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SLIPS AND SEDIMENTATION IN MATURE PLANTATION FOREST AND PASTORAL HILL COUNTRY, HAWKE'S BAY, NEW ZEALAND.

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CONTENTS

SUMMARY

Following storms in June and July 1997, a survey was carried out to determine the extent of soil slippage, the volume of sediment delivered to streams, and associated changes in channel profiles at six pre-selected monitoring sites. Upper pasture and forest catchment areas, and a lower forest catchment - due for harvest, were included in the slip survey.

The slips were triggered after an extended wet period. An unexpected result was a higher incidence of slippage under the 26- year old radiata pine forest (slips numbered 131/km^2) compared to the adjacent pasture-land (slips numbered 55/km^2).

However, a greater proportion of the mature forest area was classified very high erosion risk (10 % compared to 4 % for the pasture area), consequently, the proportion of slips was also greater (20 m^3/ha compared 0 m^3/ha for the pasture).

Low slip density (13 slips/km^2) under a young (8 year old) pine forest stand reflected a higher stocking rate (800 stems/ha) compared to the 200 stems/ha mature pine forest (the erosion risk was similar in young and mature stands). The results highlight that more information is required, for mature forests, about the extent of slippage associated with high intensity storms.

Storm flow effects on sediment levels in the stream channels was variable. Deepest scouring occurred at the pasture stream sites with an average 66 to 70 mm lowering of the stream-bed. Two forest stream sites had lesser scour (average stream-bed lowering of 25-34 mm) and the third, lower forest stream site had a significant filling ($P<0.05$) of sediment (streambed raised an average 52 mm).

Differences in the depth of scouring between the upper catchment pasture and forest sites was attributed to a larger specific discharge and a lower volume of slip derived sediment delivered to the pasture stream (77 m^3/km) than to the mature forest stream reach (109 - 113 m^3/km). In the lower forest catchment, a high input of sediment (367 m^3/km) resulted in channel fill, with 71% sourced from the failure of old road fill.

The results of this study will be useful in comparing storm induced effects in the post-harvest/re-establishment period.

Introduction

Two storm events occurred in early June and July 1997 that culminated in slip erosion within the Hawke's Bay region, and which was particularly severe in pastoral hill country in the Wairoa District (Figure 1). Liro measured the storm effects on slip erosion and stream channel morphology in two research catchments; the Pakuratahi catchment within Tangoio Forest, and an adjacent Tamingimingi pasture catchment (Figure 1). The catchments are part of an on-going forest sustainability research project, established in 1993, to determine the effects of harvesting on soil erosion, sedimentation, water quality and stream ecology (Fransen and Brownlie, 1996).

The 1997 survey preceded harvesting activities in the Pakuratahi catchment. To evaluate harvesting effects on soil erosion and sedimentation in streams, comparisons were made with pasture and un-harvested plantation forest. Research has focused on slip erosion and sedimentation which can potentially have a significant effect on water quality and stream ecosystems. Overall, erosion is very much less under pine plantations or indigenous forest than under grazed pasture or reverting scrub where livestock have not been excluded (Hicks, 1991). However, there is little information on the effect of harvested plantation forest on hillslopes prone to slip erosion. This report addresses the effectiveness of low stocked mature plantation forest stands in preventing soil slip erosion.

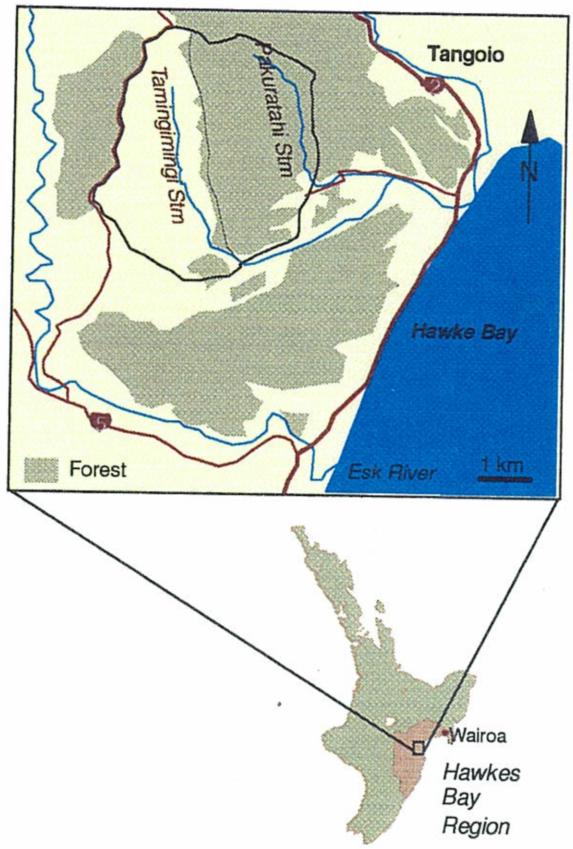

Figure 1. Location of Pakuratahi-Tamingimingi catchment study in Hawke's Bay Region.

This report also compares pastoral and forest catchment channel responses to the hillslope erosion caused by the July 1997 storm. Sediment supply and storage rates may vary over time (Mosley, 1978), and there is considerable evidence to suggest that forest harvesting activities can affect the volumes, rates and timing of water and sediment movement through a catchment (Grant et al., 1984). But less clearly understood is how stream channels respond to such changes, particularly in different parts of a catchment, and associated effect on in-stream or downstream values, such as aquatic life. Much of the current knowledge on sedimentation within forestry areas is based on evaluations of erosion rates from roads and tracks, and suspended sediment yields in streams (O'Loughlin et al., 1978; Mosley, 1980; Fahey and Coker, 1989, 1992; Coker and Fahey, 1993; Coker et al., 1993).

