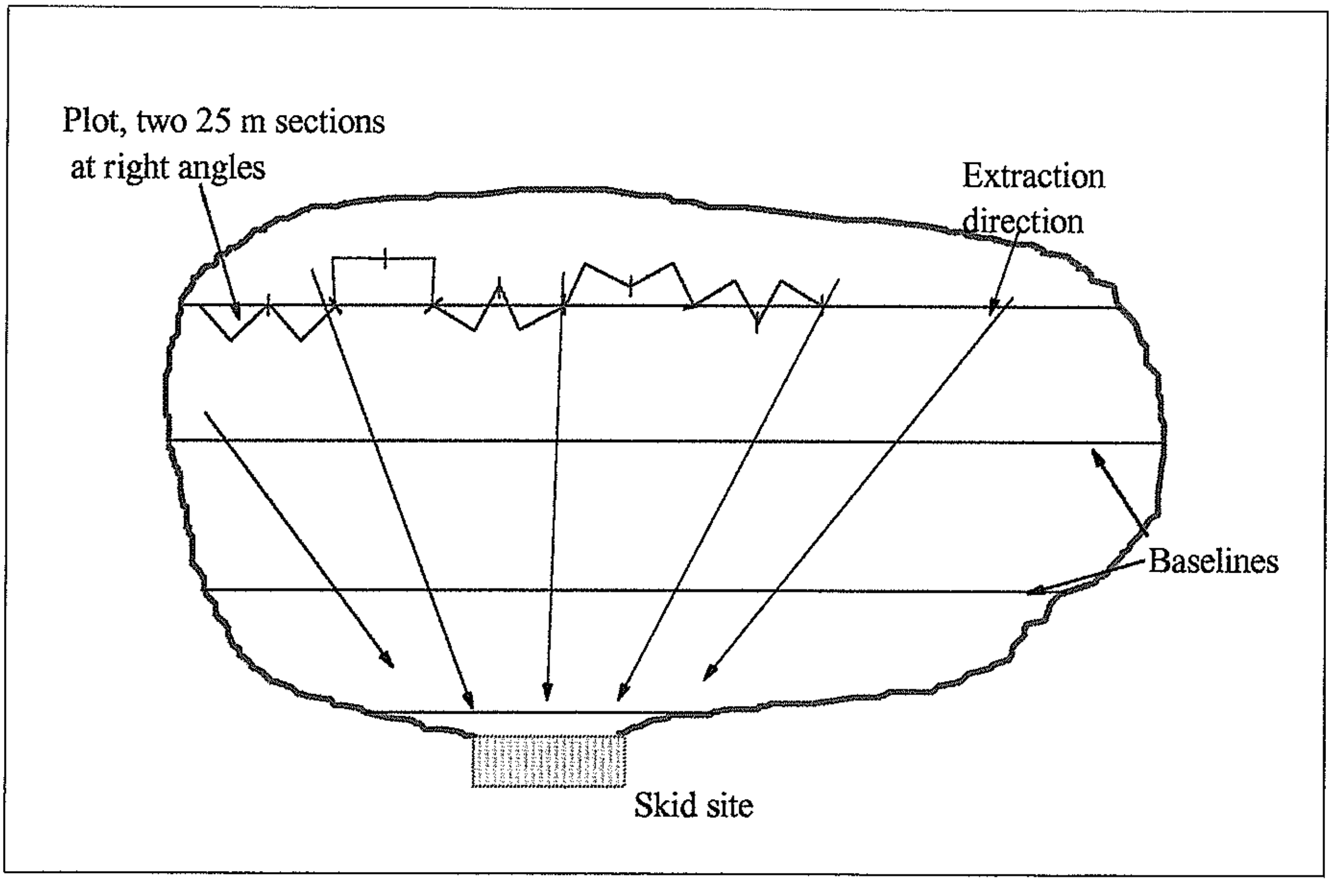
LOGGING INDUSTRY RESEARCH ORGANISATION

NEW ZEALAND

PROJECT REPORT

CUTOVER WASTE ASSESSMENT - A Comparison of Sampling Techniques and Intensities

PETER HALL



Project Report

P.R.60

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NEW ZEALAND.

CUTOVER WASTE ASSESSMENT -
A Comparison of Sampling Techniques and Intensities

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CONTENTS

ABSTRACT

In this study, a comparison was made between several options for the assessment of merchantable wood volume remaining on harvested sites after logging.

An analysis was carried out on the accuracy, precision and bias of five different sampling techniques over a range of sampling intensities.

The costs of implementing the different techniques were calculated.

The Zig Zag Line Intersect Method was found to be as accurate, as precise, less biased and less costly than the other techniques. The other techniques were based on either area plots or alternative layouts of line intersect sampling.

The Zig Zag Line Intersect Method is described.

INTRODUCTION

Most New Zealand forestry companies assess the volume of merchantable wood left on the cutover after harvesting. Improved quality management places greater emphasis on the accuracy of these assessments. Most companies set a limit of no more than 10 to 15 cubic metres per hectare (m^3/ha) of merchantable wood left on the cutover as waste. If a logging crew consistently exceeds the set limit, they are often required to return and extract the merchantable logs.

In most forest operations where the volume of waste on a cutover is assessed the actual volume is not known. This means the sampling system has to be reliable so the results (the estimated volume) can be used with confidence. The only measure commonly available is the precision of the estimated volume. Precision is determined by the amount of variation there is in the individual plots from the mean. This is often expressed as the standard deviation or confidence limit (CL). If the precision of the estimate is poor, it is difficult to say with confidence that the estimated volume is actually what is there. If, for example, the results of a set of plots gives a mean volume of 17 m^3/ha, but the 95% CL ranges from 8 m^3 to 26 m^3, then there would be little justification for enforcing the set limit of 15 m^3/ha. On the other hand, if the estimated volume was 21 m^3/ha with a 95% CL range of 17 m^3 to 25 m^3 there would be justification for concern over the volume on the cutover if the set limit was 15 m^3/ha.

The most common waste assessment method is Line Intersect Sampling (LIS), (Warren and Olsen, 1964; Van Wagner, 1968). This method estimates the volume of wood per unit area based on the diameter of logs intersected by a line of a known length. The New Zealand Forest Service Wagner Logging Waste Assessment, Manual of Procedures (Swale, 1974) recommends lines layed out in a square with 100 m sides, with one sample square per hectare of cutover. In common practice, variations of this method are used, sometimes reducing the squares to 50 m on a side. This system gives no consideration to extraction direction.

