ARTICLES

Historical slip erosion in catchments under pasture and radiata pine forest, Hawke's Bay hill country

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ABSTRACT

As part of research on the effects of erosion associated with the harvesting and re-establishment of plantation forests, historical levels of slip erosion and their probable causes were determined in two similar-sized catchments. Slips and vegetation cover were digitally mapped from a series of aerial photographs (1943-1994) using an analytical stereoplotter connected to a Geographic Information System (GIS) that facilitated spatial analyses. High levels of storm-induced slip erosion were recorded for land use under pasture in 1943 and 1988. In 1943, slips occupied 1.3% of the total catchment area which was mainly in pasture. Comparison of slip records enabled estimation of slip recovery rates (0.7 ha per year) by pasture plants and consideration of the effect of earlier major storm events on information recorded at a specific date. Extensive conversion of indigenous scrub cover to pasture land since the 1880s, a large earthquake in 1931, and two large storms in 1938 were significant influences on the relatively high level of erosion. However, establishment of radiata pine forest in Pakuratahi Catchment in the early 1970s subsequently mitigated the erosive impact of Cyclone Bola in 1988. Overlaying of consecutive slip records enabled calculation of the proportion of slips that were new and those associated with an earlier event. In the future, the impact of storm-induced erosion on harvested and re-established sites can be compared with adjacent pasture land and the historical slip records.

INTRODUCTION

Studies in New Zealand and overseas have shown that forest harvesting will increase water yields and may result in higher levels of sedimentation and erosion from forest roads, tracks, landings and site disturbance (Wallis and McMahon, 1994). However, the effect of harvesting-related erosion on soil productivity, water quality and stream ecosystems is less well known. Previous studies assessed the impact of storm-induced landslide damage on pastoral land and on afforested farmland (Harmsworth and Page, 1990; Marden and Rowan, 1993). The work covered in this paper forms part of a research project to determine the extent of erosion after harvesting and before canopy closure of a re-established plantation forest.

The research is focused in two adjacent catchments – the Tamingimingi pastoral catchment and the Pakuratahi forestry catchment – located 18 km northwest of Napier City in Hawke's Bay (Figure 1). The catchments are representative of erosion-prone hill country composed of unstable Tertiary Period rocks and thin volcanic ash cover, common in the eastern, central, and western parts of the North Island. Uneconomic farmland in these regions continues to be replaced by exotic production forests. The Pakuratahi catchment is one such area planted in radiata pine which is scheduled for harvesting soon. This article outlines:

1) the history of land use and storm history in the research catchments;
2) the GIS mapping and analyses of historical soil slip erosion from aerial photographs;
3) a comparison of the extent of erosion in two catchments; and,
4) a discussion on the causes of slip erosion in the catchments.