Catchment Description

Two thirds of the pasture and forest catchments have slopes 15° to 35°. The dominant geology comprises a gently (5-10°), SE-E dipping sequence of marine sands, mudstones and limestone (Kaiwaka Formation) up to 100 m thick. The Kaiwaka Formation is capped by layers of glacial period gravels, loess and volcanic ash (Fransen and Brownlie, 1996). Streams are fed by springs located at the basal contact of sandy and/or limestone units within the Kaiwaka Formation. The spring-fed streams maintain very stable low for long periods that are not much affected by storm events.

The steep hill country is prone to slip erosion which is triggered by storms in excess of 250 mm that frequent the east coast North Island on average 3 per decade (Page et al., 1994). Historical records document two storm-induced erosion events in the research catchments (Fransen and Brownlie, 1996). Cyclone Bola, in 1988, represents the largest rainstorm event in the region since records began in 1894. At Eskdale, 6 km south of the research catchments, Cyclone Bola produced 620 mm of rainfall in three days. The other largest storm, in 1938, produced 692 mm in four days at Tutira (12 km north of the study area; Page et al., 1994). In In the research catchments, significant slip erosion affected 0.9% and 1.2 - 1.4% of pre-dominantly pasture cover in 1988 and 1938 respectively (Fransen and Brownlie, 1996). Mean annual rainfall for 1994/ 95/ 96 was 579 mm , 994 mm and 1199 mm, respectively.

In 1970 - 71 the Pakuratahi catchment was converted from pasture and scrub to *Pinus Radiata* plantation forest. Harvesting commenced in January/February 1998.

Methodology

Hydrology

Automatic recording raingauges are stationed at the top (345 m a.s.l.) of the Tamingimingi catchment, and in the lower (21 m a.s.l.) Pakuratahi catchment near the forest boundary (Figure 2). Data from stream flow recording stations in the lower pasture and forest catchments were used to obtain specific yields. The hydrological record for the catchments commenced in 1993/1994.

Stream site selection

A total of six stream sites were selected in the pasture and forest catchments (Figure 2). The stream sections were straight to slightly meandering, with low channel gradients, and stream-banks comprising eroded alluvium (Table 1). In the Pakuratahi catchment two stream sites (P1, P2) were located in upper sub-catchments, and the third (P3) in the lower reaches of the Pakuratahi Stream. A weir and flow gauging station is located a further 200 m downstream from P3. In the pasture catchment, the lower Tamingimingi stream site (T3) was sited in an alluvial section and defined a similar catchment area as P3 for comparison. The other two pastoral stream sites were located upstream and define larger catchment areas compared to the upper Pakuratahi stream sites.

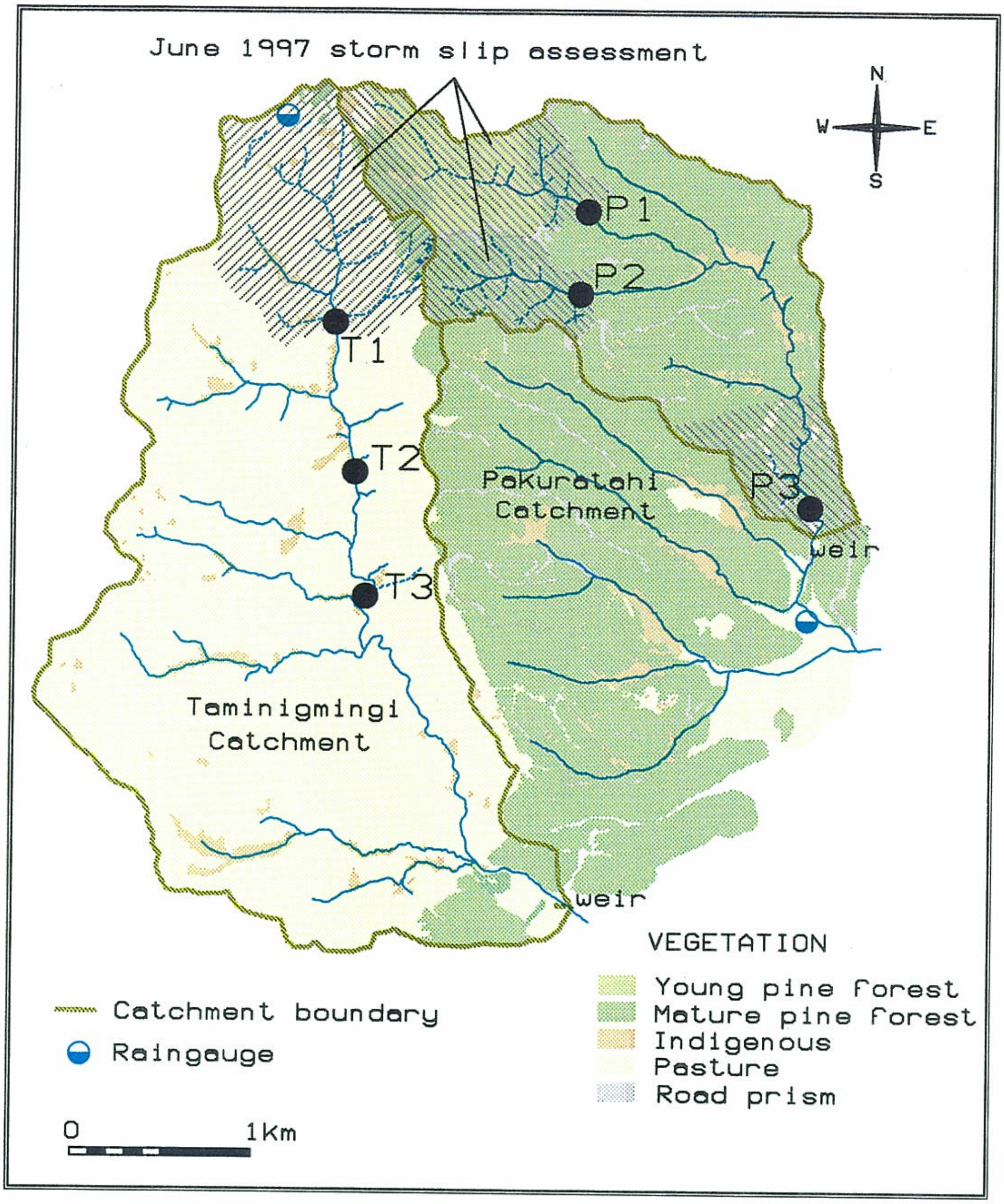

Figure 2 . Location of stream sites (filled circles) and sub-catchment areas (cross-hatched) assessed for sources of sediment. Permanent summer flow streams (solid line) and ephemeral streams (dashed line) are shown.