There are doubts within the industry as to the accuracy of the estimate of the volume per hectare from cutover waste assessments relative to the set limits of 10 m^3/ha to 15 m^3/ha. There is some justification for this:

- the layout of plots commonly used does not adequately allow for the non-random orientation of the waste wood which can lead to a biased result

- results for individual plots within a setting are often highly variable. This means that a large number of samples are required to adequately describe the site.

The objectives of this study were to compare the relative differences in the accuracy, precision, bias and cost of different cutover waste sampling systems, including line intersect (LIS).

Definitions

Accuracy - how close the estimated volume (mean of the plot volumes) is to the actual volume.

Precision - how much variation there is in the individual plot results around the mean of the plot volumes.

Bias - whether the individual plot volumes are consistently over or under estimating the volume in comparison to the actual volume.

Previous studies

Hazard and Pickford (1986) found that systematic orientation of the sample lines introduced bias to the estimated volume whereas randomly oriented lines did not. Longer lines were found to be more efficient than short ones.

Sutherland (1986) described a modified method of LIS that eliminated the orientation bias. These changes involve the placing of 50 m (2 x 25 m sections at right angles) randomly oriented line-sections around a baseline. The baselines being oriented perpendicular to the predominant extraction direction and parallel to each other (Figure 1). This system is also used as the sampling method in New Zealand Forest Research Institute's LogWaste Software package (Pont, 1993).

Warren and Olsen (1964) suggested that to get a standard error of 2 m³/ha from a cutover with a total volume of 6 m³/ha, 400 m of sample line was required. This equates to 8 x 50 m plots. If the volume per hectare rises to 10 m³, then the size of the sample should also rise, to a suggested 800 m. They also suggested that ground-based logging residue is more scattered and the logging pattern less uniform than in cable logging. This leads to greater variability in individual plot results. A greater number of plots were required in ground-based cutover to get a similar level of error as the cable logged cutover. The LIS used by Warren and Olsen was not checked against an actual volume per hectare, but against a piece count and an average piece size. The piece count was performed by two different groups who gave different answers. The accuracy of the system was checked in a larger trial based on an assumed mean piece size and was found to be essentially correct.

Van Wagner (1968) tested the theory of Warren and Olsens work with laboratory and field experiments and found the method to be valid, but also subject to errors, as in any sampling. These errors could be minimised by following correct data collection methods. Pickford and Hazard (1978), also in simulation studies, found that 1500 m of sample line per hectare were necessary to accurately (+/- 10% at 95% CL) predict the total volume of residue, where residue levels were high (240 m³/ha).

Belanger, Dumont and Belanger (1984) reported that LIS at a sampling level of 28 x 15 m lines per hectare gave errors of between 9% and 14% when compared with the actual volume of slash in the plot determined by dry weight. Similarly, Howard and Ward (1978) found that the equivalents of 9 x 50 m plots per hectare were required to get a result with an error of +/- 10% at 95% CL. The total lengths of plot line in these studies were 420 m and 450 m, respectively.

Bell, Kerr, McNickle and Woolens (1994) found that while single (400m long) lines were highly inaccurate (- 70% to + 50% errors), 4 x 100 m lines in a square gave an error of 18.1% and 3 x 100m lines in a triangle gave an error of 20.1 %. They recommended the 3 x 100m triangle as the system to use as it was cheaper, and the difference between the square and the triangle layout was not considered significant.

Brown (1974) stated that the sampling precision of LIS can be altered by the number and length of lines. In general, the more slash, the fewer and shorter lines are required to achieve a given level of precision. Precision's of 10% to 15% error were recommended for evaluating the merchantable volume and 20% for biomass or fire fuel assessments.

In this study a number of plotting systems of varying sampling intensities were applied over an area of cutover with a known volume per hectare of waste wood. Line intersect sampling was one of the systems used. The sampling intensities used were based on the findings of previous research efforts noted above.

METHODS

An area of ground-based logged radiata cutover was selected. Four, one hectare blocks were fully (100%) assessed to establish the total volume of merchantable wood. Pieces were regarded as merchantable if they were more than 3.7 m long and 10 cm in diameter at the small end. Each merchantable piece was measured for length, large end diameter (LED) and small end diameter (SED). Volume was calculated using a log volume formula (Ellis, 1982).

Five different plot types were then used within the four blocks. All plots were randomly located, using a grid and random number tables. Three types of area plots square, circular and transect (100 *th/ha*)(Figure 2) were used to collect up to a 12 % sample. Two types of line intersect plots were also used: 50 m circular lines in two 25 m semicircular sections (Circular LIS) and 50 m Zig Zag lines in two 25 m sections at right angles (Figure 1, Zig Zag LIS).

In the area plots, all the merchantable pieces within the plot bounds were measured for LED, SED and length, and a total volume was calculated. For the line intersect plots, all merchantable pieces were measured for diameter at the intersection point. The calculation for plot volumes in the line intersect plots was:

$$\textbf{Volume}\ (m^3/ha) = \left(\frac{\sum d^2}{L}\right) * 1.2337005$$

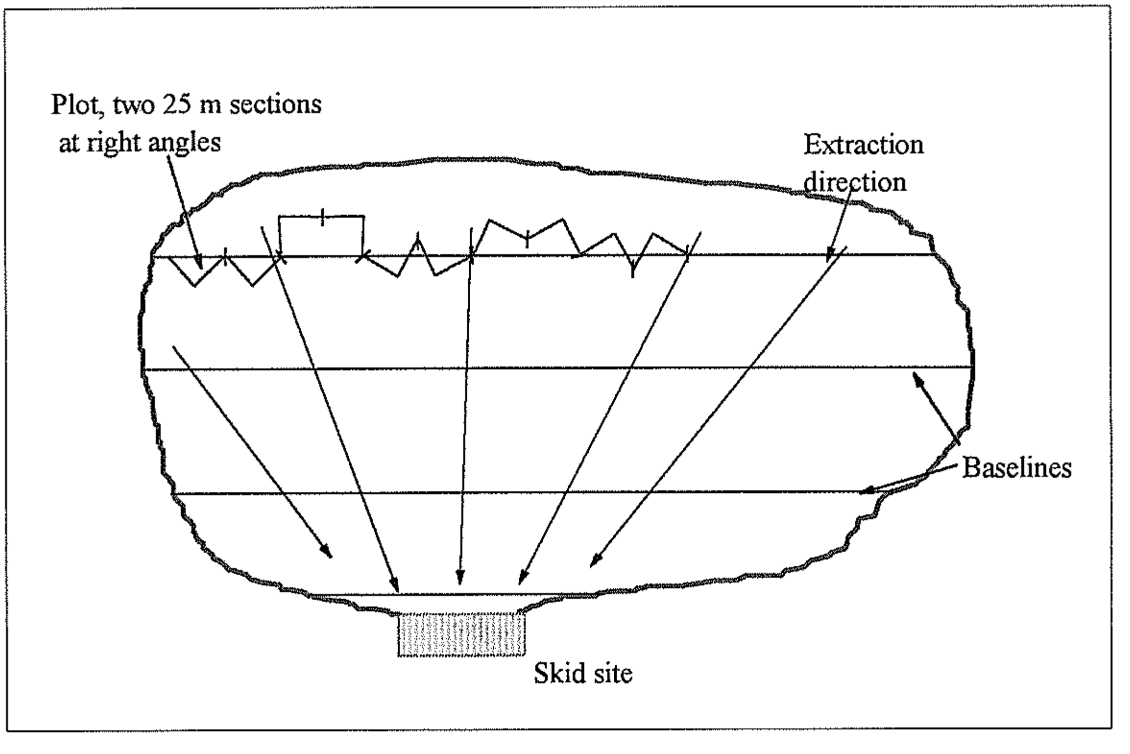

Figure 1 - Layout of Zig Zag LIS plots in a setting

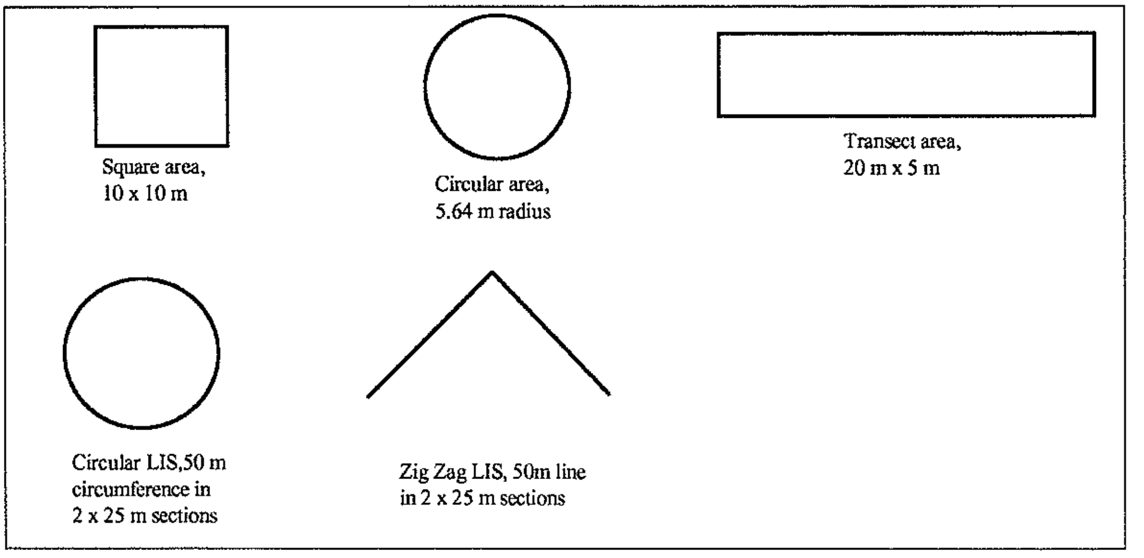

Figure 2 - Diagram of different plot types

The accuracy (estimated means, absolute error of the estimated means) and precision (95% confidence limits of the estimated means and probable limit of error (PLE) of the estimated means) were calculated for all five sampling systems over the full range of sampling intensities. The bias of the five systems was determined for only one sampling level (n=12).

The mean absolute error (%) was calculated using:

$$\left\{\frac{Estimated - actual}{Actual} \times \frac{100}{1}\right\}$$

The probable limit of error was calculated using: $\mathbf{PLE} = \left(\frac{t * se}{\bar{x}}\right) * 100$

Bias was determined by:

- calculating the standard error of the mean errors for the individual blocks

- the standard error of the total bias was then calculated from the block errors

- *t* test to determine whether bias is significant

Time study data was also collected during the various cutover assessments in order to compare the costs of implementing each system.

In addition, a check of the Zig Zag LIS system was completed in one of the blocks after it had been determined to be the preferred system. Block 4 was assessed with the Zig Zag LIS system using three new sets of plots.

RESULTS

The actual volume of merchantable wood per hectare is shown in Table 1.

Table 1 - Actual volume per hectare, 100 % sampling

Block	1	2	3	4
Volume m^3/ha.	17.9	26.8	16.2	14.2

Accuracy, Precision and Bias

Accuracy and precision of the sampling methods were determined by calculating the mean absolute error (%) and the 95% confidence limit (CL). The mean absolute error (percentage difference of the sampling system result to the actual volume) of each system is presented in Table 2.
The two sets of data (Table 2) represent measures of **accuracy** and *precision*. In general, accuracy and precision decreased with decreasing sample size.

For the area plots:

- the square area plots were the most accurate over the range of sampling intensities
- the most accurate and precise result for the square area plots came from 8 plots
- the square area plots, at >8 plots achieved results with <15% mean absolute error

For the LIS plots:

- the Zig Zag LIS results were the most accurate and precise over the range of sampling intensities
- excluding 2 and 8 plots, the other sampling intensities gave estimates with <15% mean absolute error.

The area plots showed more variation (95 % CL) in the size of the error than Zig Zag LIS plots. These differences were not statistically significant ($P < 0.05$), due to the amount of variation in both sets of data.

Bias (Table 3) is an indication of whether the sampling method is over or under predicting and by what proportion. The bias was determined for the five sampling systems at a single sampling intensity. The significance of the bias was determined by calculating the *t* value. If the t value was greater than 2 or less than -2, the bias was deemed to be significant. Only one of the sampling systems showed no significant bias ($t < 2$), that was the Zig Zag LIS. The other sampling methods had bias figures ranging from -9% to + 18% and these all had *t* values indicating significant bias.