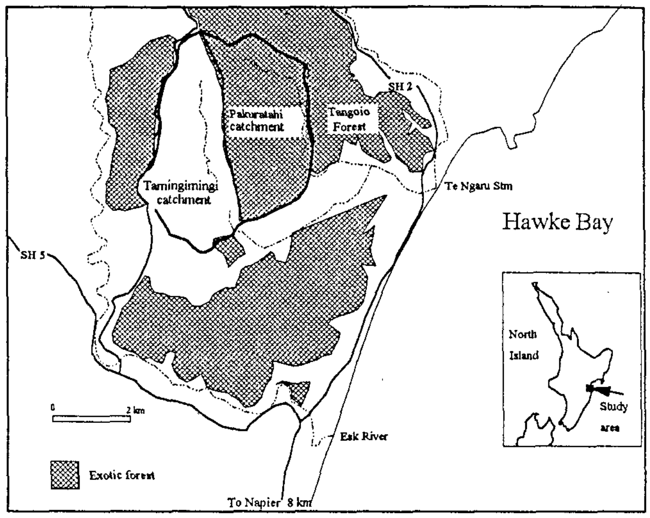

Fig. 1

RESEARCH CATCHMENTS

The catchments occupy 1573 ha, with the Pakuratahi catchment comprising 774 ha, and the Tamingimingi catchment 798 ha. Moderately to very steep valleys dissect much of the land that rises from 18 m to 355 m above sea level. Narrow ridge tops separate the valleys. A large area of subdued and rolling topography lies in the central Tamingimingi catchment (Rocky Basin). The Land Use Capability classification of VIe5 and VIIe3 reflects the potential of this steep hill country for moderate to very severe soil slip and gully erosion, and summer drought (NWASCO, 1976). The rupture zone of slips within the catchments ranges in depth from 0.5 m to 2.5 m below the ground surface. Earth materials exposed in the slips include predominantly sandy loam soils and soft bedrock. This type of mass movement is referred to here as soil slips, but they could also be classed as earth slips (NWASCO, 1979).

HISTORY OF LAND USE

Although a lack of forest cover was noted in lowland Hawke's Bay as early as 1840, this was probably the result of progressive burning by Polynesian settlers from about 920-1020 AD (McGlone, 1978). By the 1880s large areas of Hawke's Bay were cleared of scrub and fern cover, and converted to pasture (Guthrie-Smith, 1969).

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Pasture in Tamingimingi catchment was intensively grazed, while the Pakuratahi received little attention, being used primarily as a run-off for stock from the Waipunga Station until c.1919. About this time the allocation of ballot blocks for soldier settlement gradually saw more of the Pakuratahi catchment converted to pasture. Milling of the indigenous kanuka-manuka bush and small stands of matai, kahikatea, titoki and occasional totara, was an initial source of income for landowners in the Pakuratahi catchment (Mrs D. Lee, local historian, pers. comm.). Pasture conditions did not improve with subsequent changes in farm ownership. Eventually, substantial areas of the catchment reverted to scrub, due to ineffective management of the steep, difficult terrain, combined with periods of severe slip erosion. In 1971/72, Carter Holt Harvey Forests planted radiata pines in the Pakuratahi catchment that now forms part of Tangoio Forest.

STORM DAMAGE

The Hawke's Bay region occasionally experiences high-intensity rainfall, despite being one of the driest regions in New Zealand (Salinger, 1995). Mean annual rainfalls (provided by Hawke's Bay Regional Council) near the research catchments range from 813 mm to 2420 mm. Summer droughts are usually broken in autumn by torrential rain from cyclones that originate from the north of New Zealand.

Minimum rainfalls required to initiate erosion depend on terrain, vegetation cover, soil moisture and storm intensity and duration. The approximate rainfall threshold to induce significant slip erosion in the Hawke's Bay hill country is 250 mm in two to three days (Page *et al.*, 1993).

Rainfall records from four stations surrounding the research catchments show at least 80 days of rainfall over 100 mm since 1894 (Figure 2). Erosion-inducing storms occurred in 67 discrete events in this period. Most of these storms appeared to be localised at some stations.

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

Date of photography	Photo scale	Features shown
Mar 1943	1:16000	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	1:27000	Present conditions

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Erosion and flood disasters in the Esk and Te Ngaru catchments in April 1938, 1963 and 1988 incurred social, economic and land productivity losses (Campbell, 1964). These disasters followed widespread rainfalls above 200 mm in 24 hours. Other less-remembered storms of similar magnitude occurred in 1924, January 1938, 1944, 1955 and 1956.

GIS MAPPING

A historical series of aerial photographs covering the research catchments was obtained from New Zealand Aerial Mapping (NZAM), (Table 1). In addition, NZAM was contracted to obtain up-to-date photographic coverage in 1994.

Digital mapping of slips from aerial photographs was successfully used to model the extent and severity of slip erosion on pastoral hill country (Thomas and Trustrum, 1984) and to assess storm-induced erosion damage (Trotter *et al.*, 1989). In this study, to ensure a high level of mapping precision and accuracy, an AP190 analytical stereoplotter[3] was used to map surface features (slips, pasture, plantations, remnant indigenous bush, amenity trees and roads) from the various photographs into a Geographic Information System (GIS), TerraSoft[4]. Photo-control necessary for orientating photo-diapositives in the stereoplotter was provided by the Department of Survey and Land Information. Statistics provided by the stereoplotter software indicated that the precision of coordinates of the mapped features was better than one metre.