Channel profile measurements

Ten transects were installed at each stream site for measurement of channel profiles. Upper stream sites had transects set 6-7 m apart on average, and extended for 53-66 m along the stream (Table 1). The downstream sites (T3, P3) had wider spaced transects. Variations in the length of the shorter stream sections was due to a change to boulder-rapids upstream and downstream.

Table 1. Stream site transect configuration. P = Pakuratahi catchment; T = Tamingimingi catchment.

Site	P1	P2	P3	T1	T2	T3
Total length of section (m)	66	56	86	53	63	106
Average transect spacing (m)	7	6	10	6	7	12
Average width active* channel (m)	2.4	2.7	3.8	2.0	2.3	3.0
Area of channel section (m^2)	157	153	326	105	144	319
Channel gradient (degrees)	2	3	1	1	2	1
Total No. sample points	120-142	149-168	163-173	102-115	124-135	153-176

* - active channel includes flood zone

Transects were established by inserting steel stakes into the ground beyond the flood banks. Channel profiles (Figure 3) were surveyed by taking vertical readings at 20 cm intervals along a taut fibreglass tape attached between the stakes (modified after Ray and Megahan, 1978; Platts *et al.*, 1987). The tape was attached to a 10 kg spring scale (sensitive to 0.2 kg tension) at one end and a smooth grip clamp at the other end. The tape was clamped taut and then allowed to retract until the tension was satisfactorily stable. Tension was re-checked at the end of the survey. In subsequent surveys, it was necessary to achieve the same tension to ensure the same sag-tape profile would be obtained; so that changes in channel profile could be calculated with minimal error. The tape distance between stakes was also checked.

Observations were also made of the type of channel surface (bank, terrace, gravel bar, etc), classification of sediment size at the ground surface, and vegetation cover type (algae, grass, etc).

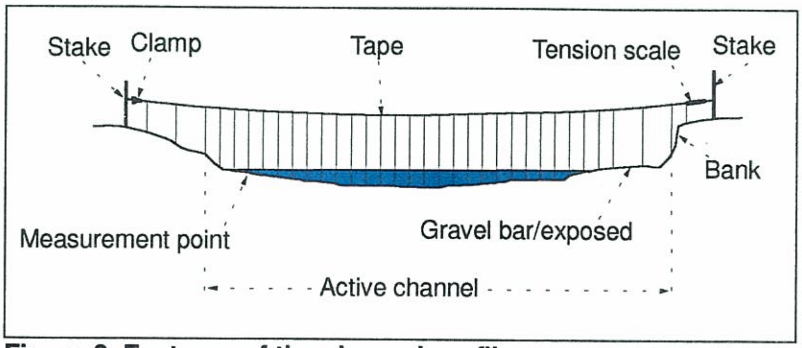

Figure 3. Features of the channel profile survey.

The transects were first set up in January (summer) 1997. Later surveys were carried out in July/August 1997 after the storms, and in November 1997.

Slip surveys

The comparative slip erosion assessment was focused mainly in the upper pasture and forest catchments defined by the T1 and P1/ P2 channel transects and the catchment boundary (Figure 2). Measurements were made of the dimensions of fresh slip scars, tree root-plate failures, and runout distant and termination points of their debris/sediment trails.

The survey covered 117 ha and 119 ha of the upper forest and pasture catchments, respectively. However, a 38 ha stand of eight-year-old pines was only partially surveyed due to the low canopy cover and high stocking rate of 700-800 stems/ha. Slip sites in the young stand were mainly located from the gully floor where debris/sediment trails could be followed to their source. Under the mature pine, slips were easily located under high canopy and lower stocking rate of 200 - 210 stems/ha.

Slopes adjacent the P3 channel transect site in the lower forest catchment (Figure 2) were also surveyed to determine slip derived sediment inputs to the stream channel and for future comparison with post-harvest impacts. Harvesting within this 34 ha area commenced in June 1998.

Table 2. Percentage slip erosion risk within 1997 slip survey areas (Figure 2).

Risk Category	Pasture catchment	Forest catchments			
	T1	P1 + P2	P1	P2	P3
Area (ha)	*118*	*116*	*74*	*42*	*34*
Very Low	21	17	18	15	49
Low	39	39	34	44	38
Moderate	21	14	15	12	9
High	15	17	18	17	3
Very High	4	13	14	12	1

Slip locations were plotted onto 1:2500 scale field maps. The slip sites were later digitised into a Geographic Information System (GIS) - TerraSoft™ - for storage and analysis. Slip scar length and width were entered into an associated database.

Slip erosion risk

A slip erosion risk classification was defined for the study catchments by combining map overlays of geology, soils, slope angle, slope aspect, and slip distribution of 1938 and 1988 storm events, and pastoral vegetation cover (Fransen, 1996). Using this classification, the area of slip erosion risk was determined for the 1997 slip survey areas (Figure 2). The P1 and P2 forest catchments have similar erosion risk potential for all categories except the *low* risk category, in which P2 has 10% greater area than P1 (Table 2). Compared to the pasture catchment, the forest catchments (PI & P2) have a greater potential for slip occurrence in the *very high* risk category, similar potential in the *high and low* risk category, and lesser potential in the *moderate* to *very low* risk category.