Table 2 - Mean absolute error (Bold) and 95% confidence limit (Italics) of the sampling results from the four blocks

No. of plots	Square area	Circle area	Transect area	**No. of 50m lines**	Circular LIS	Zig Zag LIS
15	-	-	-	15	**12.2** *19.1*	**11.6** *8.7*
12	**13.7** *22.0*	**24.1** *17.4*	**26.2** *16.6*	12	**14.0** *18.6*	**8.7** *13.2*
10	**13.1** *23.4*	**29.6** *17.1*	**32.5** 12.2	10	**20.8** *19.0*	**13.7** *10.0*
8	**13.0** *8.0*	**28.5** *15.0*	**23.2** *21.5*	8	**26.0** *17.7*	**16.3** *7.9*
6	**20.1** *3.9*	**21.7** *7.1*	**34.4** *24.9*	6	**22.4** *24.0*	**7.3** *5.2*
4	**19.1** *14.0*	**29.5** *9.3*	**45.0** *41.2*	4	**35.7** *58.4*	**10.7** *16.9*
2	**44.4** *27.2*	**58.8** *67.7*	**46.9** *31.0*	2	**118** *232.7*	**19.8** *30.7*

Table 3 - Bias of the estimated volumes, (over or under estimating the volume) at 12 plots

Sampling method	Mean bias	Standard error	t value	Significant bias
Square area	-9.08 %	1.96 m³/ha	-4.62	yes
Circular area	3.68 %	1.46 m³/ha	2.52	yes
Transect area	18.44 %	2.19 m³/ha	8.42	yes
Circular LIS	8.07 %	1.79 m³/ha	4.51	yes
Zig Zag LIS	-2.24 %	2.05 m³/ha	1.09	no

The measures of accuracy, precision and bias can be used together to determine which system is giving the best result overall. For example, consider Zig Zag LIS at 12 lines (shaded cell, Table 2). The mean absolute error was 8.7% (+/- 13.2 % at 95 % CL) giving a range of -4.5 % to 21.9%. The average bias over the four blocks was - 2.2%, showing a tendency to under predict by 2% (Table 3).

In this study the Zig Zag LIS was as accurate and precise as the other systems and was the only system that showed no significant bias (shaded cells, Table 3).

Probable Limit of Error

Probable Limit of Error (PLE) calculations (Goulding and Lawrence, 1992) were also used to assess the data. PLE is the confidence interval expressed as a percentage of the estimated mean. For example, a PLE of 10% at the 95% confidence interval implies that the true (population) mean is within +/- 10% of the sample mean, unless a one in twenty chance has occurred. One advantage of PLE as a precision statistic is that it is a relative measure and can be compared between assessments of different populations.

A low PLE gives confidence in the sample mean as an estimate of the true mean. The size of the PLE depends upon the variation between samples and on the number of samples. If, for example, the waste wood is evenly distributed across the cutover a PLE of a certain level can be achieved with fewer samples than if the same amount of waste is concentrated in piles. Even distribution of slash is rarely the case.

The results of the PLE calculations for all plot types and sampling levels are shown in Figure 3. In this study the return for increasing sample size diminishes once the number of plots increases beyond 12 to 15.

Note: In Figure 3 the lines for square area, circular line intersect and Zig Zag line intersect plots are virtually the same and are hard to distinguish from each other.

For PLE, there was little difference between the plotting systems with the exception that the circular area plots appear to be slightly less variable.

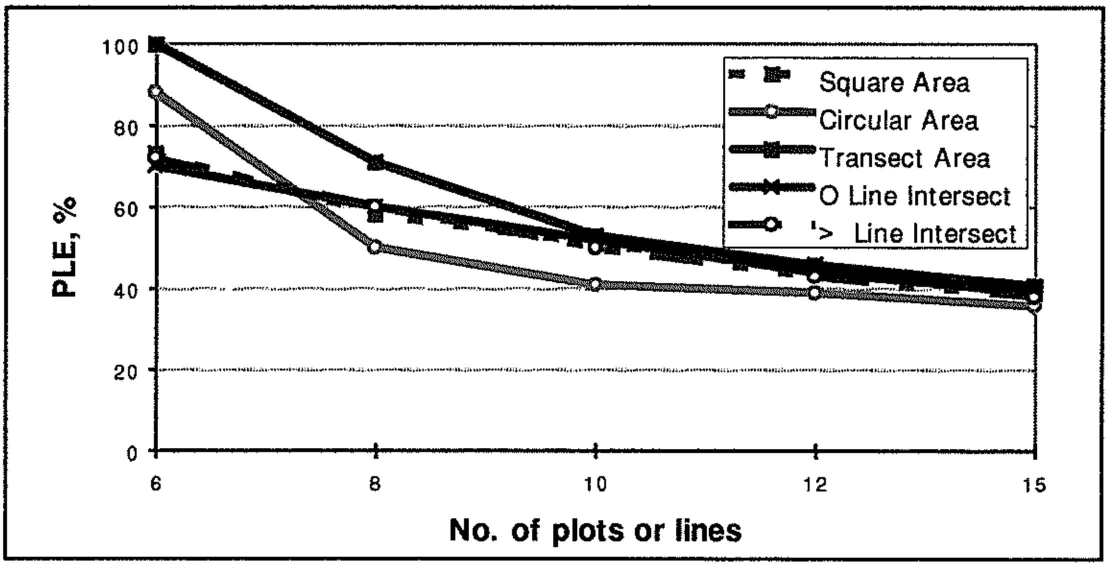

Figure 3 - Sample size vs PLE

The PLEs in Figure 3 relate to the particular plots in the sample. A different PLE would be gained from a different set of plots. The apparent poor performance of circular area plots at 6 plots is an anomaly specific to the data set used. However, the trend for decreasing PLE with increasing sample size would remain.

The differences in the accuracy, precision, bias and PLE all indicate that there was little significant difference in the results from the different systems.

Sampling System Costs

The usefulness of any assessment method is related to its cost. The costs of implementing each system are shown in Figure 4. **Note:** In Figure 4 the lines for circular area plots and transect area plots are virtually the same and are hard to distinguish.

