index prediction was tested against actual slip data for the catchments. This was undertaken through the density of actual slips predicted by SINMAP to be within the lower and upper thresholds (i.e. susceptible to erosion).

### Statistical Modelling Approach

An empirical nonlinear regression model was derived to predict the probability of shallow land sliding for a given intensive rainfall event. This model was fitted using the SAS NLIN procedure. The dependent (erosion) variable was derived using a grid covering the site with value 100 if the grid location was on a slip and 0 otherwise. This variable was derived for 5 aerial images relating to 5 rainfall events (in 1938, 1968, 1980, 1988, and 1989). This dependent variable represents the % slip area. The independent variables used in the regression were 72 hour rainfall (mm), slope (in 5-degree classes), soil type (four soil classifications grouped into 2 types: Pallic and Pumice/Recent), vegetation cover (pasture, indigenous scrub, exotic forest), and aspect. Other variables explored for inclusion in the regression model were various alternative terrain attributes (but slope and aspect were found to perform best), and lithography (this appeared to have some influence on slipping but less so than soil type).

## Results and Discussion

### SINMAP

With increasing DEM accuracy from 20 m to 1 m, the SINMAP prediction increases in accuracy (see appendix 1). In the 1 m DEM there is a distinct area of stable material on ridge tops and less upper threshold material (which has higher erosion susceptibility) compared to the 20 m DEM. The SINMAP prediction shows greater detail for the research catchments than the current Erosion Susceptibility 4 Classes surface[4] (Figure 4).

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Land use had a significant impact on the predicted erosion susceptibility with higher susceptible ratings for pastoral land use compared with pine forestry. (Figure 3), due to the greater root cohesion of *P. radiata*. The landslide data from the research catchments showed that there <1% of landslides occurred after afforestation in the Pakurutahi catchment.

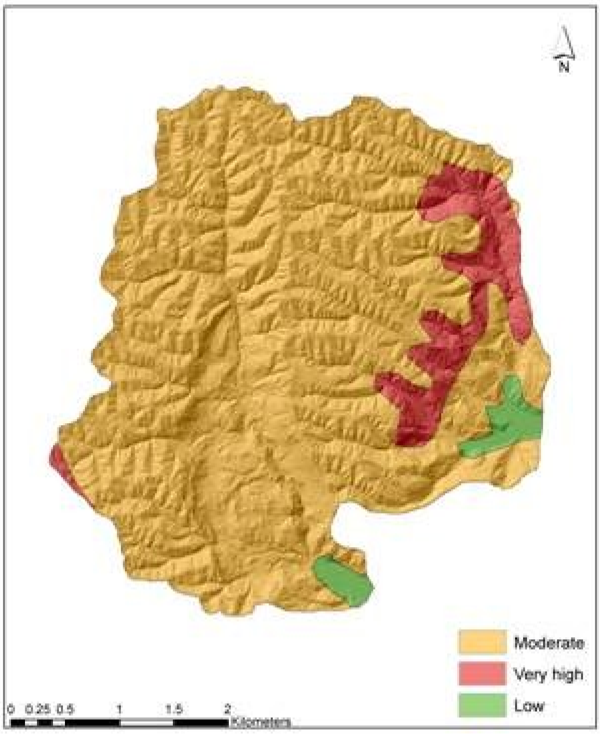


**Figure 4: Erosion susceptibility 4 classes surface for the research catchments[4].**

Using the best available data for SINMAP parameter values is desirable as predictions were much poorer when SINMAP default values were used (data not shown). For pasture land use, the 5 m DEM predicted erosion susceptibility the best (data not shown). Further validation of prediction capability of SINMAP across a number of sites along with more sensitivity analysis of the input parameters is required before a definitive statement can be made on which resolution provides the best results for a range sites.

### Statistical Modelling Approach

Analysis of the slipping data show that the probability of landslip damage on this site is strongly influenced by the rainfall intensity, slope, vegetation cover and soil type (Figure 5a, 5b, 5c).