Results

Storm event analysis

Local landowners confirmed that slips mainly occurred after the July 1997 storm. In the upper Tamingimingi catchment, the total storm period rainfall was 159 mm in June and 285 mm in July. The maximum daily rainfall on the 2 June appeared to be evenly distributed over both catchments. However, during the July storm the maximum daily rainfall differed by 86 mm between the upper and lower catchments (Table 3). April and May were particularly dry months(Figure 4), but leading up to the June storm an average of 86 mm rainfall occurred over ten days. The June storm had an estimated return period of 1.5 to 2 years (Tomlinson, 1980). For the July event, return period estimates were 5 years for the upper catchment and 1.5 years in the lower catchment. An additional 60 mm of rainfall occurred in the 26 days between storm events.

Table 3 . Summary of 1997 storm rainfalls.

Period	Mean Total (mm)	Daily Maximum		Difference Daily Max.	Daily Mean
		Upper catchment	Lower catchment		
1 - 3 June	150	118	104	14	111
30 June - 4 July	233	183	97	86	140

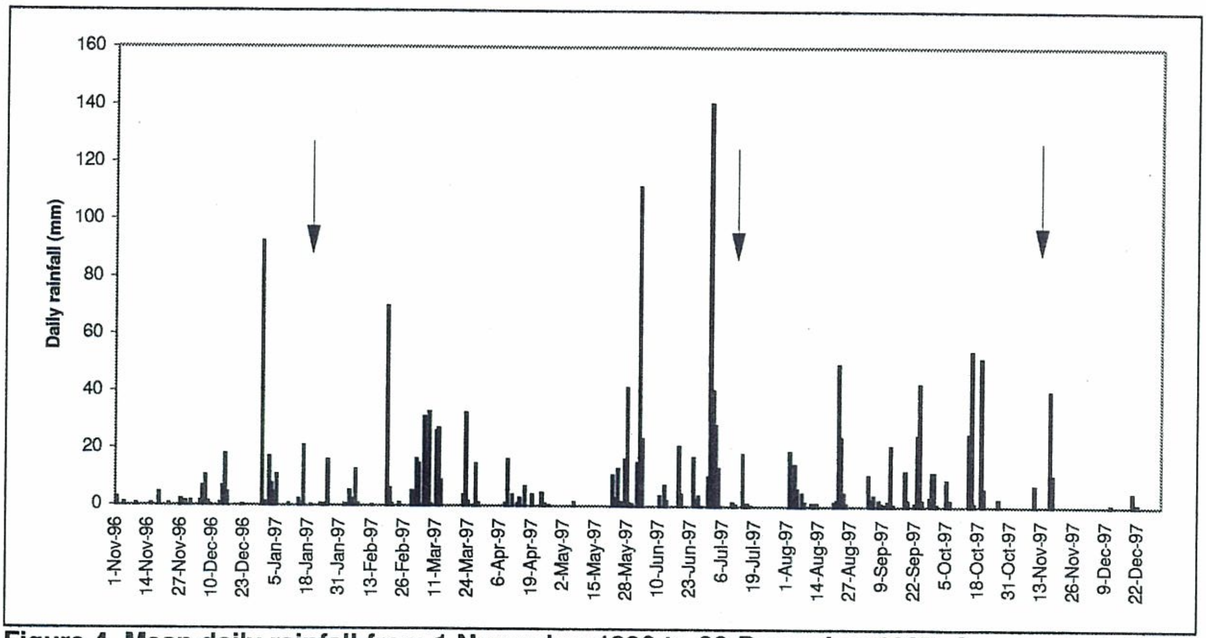

Figure 4. Mean daily rainfall from 1 November 1996 to 30 December 1997. Arrows depict date of channel profile surveys.

Storm flows were gauged at weirs within each catchment. Specific peak flow yields in the Pakuratahi Catchment on the 2 June and on the 1 July were respectively 46% and 31% less than peak flows in the Tamingimingi catchment (Table 4, Figure 5). The runoff response ratio (peak flow divided by average daily flow) in the Tamingimingi catchment, indicates quicker runoff response from the pasture catchment than the forest catchment. In July the runoff response - in the pasture catchment -was slower than in June; whereas in the forest catchment the runoff response was slightly faster.

Table 4. Storm flow characteristics.

Catchment	Pasture		Forest	
Date	2 June	1 July	2 June	1 July
Peak Flow (l/s)	5620	7712	1285	2255
Average Daily Flow (l/s)	1958	3442	704	1199
Specific Peak Flow (l/s/km^2)	702	964	378	663
Response ratio	2.87	2.24	1.82	1.88

Channel changes

Data analysis focused on changes in the stream bed (Figure 3), which is a zone of sediment deposition and scour, and a habitat for aquatic life.

From January to July 1997, stream scour occurred in the pasture and upper forest sites, and noticeable stream filling in the lower forest catchment site (Figure 6 & 7). No significant differences in mean change in stream bed level occurred between the pasture stream sites and the P2 forest site, which had a lower mean change (Figure 8). However, the mean change in level at the P1 forest site was significantly less than that for the pasture sites and the P3 forest site, but not the P2 forest site.