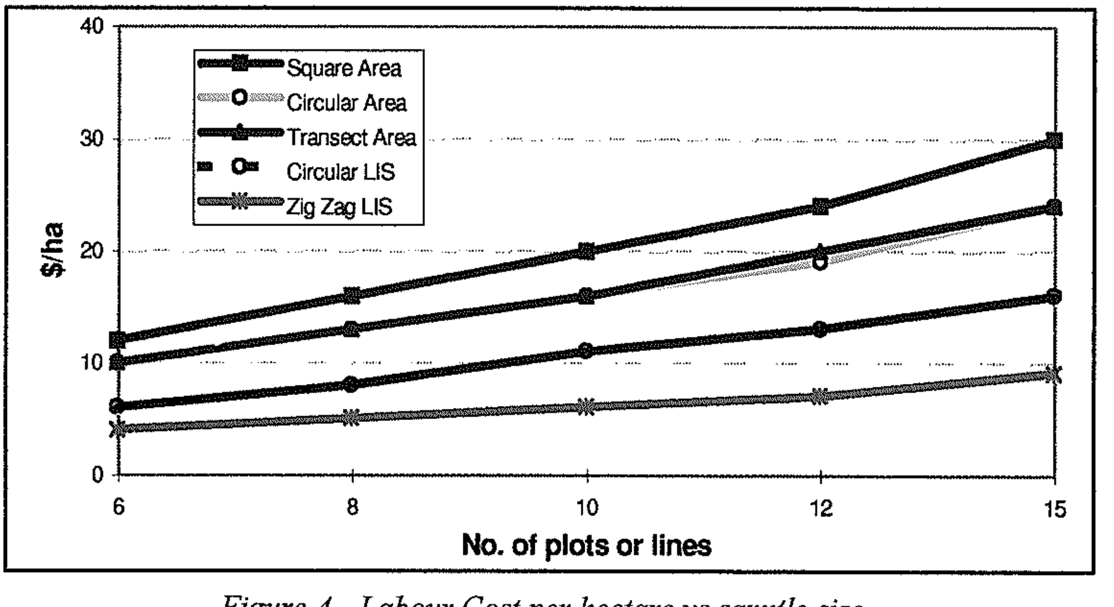

Figure 4 - Labour Cost per hectare vs sample size

Zig Zag LIS clearly had the lowest labour cost per hectare (Riddle 1994) at all sampling intensities (Figure 4). This is because it can be carried out quickly and easily by only one person. All the other systems require two people to complete the plot layout, measurement and recording. LIS systems also require only one measurement per log (diameter at the intersection point). Area plots require three measurements per log (length, LED and SED) which increases not only data collection times but data entry as well. Circular LIS plots had the next lowest cost, being quick to measure, but still requiring two people for the plot layout.

Summary

The Zig Zag LIS method was as accurate and precise as the other systems. It had no significant bias where the other systems did. It is also the system that costs the least to implement. Some further work was then focussed on the Zig Zag LIS as it appeared to be the best system overall.

Accuracy of the Zig Zag LIS

The variation from the true volume of one of the blocks (block 4) given by repeat 10 and 15 line Zig Zag LIS sampling was tested to determine whether it would give a consistent result. Three sets of plot data were gathered. The known volume was 14.2 m^3/ha. At 15 lines, the results ranged from 12.1 m^3/ha to 17.4 m^3/ha. The standard deviation of the mean was 2.8 m^3/ha, so the 95% confidence limit of the estimated mean (14.2 m^3/ha) was ± 5.6 m^3/ha (8.6 m^3/ha to 19.8 m^3/ha).

At 10 lines, the results ranged from 11.5 m^3/ha to 14.2 m^3/ha. The standard deviation of the mean was 3.8 m^3/ha, so the 95% confidence limit of the estimated mean (12.5 m^3/ha) was ±7.6 m^3/ha 4.9 m^3/ha to 20.1 m^3/ha).

The 50 m Zig Zag LIS system was also trialed on two different logging settings (one ground based, one cable logged), using ten 50 m lines. The system was applied to the same piece of cutover using different plot points five times. This was done to determine the variation likely to occur if this system was used operationally.

The results (Table 4) indicate that the Zig Zag LIS system estimates of the merchantable volume were consistent. The variation was less than that found in the main study.

Attempts to determine a better Zig Zag LIS system were made by combining data sets. Fewer but longer plots (7 x 100 m) gave a similar PLE to 14 x 50 m plots. Moving to 14 x 100 m plots reduced the PLE by around 10% but increased the cost by 100%.

Table 4 - Results of Zig Zag LIS "Test" (n=5)

	Mean, (m^3)	s.d. (m^3)	s.e. (m^3)	PLE (%)	95% CL (m^3)
Ground based	14.2	0.9	0.4	8	± 1.1 (13.1 - 15.3)
Cable	8.1	0.9	0.4	14	± 1.1 (7.0 - 9.2)

Operational use of Zig Zag LIS

The results of the system comparison determined **relative** accuracy, precision, bias and cost of the sampling methods. However, the sampling levels used in the study are not necessarily those which would be used operationally by forest companies.

Cutovers are assessed setting by setting rather than by the hectare and the **number** of plots is important to getting an accurate answer. A useful sample size is two to four 50 m lines per hectare (dependent on the size of the setting and the variability of the slash). A progressive calculation of PLE should be used to indicate whether a greater sample is required. A total number of plot lines per setting of 20 to 30 is suggested.

A description of the Zig Zag Line Intersect Method used in this study is attached in the Appendix.

CONCLUSIONS

- The Zig Zag LIS was the most cost efficient system. It gave an answer that was at least as accurate as and less biased than the other systems at a substantially lower cost.

- The square area plots were the best of the area plot methods and transect area plots were the worst.

- Sample size should be calculated for each individual setting. There is no defined number of lines per hectare that will be suitable for all situations; such a policy would be inaccurate for small settings and wasteful for large ones.

- There is still subjectivity involved in determining if set limits of merchantable volume per hectare have been exceeded, as the result is an estimate only and the actual volume is not known.

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The costs stated in this report were derived using the procedures shown in LIRO Business Management for Logging. They are indicative only and do not necessarily represent the actual costs of this operation.

APPENDIX

Zig Zag Line Intersect Method of Cutover Waste Assessment

Equipment required:

Hip chain
Diameter callipers
Compass
Random number tables
Compartment map
Notebook

Personnel required:

one

METHODS

The location of the skids used and the area logged are required. These are determined from compartment maps and aerial photographs.

The predominant extraction direction is identified. Baselines are established perpendicular to the predominant extraction direction and parallel to each other.

The setting may need to be subdivided to ensure that the baselines remain perpendicular to the extraction direction. If this is necessary the required sample size and calculation of total volume is still determined for the whole setting.

Plot lines are installed along the baselines, using random number tables to obtain a compass bearing for the beginning of each line.

Bearings which give a plot direction that is greater than 90° to the baseline are discarded.

Plots are 50 metres long, in two 25 m sections at right angles to each other.