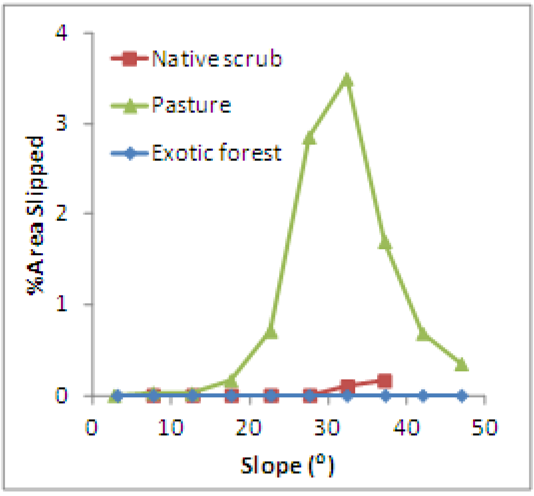


**Figure 5a: Slipping vs. slope by vegetation cover in the 1988 cyclone Bola event.**

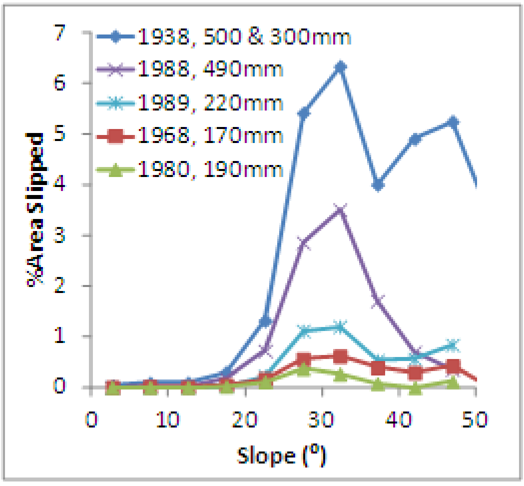


**Figure 5b: Slipping vs. slope on pasture land for 5 major rainfall events.**

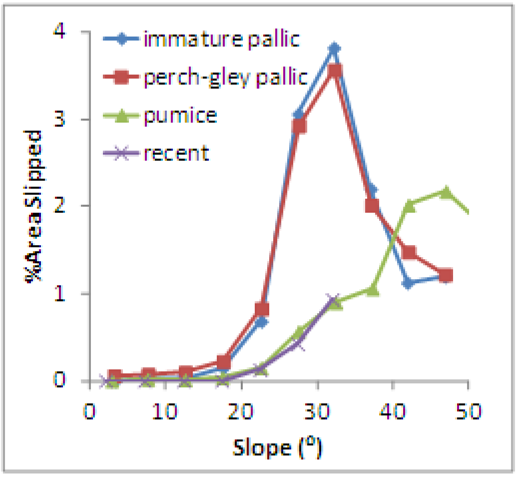


**Figure 5c: Slipping vs. slope on pasture land by soil type.**



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An empirical nonlinear regression model was fitted to predict % slip area at Pakarutahi. The model had the following form:

Probability of slipping = R x S x V x A

Where;
R = rainfall effect = max(Rain-R_threshold, 0)
S = soil/slope factor
V = vegetation cover factor
A = aspect adjustment = 1 + g x cos(Aspect - f)

R_threshold is the threshold (72 hour rainfall in mm) below which no slipping is predicted to occur for each soil type.

The vegetation cover factor V has values 1, 0.23 and 0.005 for pasture, indigenous scrub, and exotic forest.

Aspect had a marked influence on the probability of slipping, although the effect varied both in extent and direction for each of the five rainfall events. Further investigation is needed to determine whether this effect can be related to climatic variables such as wind strength and direction at the time of each event. The importance of the aspect effect in the model suggests that prevailing wind direction during such extreme events may warrant consideration when evaluating erosion risk.

The mean actual and predicted percentage slipping showed good agreement with no bias for each event (Figure 6). These results demonstrate that the model accurately predicts the likelihood of slipping (as a percentage by area) for a rainfall event of known intensity at any location within the study site.