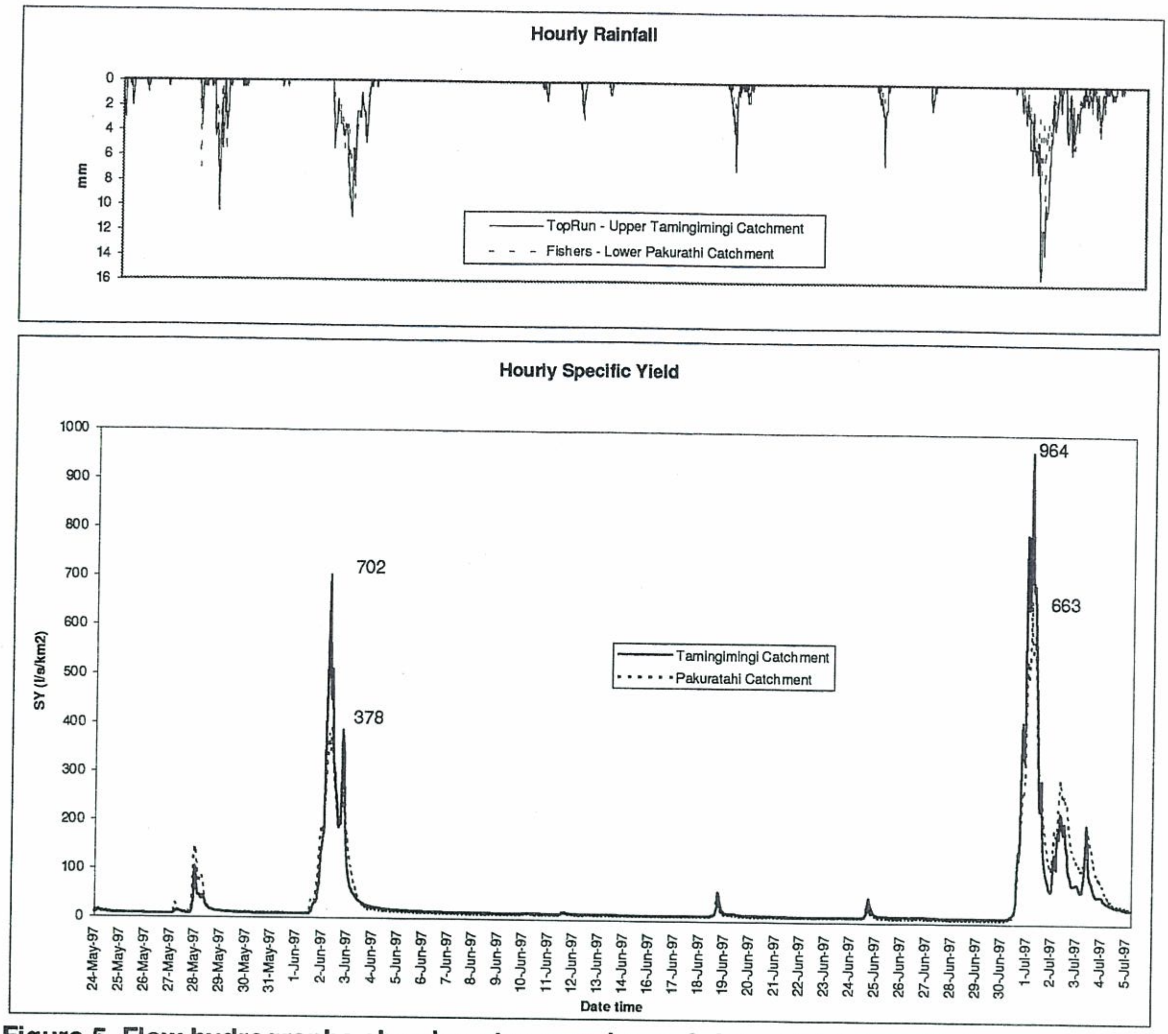

Figure 5. Flow hydrographs showing storm peaks on 2 June and 1 July 1997

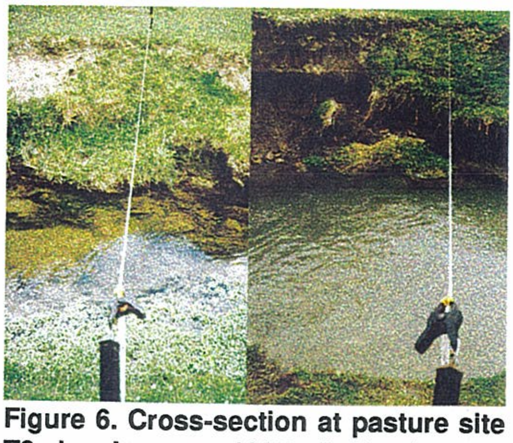

Figure 6. Cross-section at pasture site T3 in January 1997 (left) showing typical channel conditions since 1993, with abundant watercress and algae. To the right is the effect of the post-July 1997 storm showing renewed bank collapse and low water clarity, due to suspension of fine solids in the stream.

Figure 7. Cross-section at lower forest catchment site P3 in January 1997 (left) showing typical channel conditions; abundant watercress and algae (similar to pasture site, T3). Post-July 1997 storm channel widening and sedimentation is evident.

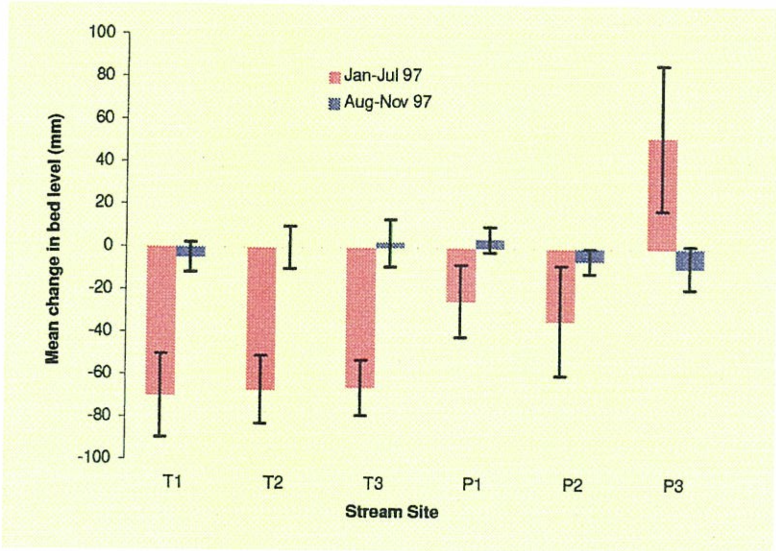

Figure 8. Mean change (with 95% confidence interval) in channel profiles in the Tamingimingi pasture (T1-T3) and Pakuratahi forest (P1-P3) catchments.

