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Interception and throughfall in a regenerating stand of kanuka *(Kunzea ericoides* var. *ericoides),* East Coast region, North Island, New Zealand, and implications for soil conservation

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Abstract

Throughfall and stem flow were measured for a regenerating stand of kanuka (*Kunzea ericoides* var. *ericoides),* on the East Coast of the North Island, New Zealand. The site has an annual rainfall of nearly 1800 mm. Measurements throughout the 3 years of the study were made at about monthly intervals, but for the last 18 months some throughfall troughs had small tipping buckets attached, the tips and rainfall being recorded by a datalogger. Throughfall was 57% of gross rainfall, leaving 42% unaccounted for as interception loss; stemflow was about 1% of rainfall. Relationships between throughfall and rainfall on both a monthly basis and for individual storms are presented. There is some evidence that throughfall is higher in winter than in summer, so summer interception losses are higher. Interception loss as a percentage of rainfall is high compared to other interception studies of woody vegetation in New Zealand. The results are consistent with other studies if the annual losses are viewed in terms of annual rainfall, and the relationships between storm interception loss and rainfall are comparable with those for other vegetation communities. For the 3 years of the study, an annual interception balance for this kanuka stand at Waimata was: Rainfall (1780 mm) = Throughfall (1020 mm) + Stemflow (20 mm) + Interception Loss (740 mm). An estimate of interception loss for individual storms (in mm) is:

$$\text{Interception loss} = 0.32*\text{Rainfall} + 2.$$

Because of kanuka's substantial rainfall interception and below-ground

biomass, retaining existing areas of kanuka and allowing the passive reversion of severely eroding farmland to kanuka could provide comparable protection to a closed-canopy stand of *Pinus rcidiatci* for hill country areas in need of soil conservation and erosion prevention.

Introduction

When studies following Cyclone Bola in 1988 compared landslide density with vegetation type, it was shown that stands of mature regenerating kanuka (*Kunzea ericoides* var. *ericoides*, or white tea tree) provided a high level of protection against storm-initiated landslides (see, for example, Marden and Rowan, 1993; Bergin *et ciL*, 1995). This relationship was particularly strong for East Coast North Island hill country underlain by Tertiary sedimentary bedrock, where landsliding is typically shallow and translational (Marden *et al.*, 1991). In this region kanuka is a widespread precursor of tall forest and is also the primary coloniser of landslide scars and abandoned pastoral hill country. Recently, there has been increasing pressure to convert areas of regenerating kanuka to exotic plantation forest species, including radiata pine (*Pinus radiata).*

Considerable scientific data show that exotic species provide effective protection against the initiation of shallow landslides and other forms of mass movement during large rainfall events (O’Loughlin, 1984; O’Loughlin and Zhang, 1986; Marden *et ai,* 1991). However, little research of a similar nature has been undertaken on indigenous species, including kanuka. In recognition of this, a research programme was initiated to gather process- based information for evaluating the performance of kanuka in stabilising erosion-prone hillslopes. Research so far has been to establish relationships between stand dynamics and landslide density (Bergin *et ai,* 1993, 1995), to determine the contribution of live roots to soil reinforcement (Ekanayake *et ai,* 1997), and to define the rate of deterioration of root- wood strength following clearfelling (Watson *et aL,* 1997), To extend that work, there was a need to determine the water balance of a kanuka stand and how it might influence slope stability.

There are no published data on the water balance of kanuka stands in New Zealand, but information for a similar species, manuka *(Leptospennum scoparium),* is available for a stand in a regenerating forest catchment at Taita in the lower North Island (Aldridge and Jackson, 1968), and for a stand at Puketurua in Northland (Blake, 1965). Therefore, this study was undertaken to measure rainfall interception to provide information on how a closed-canopy kanuka stand influences the site water balance and the implications for soil conservation. The site chosen for this work was that used by Ekanayake *et al.* (1997) and Watson *et ai* (1997) on the East Coast of the North Island, and is 30 km south-east of

Mangatu Forest where similar work had been carried out in *P. radiata* plantations (Pearce *et al.*, 1987).

Site description

The south-facing study site is located at Kaharoa Station in the Waimata Valley (38° 30’ S, 178° 04' E), approximately 20 km north of Gisborne City. The site is representative of marginal pastoral hill country on Tertiary sedimentary bedrock. When abandoned, such hill country reverts to dense, closed-canopy, indigenous scrub.

The chosen study site is a closed kanuka stand with trees 16-40 years old. The mean height of trees in the stand is 13 m and the stand density is 3900 stems per hectare. Understorey species, where present, include *Cyathodes juniperina* and *Leucopogon fasciculatus* (mingimingi), *L. scoparium* (manuka), and *Coprosma rhamnoides* (twiggy coprosma), and form a dense layer 1.5-2.5 m above ground level. In parts of the stand where the understorey has been grazed, the groundcover is a low grass sward.

Soils are typically stony, 3 m deep, and vary from Orthic Recent Soils and their intergrades to Brown Soils (on well-drained sites) and Gley Soils (on poorly-drained sites). The soils are typical of a slope that is being eroded or has received sediment mainly as a result of slope processes (Hewitt, 1992), and correlate with the Inceptisols of Soil Taxonomy (Soil Survey Staff, 1992). Ground slope is about 23 degrees.