To examine the error in digitising, the areas of 31 slips on the 1988 aerial photographs were sampled three times. A paired t-test, used to test for consistency among the three sample means, showed no significance differences (P=0.05). The standard deviation of the differences was 18 m^2. This implies that the standard deviation for digitising a single slip is 12.7 m^2 (= $18/\sqrt{2}$). From this, the 95% confidence interval for the mean slip area (69.2m^2) for 1207 slips mapped in 1988 is ± 0.7 m^2 (i.e. ± 2 x $12.7/\sqrt{1207}$). For the total slip area across both catchments (8.4 ha) the error converts to ± 0.08 ha. This shows that for large populations, errors associated with digitising slips is likely to be insignificant.

Not mapped were the slip debris tails that were recolonised by pasture plants and generally ill-defined on the aerial photographs. The down-slope margin of slip scars was inferred, where covered by slip debris.

ANALYSES OF SOIL SLIPS

The highest slip erosion levels recorded in the research catchments were in 1943 and 1988 (Figure 3). GIS area analysis of the 1943 record for the combined catchments (1573 ha) gave a total of 20 ha or 1.3% of the catchment area influenced by slip erosion.

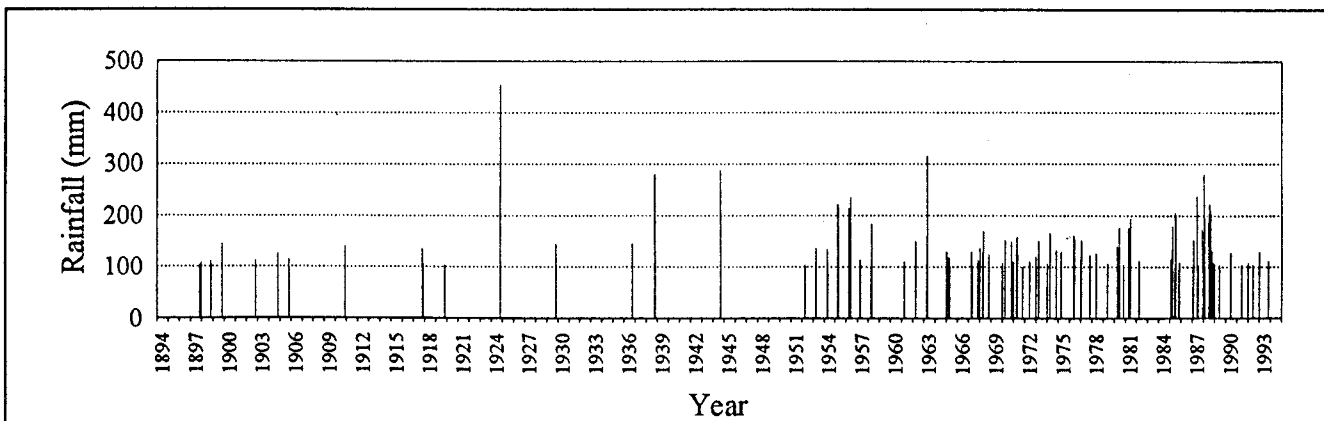


Figure 2. Rainfall exceeding 100 mm in 24 hours recorded from stations at Tareha, Tangoio, Te Ngaru and Eskdale. Data were incomplete and limited to fewer stations prior to 1967.

	Year	Pasture %	Indigenous Scrub %	Exotic Forest %	Slips %	Slip density No. / km^2
Pakuratahi Catchment (774.4 ha)						
	1943	83.1	17.8	0	1.37	296
	1970	60.1	39.5	0.4	0.07	16
Forest planted in 1971/72	1981	15.0	6.5	76.5	0.01	2
	1988	15.5	6.5	73.0	0.14	22
	1994	10.2	6.8	77.9	0.02	7
Tamingimingi Catchment (798.7 ha)						
	1943	90.8	9.0	0	1.18	232
	1970	93.1	6.7	0	0.16	45
	1981	93.7	2.7	3.3	0.06	17
	1988	92.9	2.7	4.0	0.91	130
	1994	92.6	2.9	4.1	0.34	75

Table 2. Percentage area of catchments in vegetation cover and soil slips. Minor areas of roads and amenity trees are excluded.