From August to November 1997, mean change in stream bed levels were small and not significantly different between sites. This was attributed to low rainfall during this period, and absence of major storms and associated erosion and sediment inputs to the channel system.

Bank erosion occurred along all stream channels (pastoral and forest streams) as slumps or bank collapses, and as intermittent lateral scour. The volume of sediment derived from upstream bank erosion was not measured. However, the observed extent of bank erosion did not greatly differ between pastoral and forest streams.

Slips

Pasture covered 107 ha (90%) of the area surveyed in the Tamingimingi catchment. In the upper Pakuratahi catchment, 62 ha (52%) was covered in 26 year old pine, and 38 ha (34%) in 8 year old pine.

Slip density was highest in the mature forest with 131/km^2 compared to 54/km^2 in the pastoral catchment (Table 5). In the eight-year-old pine stand slip density was considerably less at 13/km^2. However, only five slips were found within the densely stocked stand.

Under the mature forest stands slips were usually located between the trees. Approximately 16% of slope failures were associated with toppled trees/windthrow and root plates.

The total area in slips was similar in both catchments (Table 1), and is explained by the greater average area of a slip in the pasture catchment than the forest catchment (Table 6). However, the percentage area in slips was slightly greater under the mature forest than under pasture land.

Erosion risk analysis revealed that the mature forest stand had a higher proportion (20 m^2/ha) of slips in the *very high* risk category compared to pasture which had no slips in this category (Table 7). The mature forest also had higher proportions of slips in the *moderate and low* risk categories. In the *high* risk category the pasture area had a slightly higher proportion of slips than the mature forest.

Table 5. Slip erosion statistics for the July 1997 storm event.

Tamingimingi catchment T1 = 118.5 ha	Area (ha)	Number of slips	Slips per km^2	Total area in slips (ha)	% area in slips
Pasture	106.9	58	54	10.0	0.09
26 yr old forest	6.5	4	62	0.7	0.10
Indigenous	3.2	1	-	0.04	0.01
Road	0.6	-	-	-	-
Other	1.2	-	-	-	-
Pakuratahi catchment P1+P2 = 116.4 ha					
Pasture	3.9	-	-	-	-
26 yr old forest	62.5	82	131	9.5	0.15
8 yr old forest	38.4	5	13	0.7	0.02
Indigenous	6.1	7	115	0.3	0.04
Road	5.3	5	94	1.8	0.34
Other	0.2	-	-	-	-

Table 6. Summary statistics of slip scar area.

Tamingimingi catchment	Average area (m^2)	Std Dev.	Min	Max
Pasture	19	27	0.5	150
26 yr old forest	16	14	3.0	36
Pakuratahi catchment				
26 yr old forest	12	12	1	72
8 yr old forest	13	21	1	50
Indigenous	5	5	1	12
Road	36	19	20	63

Table 7. Area of risk categories for pasture and mature forest and percentage of slips in each category. Risk categories defined in Fransen (1996).

Risk Category	Pasture (T1)				Mature forest (P1 + P2)				Diff.	Young forest (P1)	
	Area (ha)	%	Area in slips (m^2)	m^2/ha	Area (ha)	%	Area in slips (m^2)	m^2/ha	m^2/ha	Area (ha)	%
Very Low	22	21	188	8	9	13	26	3	-5	6	16
Low	42	39	301	7	22	36	353	16	9	13	34
Moderate	23	21	191	8	9	15	147	16	8	7	18
High	16	15	361	23	12	20	221	18	-5	7	18
Very High	4	4	0	0	10	16	199	20	20	5	13
	107				62					38	

Slip debris inputs

An important factor impacting on sediment levels in streams is the volume of sediment entering the channel system from slip areas. Slip volumes estimated for each survey area are shown in Table 8.

Pastoral slopes in the catchment above T1, generated 97 % of the total slip volume. Above the P1 forest site, 70 % of the slip volume was generated under the mature forest. Above the P2 forest site the mature forest contributed 79 %, and roadside slips - 17 %, of the total volume. In the lower forest catchment, 71 % of the slip scar volume was associated with road-side slope failures. A 600 m long mid-slope road was constructed in 1982 to access areas for production thinning operations. Runout of slip debris reached distances of 120 m, terminating on a range of slope forms (Table 9 and 10). Long debris paths did not always terminate in the channel. Forty-two percent of slip debris travelled over 20m on pasture slopes compared to 49 % on mature forest slopes.

Fewer land slips entered the channel system from pastoral slopes than from the forested slopes (Table 10). Slip debris that terminated on gully floors (having no distinct channel features) had negligible quantities of sediment delivered to the channel system. As the gully floors are natural sites of sediment accumulation, it is likely that continuing supplies of slip debris and sediment will be stored here and entrapped by re-establishing plants.

The volume of slip debris and/or sediment entering channels cannot be directly measured with certainty as it usually relies on detailed measurements of the volume of the slip scars and slope deposits, and calculating their difference. From visual estimates, the proportion of slip material remaining on slopes averaged 69 % ± 14 % ($P < 0.05$).

From Table 8, and a lower limit of 55 % retention of debris on slopes, the estimated total volume of slip debris per

Table 8. Volume of slip debris from all land-use/vegetation classes, July 1997.

Volume	Pasture - T1	Forest - P1	Forest - P2	Forest - P3
Total (m^3)	909	206	820	817
Area (km^2)	1.18	0.74	0.42	0.34
Unit area (m^3/km^2)	770	278	1952	2403

Table 9. Percentage of slip runout distances, July 1997.