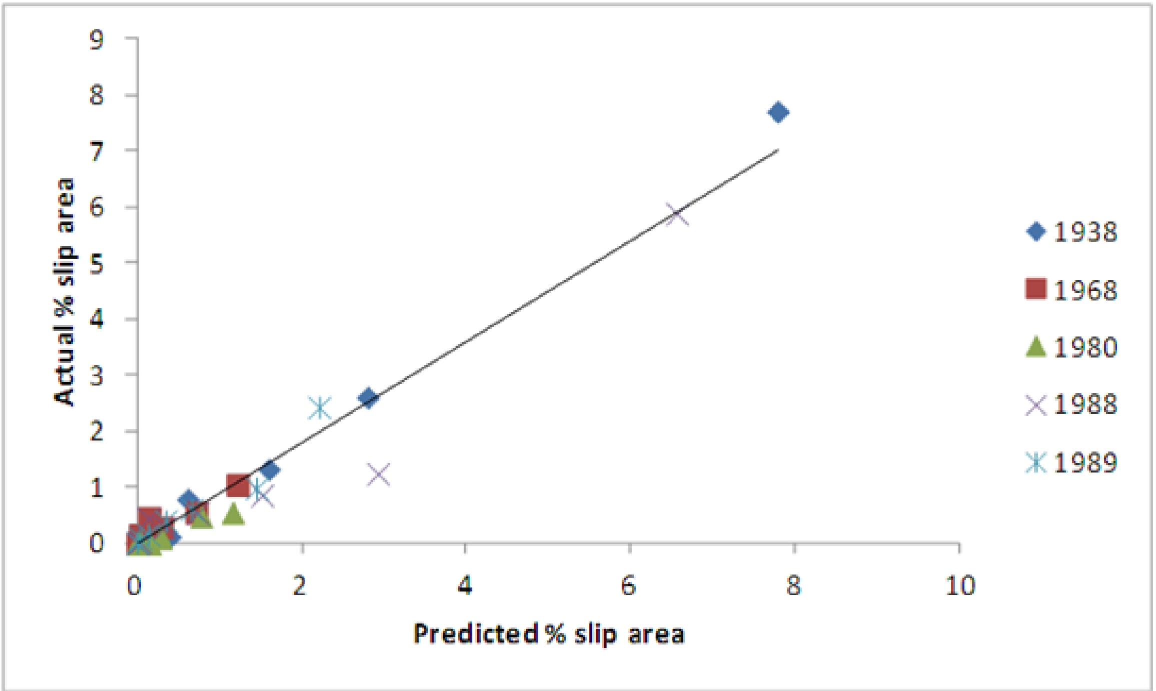


**Figure 6: Actual versus predicted % slip area for risk classes in each of the 5 rainfall events ($R^2$ = 0.96).**

## Conclusions

SINMAP is a freely available software tool that predicted well the erosion susceptibility for the two catchments in the Hawke's Bay. We recommend that SINMAP is run with the best available data as the default parameter values resulted in poorer predictions of erosion susceptibility. Because SINMAP is only a predictor of shallow landslide erosion it can therefore, only be applied to areas where this type of erosion is dominant for example in the East Coast and Hawke's Bay. This may restrict SINMAP's usability in some areas in New Zealand where landslide erosion is not dominant.

The detailed erosion data associated with the two research catchments allowed development of a statistical model to predict landslides. This approach can be applied to other areas in New Zealand where


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this type of data exists to support the statistical model.

The outcome of this research demonstrates how SINMAP and a statistical model approach can be used to predict shallow landslide erosion at a very detailed resolution. Further validation and data collection is required before these approaches can be applied at a national level.

The steps to achieve an improved national level erosion risk surface are described for SINMAP and the statistical modelling approach.

SINMAP:

- Further investigation into SINMAP parameters.
- Testing at other locations (e.g. prone to and not prone erosion).
- Comparison of SINMAP with other erosion models.
- SINMAP only predicts shallow landslide erosion and would need to be use in conjunction with other tools predict a national erosion surface.

Statistical modelling approach:

- Worked well for the research catchments (Tamingimingi and Pakurutahi). The model only applies to this area and the two soil types (three soil orders) present.
- The methodology would need to be repeated for the remaining soil orders (15 in New Zealand).
- Tested at 20 m resolution DEM.