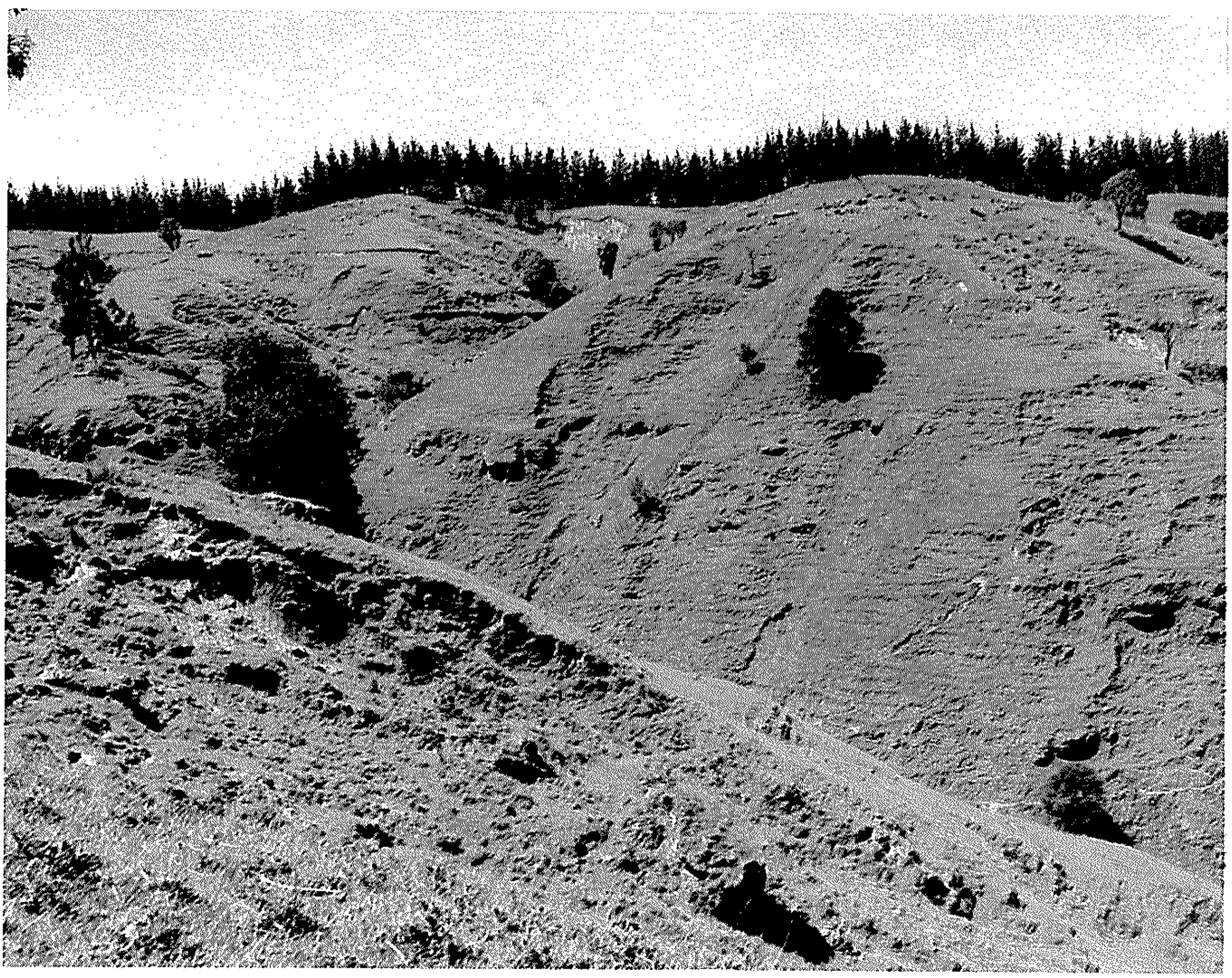
LOGGING INDUSTRY RESEARCH ORGANISATION

NEW ZEALAND

PROJECT REPORT

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

PIETER FRANSEN



Project Report

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.

New Zealand Logging Industry
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NEW ZEALAND

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

P. R. 59 1996

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CONTENTS

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.

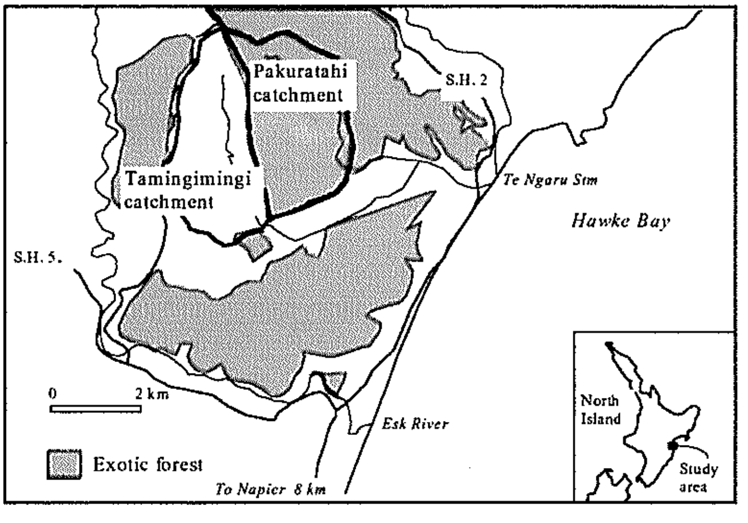

Figure 1 - Location of research catchments

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

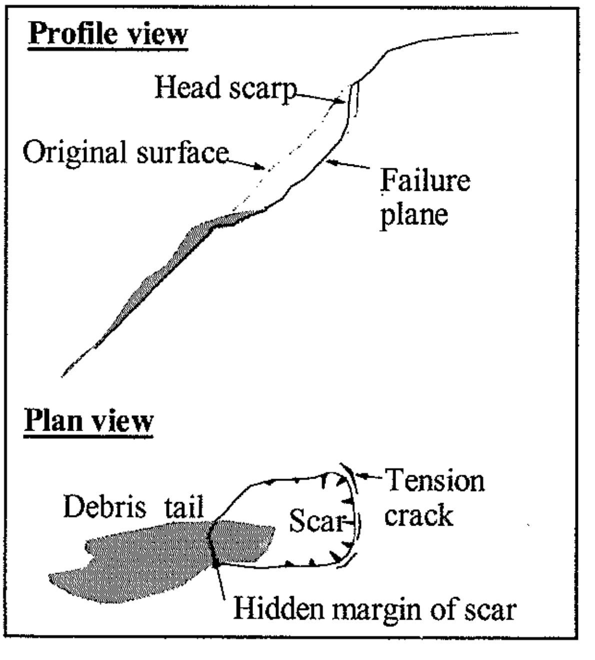

Figure 2 - Slip features

[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.