Extensive slip erosion affected 0.5% of the combined catchments in 1988. The Tamingimingi had 0.9% of its area occupied by soil slips, whereas only 0.1% of the area was eroded in the Pakuratahi catchment. At that time the radiata pine forest was 17 years old and covered 73% of the Pakuratahi catchment (Table 2).

Slip records comprise new (or recently formed) and old scars (those formed in an earlier event) of unknown proportion. New scars may occur on previously stable areas on slopes, or on old scars that have healed, or remained bare of vegetation. Erosion assessments must clearly establish which slips were the result of a new erosion event.

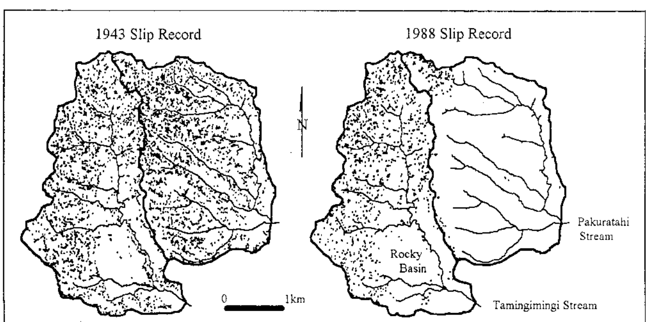


Figure 3. Extent of soil slip erosion recorded in Tamingimingi and Pakuratahi catchments after storm events. In 1988, 73% of the Pakuratahi catchment was in forest.

GIS spatial analysis of slip records enabled the identification of old slip scars produced in an earlier event. Analyses were performed by overlaying consecutive slip records, or any records of interest (e.g. 1988 over 1943; Figure 4). An overlay report produced in the GIS was transferred to a computer worksheet for further analysis.

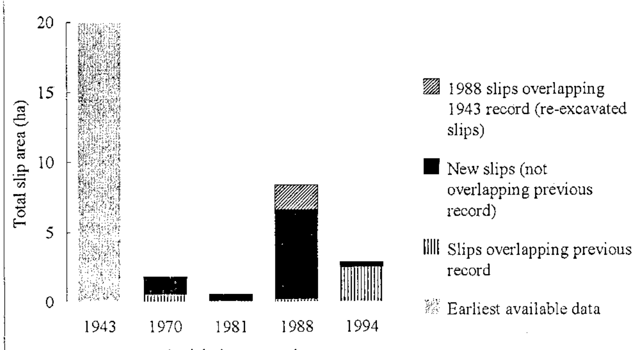


Figure 4. Area of slippage overlap in Pakuratahi and Tamingimingi catchments.

Slips that did not overlap were clearly unrelated and had therefore developed on previously unscarred ground. They accounted for 71% (by area) of the 1970 record, 88% of the 1981 record, 76% of the 1988 record, and only 15% of the 1994 record (Figure 4). Fewer new slips in 1994, compared with 1988, suggest minor erosion events in the intervening years.

Eighty-five per cent of slips in the 1994 record overlapped the 1988 record. The GIS overlaying process reveals a range of slip overlaps; from areas just overlapping to completely overlapping. Minor overlaps indicated that the slips were probably new since 1988. Major overlaps (near 100% of the slip area) indicated the slips were formed in 1988. Overlaps could also indicate a re-excavation or lateral extension of an earlier slip. Variability in the size of the overlain slips reflects interpretation error in mapping, the rate of revegetation of the scar, and the inherent soil-site condition. Estimation of the proportion of new slips in the overlapping areas is problematic.

For the 1988 record, 19% and 2.5% of the total slip area overlapped the 1943 and 1981 record respectively. The 1943 overlap result does not suggest that scars persisted until 1988. It was very likely that all of the 1943 slips had revegetated prior to 1988 (explained below). However, the result suggests that those overlapped 1943 scars were re-excavated in 1988.