## Acknowledgements

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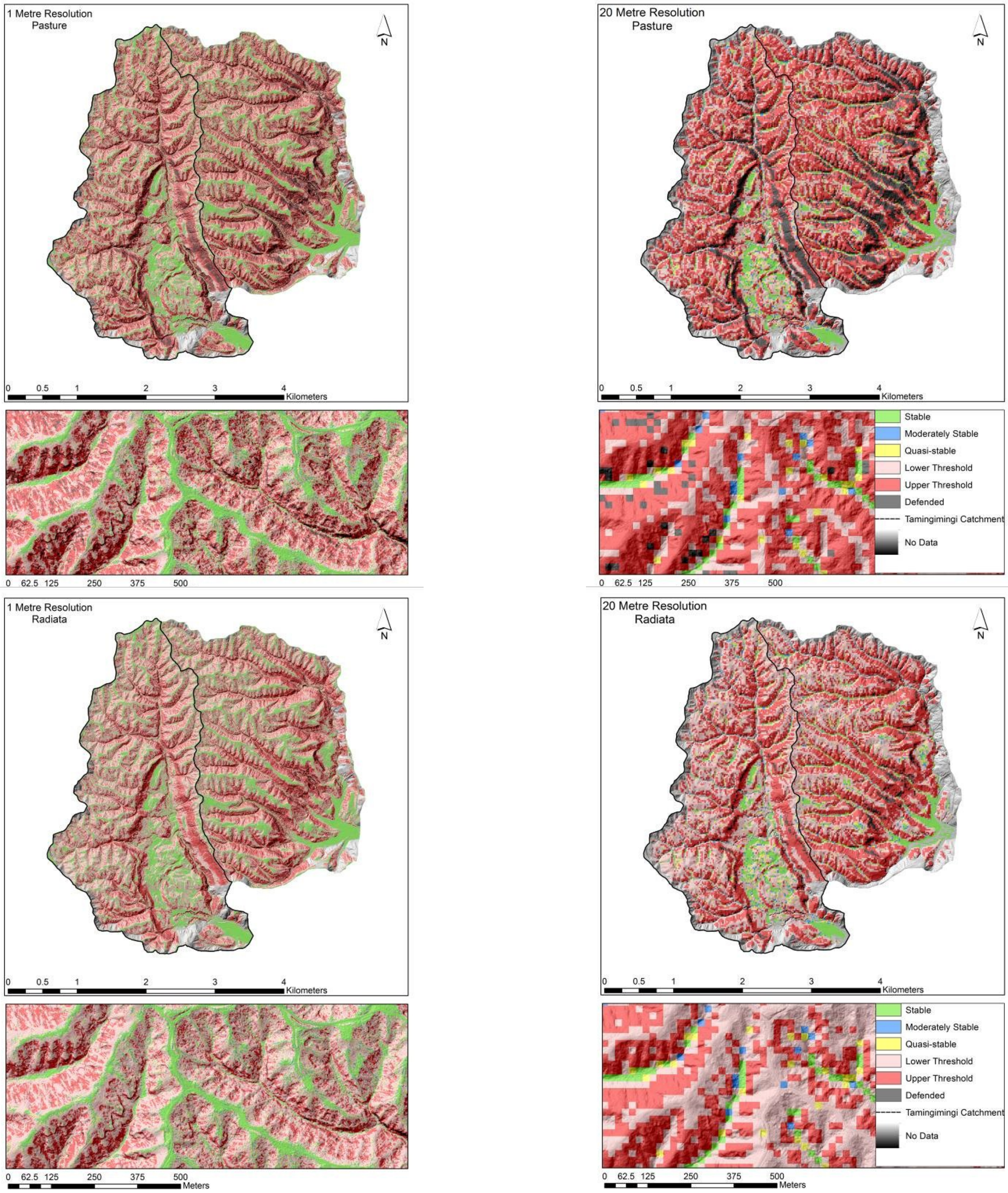
## Appendix




**Appendix 1: SINMAP stability index for both Tamingimingi and Pakurutahi catchments in these examples as pasture (upper two figures) and in P. radiata (lower two figures) derived from a 1 m and 20 m DEM (left to right).**