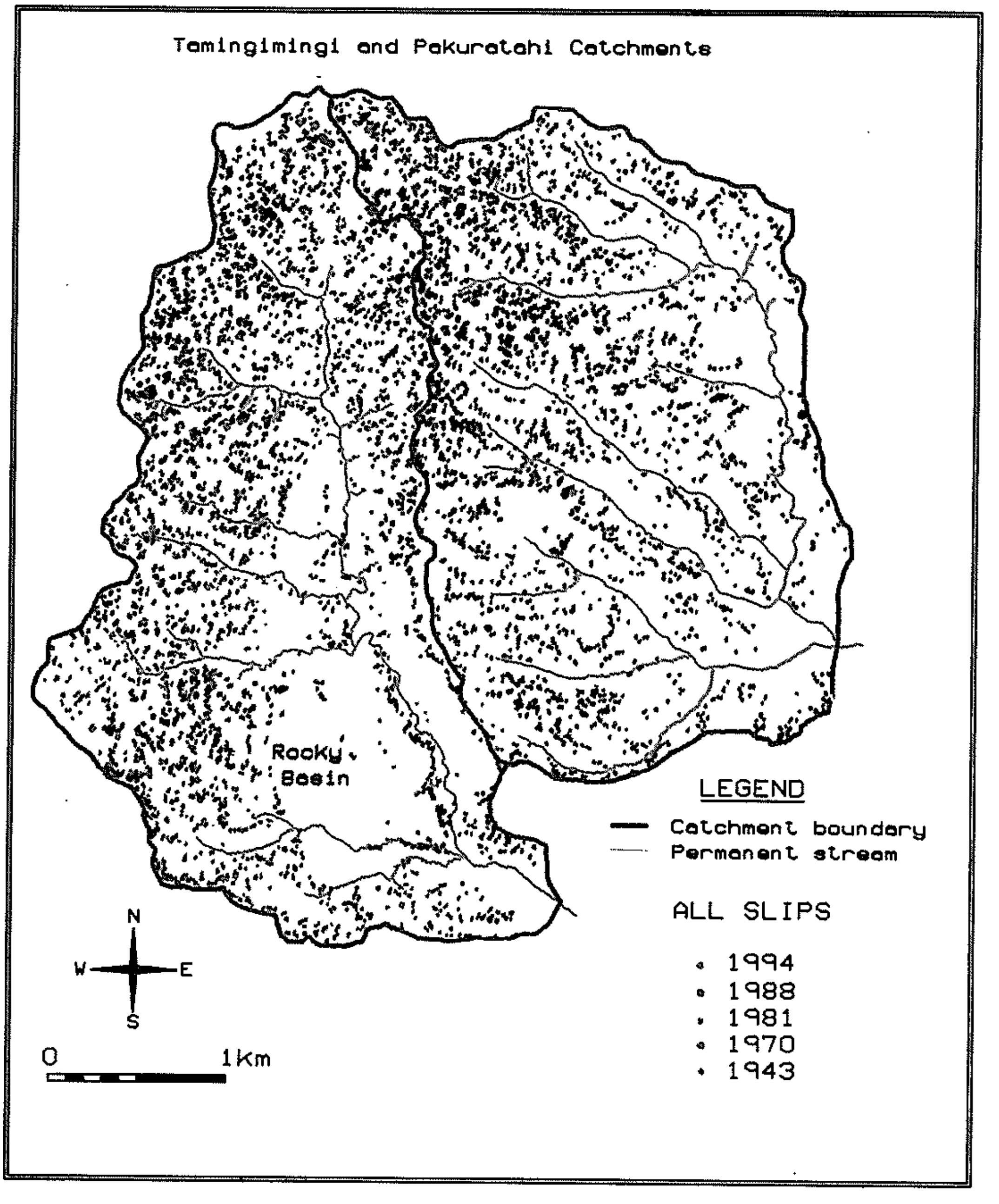

Figure 3 - Slips used in GIS cross tabulation analyses represent 2% of the research catchment area