SLIP RECOVERY RATES

Comparison of successive slip records provided an indication of the rate of slip recovery by pasture plants. At least 38% of the area of Cyclone Bola slip scars persisted to 1994, while the remainder could not be detected on the aerial photos due to concealment by grasses and weeds.

Calculation of a slip recovery rate after Cyclone Bola gave 0.66 ha/year. This is the difference in the total area of new slips in 1988 and the total area of 1994 slips overlapping 1988 scars, over the six years. Similarly, the 1943 scars recovered at about 0.7 ha/year.

Overlay analysis showed only 3% of the 1943 slips evident in the 1970 record (Figure 4). Thus it took almost 27 years for the 1943 slips to heal over by recolonisation of pasture plants. Trials elsewhere in North Island hill country showed that it took about 30 years for slip scars to regrass completely (Hicks, 1988).

CATCHMENT RESPONSE TO SLIPPAGE

A requirement for comparing the effect of future forest harvesting with pastoral land is that the catchments be inherently similar in their response to slip erosion. This will depend on the physical and land-use characteristics of the catchments. Geology, soils, and landforms are comparable between the Tamingimingi and Pakuratahi catchments, but land use (or type of vegetation cover) today is not. However, in 1943 the catchments were predominantly in pasture with scattered areas of indigenous scrub (Table 2).

On the basis of the 1943 data, the Tamingimingi and Pakuratahi catchments showed a similar response to slip erosion. In the Pakuratahi, slips affected 1.4% of the total catchment area, compared to 1.2% in Tamingimingi. Minor slip erosion on a large (160 ha) area of predominantly subdued relief in the Rocky Basin accounts for the lower figure in the Tamingimingi catchment (Figure 3).

Larger areas of scrub occupied the Pakuratahi catchment (18%), compared to the Tamingimingi catchment (9%) in 1943. This difference did not proportionally affect the level of slippage. There were very few slips mapped within the areas of scrub, suggesting that ground protection was adequate. Scrub density, while unknown, was sufficient to prevent extensive slippage, despite the likelihood of stock damage. It was common for farmers to use sheep and cattle to clear the scrub. Bergin *et al.* (1993) found that a high level of protection against slippage was provided by mature fully-stocked scrub stands compared with under-stocked scrub stands.

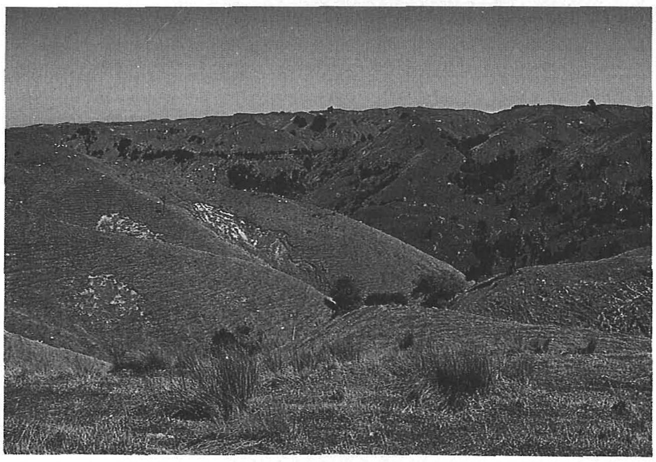
FACTORS INFLUENCING SLIP EROSION

Erosion is seldom attributed to a single cause. While a storm is usually the primary trigger of mass movement, unstable ground conditions, soil and rock type, deforestation or land-use activities are also important. Determination of the causes of slippage must take into account: 1) preceding ground conditions, 2) geomorphological (land-forming) processes, 3) physical processes, and 4) man-made processes (Popescu, 1994). This discussion now considers some of these processes.

Since 1943 the area in pasture remained relatively unchanged in the Tamingimingi catchment. But the impact of slip erosion was greater in 1943 than in 1988 (Table 2).