Distance class (m)	< 5	6 - 10	11 - 20	21 - 40	41 - 80	81 - 120
	Percent of slips					
Pasture (T1)	46	12	9	7	21	5
Mature Forest (P1+P2)	38	13	14	18	15	1

Table 10. Percentage of slip debris terminating on landforms in the catchment above T1, P1, P2 sites and in the vicinity of P3 site.

Landform	Pasture	Mature Forest		
	T1	P1	P2	P3
channel	29	54	47	50
gully floor	20	7	24	0
gully floor pond	5	0	0	0
road ditch				22
track	7	7	25	3
hillslope	39	32	3	25

unit area of catchment entering the channels was: 3.4 m^3/ha for the entire pasture catchment (T1), and 1.2 m^3/ha and 8.7 m^3/ha for the entire P1 and P2 forest catchment respectively. The contribution from the pasture only and mature forest areas differed slightly than for the entire catchment, with 3.7 m^3/ha for the pasture (T1), 2.6 m^3/ha for P1 and 7.8 m^3/ha for the P2 mature forest.

In the lower Pakuratahi catchment at least half the slip debris flowed into an ephemeral gully that exited into the Pakuratahi stream 80 m upstream of the transect site (P3). For 1 km of stream reach above site P3, an estimated 10.7 m^3/ha of debris entered the Pakuratahi Stream for the 34 ha survey area. Debris inputs for a further 2 km upstream were insignificant, because slip and rock falls were infrequent (total of 20) and had low volumes. Half of the slip debris terminated at the foot of the slope. The other half of the debris, from rock falls, appeared to have been transported only a few metres from the point of entry into the channel.

Discussion

It was an unexpected result that more slips occurred under mature forest than under pasture during the July 1997 storm. No published accounts have been found that describe a similar result. Previous researchers in New Zealand have found that soil slip erosion is very much less under pine plantations or indigenous forest than under grazed pasture and reverted scrub open to livestock (Phillips *et al.* 1990; Hicks, 1991; Marden *et al.*, 1991). This study corroborates these earlier findings for young pine stands less than 10 years old.

The differences in slip erosion between mature forest and pasture reported here could be due to several factors:

- inherent differences in the stability of slopes within each catchment
- rainfall characteristics and catchment wetness
- vegetation cover characteristics

Erosion risk

The erosion risk assessment suggests that the upper forest catchments were more susceptible to slip erosion than the upper pasture catchment because of the greater proportion of catchment area in the very high risk category (Table 2). Therefore it could be expected that, for any storm event, more slips could occur within the forest catchments. This certainly was the result for the July 1997 storm, which had 20 m^3/ha of slips in the very high risk category. That there were no slips in this category in the upper pasture catchment represents a disproportionately low slip erosion response on these slopes (Table 7). This suggests that factors other than those represented in the erosion risk mapping were important in triggering slips.

Rainfall characteristics and catchment wetness

Rainfalls of 250 mm in 2-3 days, or greater than 100 mm in 24 hours, is the approximate threshold value required to initiate significant erosion in East Coast hill country (Hicks, 1989; Page *et al.*, 1994). This threshold was exceeded in the two 1997 storm events in the Pakuratahi - Tamingimingi catchments (Table 3).

A large difference in rainfall between the upper Tamingimingi and lower Pakuratahi catchments suggests that there was a rainfall gradient during the July storm. However, any rainfall gradient developed during the course of the storm did not appear to influence slip densities;

especially as the mature forest was up to 1 km further from the raingauge than the pasture and young pine stands (Figure 1).

Crozier and Eyles (1980) found that size and effectiveness of a slip-triggering storm was related to pre-storm soil moisture conditions and preceding climatic conditions. The June storm did not cause any noticable slippages on slopes. This was likely influenced by dry antecedent soil conditions resulting from low rainfalls during April and May. The 150 mm of storm rain plus 86 mm ten days prior to the June event was probably insufficient to recharge the soil to generate pore-water pressures required to initiate slope failure. However, rainfalls through June continued to increase soil moisture levels.

Specific storm yields (runoff rates) from the greater catchment were higher for pasture than from the forest (Figure 5). The expected effect of a forest cover is to limit the volume of storm runoff, through greater wet-canopy evaporation rates and greater soil moisture storage capacity. However, it appears that during the July storm the soil water storage capacity was exceeded, and positive pore-water pressures developed sufficient to generate slippage. Both pasture and forest soils were still very wet, to the point of saturation, at the time of the field survey in mid-July. On forest slopes, trails of disturbed litter were indicative of concentrated overland flow. Some of these runoff trails were sourced from ridge-spur machine tracks formed during production-thinning operations in the 1980's. These tracks were likely to have compacted soil and poor infiltration.

Vegetation characteristics

Slips under the mature forest stands were usually located between the trees, with approximately 16% of slope failures associated with toppled trees/windthrow and root plates. The low stocking rate may partly explain the higher slip density under the mature forest compared to the young pine stand. In the middle ground between the well-spaced (6-7 m) mature trees, roots are likely to be smaller and sparse and lack sufficient strength to re-enforce the soil. Phillips and Watson (1994) show that most tree roots are concentrated within a 2 m radius of the trunk, but with the main laterals extending up to 10 m. Another factor potentially contributing to slope failure is increased permeabilities and pore-water pressures in areas around old tree sites. The decayed stumps and roots of production-thinned trees could act as conduits for storm water. Ground cover plants were sparse; there is a relatively high concentration of goats within the Pakuratahi Forest compared to other forests in the region. This lack of ground cover potentially reduces the effective protection against slope failure.

The proportion of *very high* and *high* erosion risk was not significantly greater (2-3%; Table 7) under the mature pine than the young pine, suggesting that the younger stand had a significant effect in mitigating slip erosion.