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		

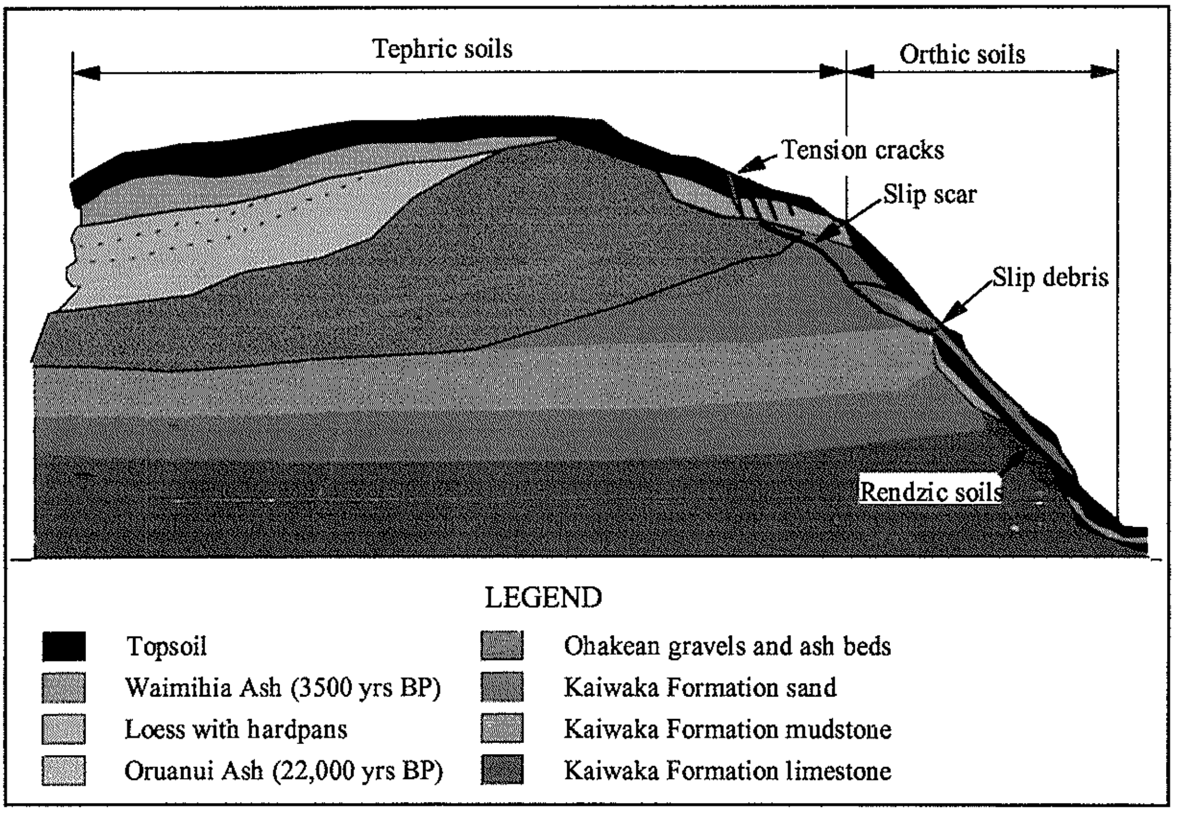

Figure 4 - General association of soils and geology in Pakuratahi and Tamingimingi catchments

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).

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).

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 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°.

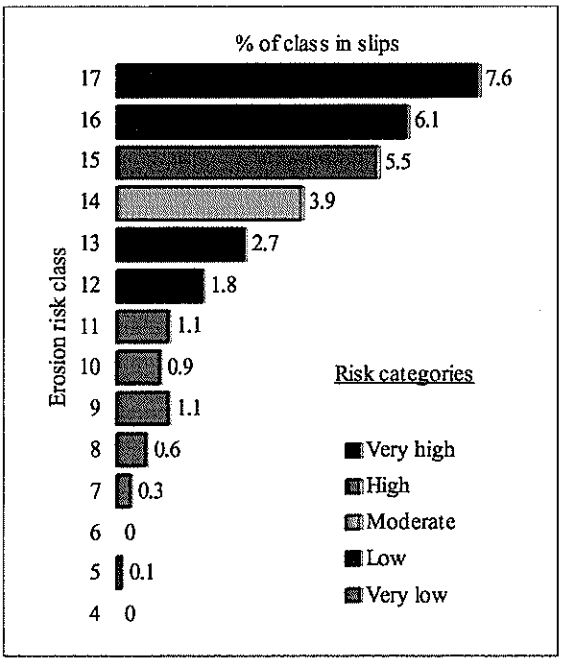

Figure 5 - General risk categories from composite slip erosion classes

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

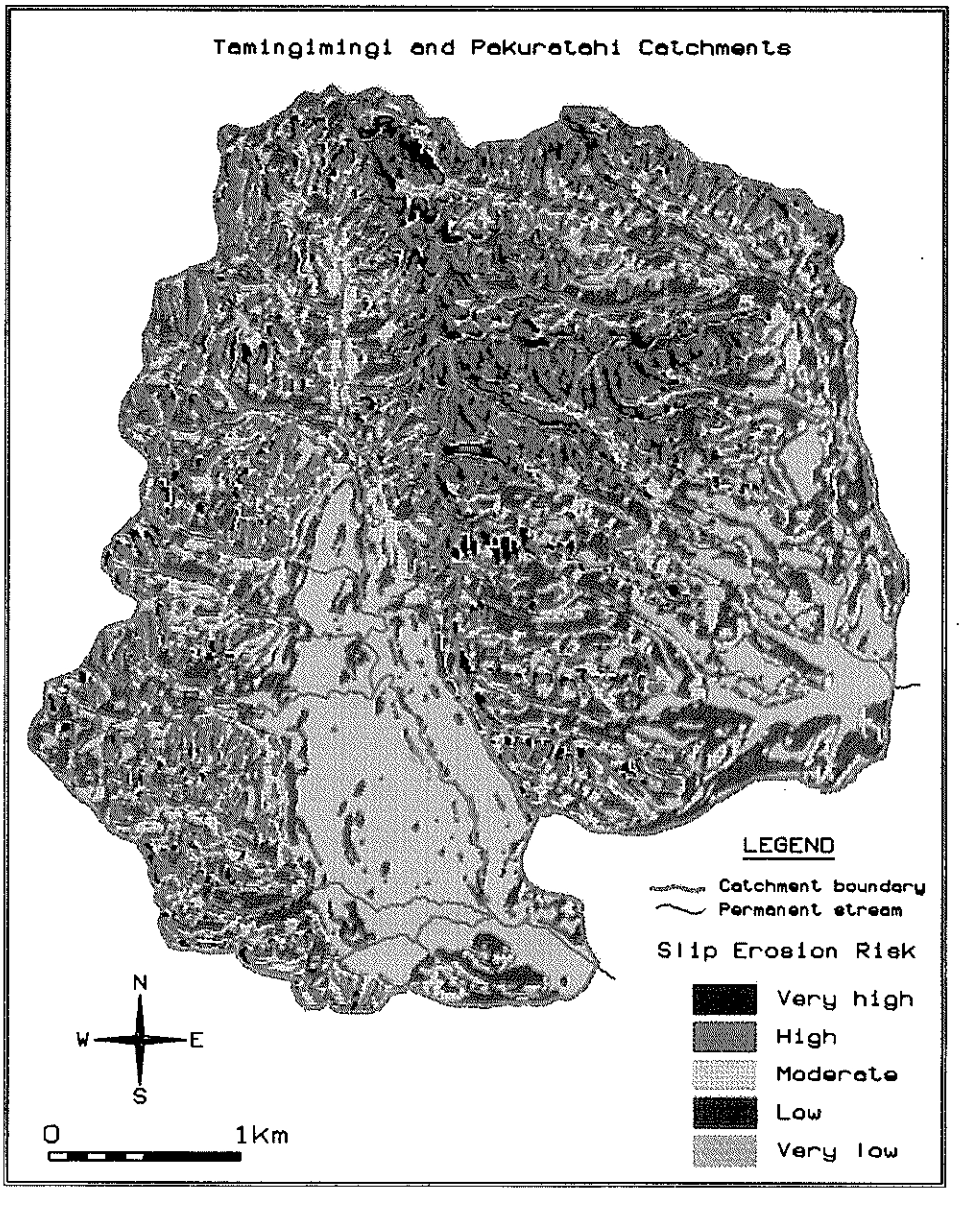

Figure 6 - Erosion risk map

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.

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