Two large storms occurred in January and April 1938. The January storm was of high intensity (229 mm in 24 hrs) and triggered some slips in the surrounding area (SCRCC, 1957). The April storm had a disastrous impact throughout the region. One notable factor was that the rainfall intensity on the first day of this storm – as recorded at Esk to the south of the research catchments – was 145 mm greater than Cyclone Bola in 1988.

Extensive ground cracking probably increased the potential



Typical slip erosion scars and terrain in the Tamingimingi catchment.

Slip scar in a small clearing in the forested Pakuratahi catchment, Central Hawke's Bay.

for the severe slippage associated with the 1938 storms (Campbell, 1945). Campbell noted the formation of many cracks (up to one metre deep) after the 1931 Napier earthquake and as a result of soil shrinkage during drought in the Tangoio area.

Storm runoff flooding these cracks potentially increases the hydrostatic pressure above the resisting forces of the soil mass, thereby causing slippage. Drought conditions also existed prior to Cyclone Bola (Harmsworth and Page, 1991).

Earthquake-induced slippage was recorded in photographs of the Pakuratahi area (Lee, pers. comm.), but the proportion of slips in the record is not known.

Slips that were generated in the large 1924 storm were unlikely to be visible on the aerial photographs of 1943. By this time most of the 1924 slips had probably healed over. This is partly supported by the observations of Campbell (1945) who reported that the slipping associated with the 1938 storm was much greater than the 1924 event.

Protective forest occupied 4% of the Tamingimingi catchment area in 1988. These areas were in pasture and had intense slippage in 1943, but were unaffected in 1988. The small area of forest, and indigenous vegetation, had a minor influence on overall slip numbers in the Tamingimingi catchment.

Cyclone Bola in March 1988 caused widespread erosion in the Tamingimingi catchment. Storms (100-200 mm) in 1985 and 1987 also could have induced slippage and consequently contributed to the slip record. Most of the Pakuratahi catchment, however, was unaffected by soil slips. The contrast between the two catchments was primarily the result of the establishment of the plantation forest covering 73% of the Pakuratahi catchment.

Extensive slipping did occur in the upper Pakuratahi catchment in 1988 (Figure 3, Table 2). On a small, privately-owned, 45 ha pasture block, 1.9% of the area suffered slippage. This higher figure was largely due to the greater average area of individual slips (100 m^2), compared with the Tamingimingi catchment (70 m^2). Within the forest, slips occurred in grassed and a few wind-fallen areas among the trees. Only a few slips, attributed to Cyclone Bola, occurred under the forest canopy.

CONCLUSIONS

As part of ongoing research into inter-rotation forest harvesting impacts, historical levels of slip erosion and their probable causes were considered in two similar-sized catchments in Hawke's Bay. The Tamingimingi catchment has been retained in pasture since the turn of the century. Pastoral farming did not succeed in the Pakuratahi catchment which was converted to radiata pine forest in the early 1970s.

Historical slip erosion and land-use patterns were mapped from an archive of aerial photographs, using an analytical stereoplotter linked to a GIS. The earliest record of widespread erosion in 1943 showed that the catchments were similarly affected, with 1.2-1.4% of the area lost to soil slips. Erosion was caused by four triggering factors: removal of large areas of protective scrub cover for pastoral development, an earthquake in 1931, and two high-intensity storms in January and April 1938.

A second major event in 1988 contrasts with the 1943 record. When Cyclone Bola struck in 1988, slips occupied 0.1% of an afforested catchment, compared to 0.9% of the pastoral catchment. As well, slippage was less extensive within the pasture catchment in 1988 than in 1943. The higher rainfalls on the first day of the April 1938 storm may have contributed to the greater slippage recorded in 1943.

The study has emphasised that erosion records must be carefully examined to determine the influence of older slip scars. These scars could misrepresent the true level of erosion associated with an event. Historical soil slip erosion records are useful as a benchmark for future appraisal of harvesting-related impacts and forest re-establishment activities. The integrated use of photogrammetry and GIS is valuable for the analysis and management of spatially complex land resource data.

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Effects of trees on soil properties

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The proceedings may be ordered from: Dr D.J. Mead, Field Service Centre, Box 84, Lincoln University, New Zealand. Cost: $20 including postage.