Fransen and Brownlie (1996) reported very low (22/km^2) slip densities in 17-year- old forest in the Pakuratahi catchment after Cyclone Bola in 1988. The slips mapped from aerial photographs were only detected within grassed and windthrown areas in the forest. Considering the number of slips during the June 1997 storm, it is now suspected that a greater number of slips were initiated under the forest canopy during Cyclone Bola.

The upper pasture catchment in July 1997 was not severely affected compared to major storms where slip densities were 2-3 times greater, with 184 slips/km^2 for the 1938 storm and 177 slips/km^2 for Cyclone

Bola. In the pre-forest upper catchments the 1938 storm slip densities were 287/km^2 and 385/km^2. After Cyclone Bola the slip density in the area now planted in young pines was 228/km^2 which was then under pasture (Fransen and Brownlie, 1996). Rainfall for these major storms events were in the order of 600 mm in 3 - 4 days.

Sediment supply and channel changes

The sediment supply to and within channels and the available stream power to transport sediment determines whether scour or fill will occur. Stream power is a function of the sediment loading and discharge (Leopold et al., 1964). The July 1997 storm event generated slips that contributed variable amounts of sediment to the channels. The higher specific discharge of the Tamingimingi Stream (Figure 5) indicates that the available power to erode and transport sediment was greater, compared to the Pakuratahi Stream .

It is apparent that the lower volume of slip debris, and the greater volume of storm runoff entering the middle to upper reaches of the pastoral Tamingimingi Stream, resulted in deeper scouring of the active channel (Figure 10). Both research and field observations have shown that the rate of sediment detachment is reduced with increasing concentration of sediment transported within a channel (NSERL, 1989).

Scouring at the P2 forest site (while not significantly different to the T1 pasture site) was less and appeared to be influenced by the higher input of sediment from slips (Figure 10). However, the shallower scouring at the P1 forest site had lower total slip volumes than the P2 site. The result may be confounded by the higher proportion of young forest cover (52%) than mature forest cover (34%) within the P1 catchment and potential differences in runoff. When only the mature forest contribution is considered, the effective sediment supply to the streams above P1 and P2 was similar (109 m^3/km and 113 m^3/km).

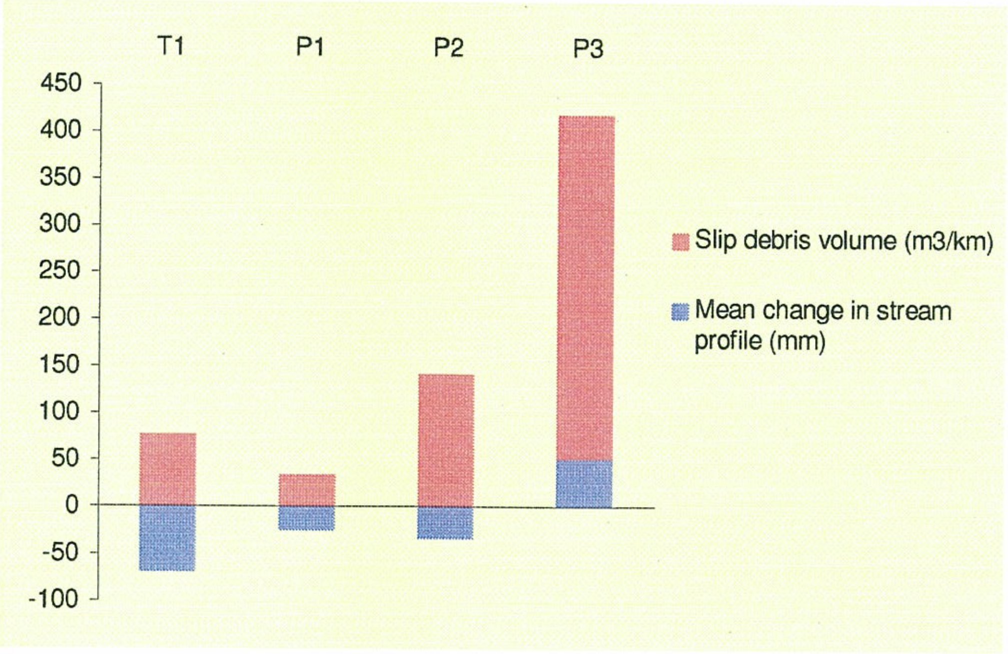

Figure 10. Comparison of volume of slip debris per unit length of stream with change in channel profile. Channel lengths were 5.3, 2.7, 2.6, 1 km for T1, P1, P2, P3 respectively.

Conclusions

Wet antecedent conditions and two storms in June and July 1997 culminated in slip erosion in pasture and 26 year-old-pine forest catchments in the Tangoio District, central Hawke's Bay.

The overall density of slips for the 1997 storm event was 2 - 3 times less than for major historical storm impacts for catchments that have remained in pasture and catchments converted from pasture to forestry.

In contrast with previous research findings, a greater level of slip erosion occurred in catchments under mature plantation forest than under pasture. This was attributed to a larger proportion of the mature forest area in the high to very high erosion risk category (as defined by historical slip distribution and geological, soil, slope steepness and aspect characteristics) than the pasture area. However, for the July 1997 event there was a disproportionately lower number of slips than expected within the pasture catchment in the very high erosion risk category.

Stream sediment levels - at five sites - were scoured 20 to 70 mm in the pasture and upper forest catchments. The lower forest stream site had significant sediment fill to an average 50 mm above the previously surveyed level.

The pasture stream sites had the deepest scouring of the active channel. This was attributed to the lower density of slips, the lower total volume of slip debris entering the pasture stream, and the greater volume of storm flow, than the upper forest stream sites. At the lower forest stream site, 70 % of sediment inputs was derived from road-side slope failures of a 15 year old road.

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