The climate of the region is warm, temperate, and maritime with moist summers and cool wet winters — snow falls are rare. Average rainfall for the region is just over 1600 mm a year. The 1951-1980 normal (a normal is the average rainfall for a 30-year period) for a long-term site in the Waimata Valley 5 km from the study site is 1631 mm (New Zealand Meteorological Service, 1984). Average monthly rainfall is 100 mm in summer and 160 mm in winter.

At Kaharoa, located 1 km from the study site, the 1951-1980 normal is 1611 mm (New Zealand Meteorological Service, 1984). Annual rainfall during 1984-1997 ranged between 1040 and 1890 mm with a mean of 1470 mm (J. and S. Hall, Kaharoa, unpublished data). The rainfall measured since 1980 is lower, and is consistent with an average decrease (about 5%) at 7 sites within 30 km of Kaharoa when their 1951-1980 normals (New Zealand Meteorological Service, 1984) are compared to 1961-1990 normals (Tomlinson and Sansom, 1994). Monthly rainfall at Kaharoa can be highly variable and between 1984-1997 it ranged from 2 to 560 mm. Lengthy periods with little or no rain are common during January to April (midsummer to late autumn).

This region has a history of extreme floods, generally resulting from high-intensity rainfall during extra-tropical storms. There have been 29 extreme floods since 1900, with regional landsliding associated with 6 of these events (Kelliher *et aL,* 1995) — Cyclone Bola in 1988 being the most recent notable event.

Data collection

Measurements began in February 1995 and continued until February 1998. Gross rainfall was measured initially using a Belfort chart-recording raingauge located in a clearing 100 m from the interception plot site. In June 1996 this raingauge was replaced with a tipping-bucket gauge wired to a Campbell CR10 datalogger. An adjacent manually- read, 127-mm diameter, standard meteorological raingauge was used to check the reliability of the rainfall record, and data from the recording raingauges have been corrected to the catch in that raingauge. Rainfall data have also been checked for reliability against the daily rainfall recorded at Kaharoa.

Throughfall under a canopy is highly variable from point to point, especially at drip points on branches, and samples from networks of raingauges tend to have a very high scatter about the mean. For example, throughfall samples measured by Rowe (1975) using standard raingauges often had coefficients of variation of over 50% of the mean. There are examples where over 30 raingauges would be needed to obtain a reasonable estimate of mean throughfall using standard raingauges (Czarnowski and Olszewski, 1970; Peterson and Rolfe, 1979). A study at Taita in New Zealand has shown that it was preferable to use trough gauges made from PVC household guttering to measure throughfall instead of standard 127-mm diameter raingauges (Aldridge and Jackson, 1968). That and subsequent studies using4 to 11 troughs (1.8 m by 0.1 m) gave adequate sampling (Aldridge, 1968; Aldridge and Jackson, 1973; Jackson and Aldridge, 1973).

For this study throughfall was collected in 15 troughs placed below the canopy. Each trough was 5~m long and made from PVC household guttering; the total plan area covered was 8.4 m^2. Where there was an indigenous understorey, 5 troughs were set up beneath the understorey, 50 cm above the litter to avoid ground splash, with another five troughs, horizontally offset, positioned between the understorey and the canopy, about 2 m above ground level. Five troughs were installed between 1,5-2 m above ground where there was no understorey, only a grass sward. Throughfall collected from each trough was stored in a separate drum, the amount in each drum being measured at approximately monthly intervals.

In June 1996, 9 of the troughs (3 of each set of 5) were individually equipped with tipping-bucket mechanisms designed and built at Landcare Research, Lincoln. These mechanisms (bucket capacity 500 ml per tip) were wired to the datalogger connected to the tipping-bucket raingauge, and were calibrated for each storm period by dividing the total throughfal! collected during the storm by the number of tips recorded. Data are missing for a period when the cabling was stolen.

Stemflow was collected from 22 trees located within one 10 m x 10 m plot. These stems were representative of the 65 stems in the plot; diameters ranged between 2 and 20 cm. On each stem, lead strips were moulded into a U-shaped trough and spiralled around the stem to catch the stemflow, which was led off into individual containers. Measurements began in March 1997. An estimate of stemflow for the plot as a whole was obtained by multiplying the average volume collected per stem by 65 and converting the result to mm depth.

Statistical tests

All statistical tests have been carried out at the *5%* level of significance. Tests for significance of regression relationships and t-tests were those in the Quattro Pro spreadsheet package, while tests for differences between regression relationships followed procedures in Freese (1967).

Results

Gross rainfall

At Kaharoa, rainfall was 1285 mm in 1995, 3 825 mm in 1996, and 1765 mm in 1997, giving an annual average of 1625 mm. This compares well with the 1951-3980 annual rainfall normals for Kaharoa (1611 mm) and Waimata Valley (1631 mm) and indicates that rainfall over the study period has been about normal. Monthly rainfall totals ranged between 20 and 354 mm, with 9 am to 9 am daily totals of up to 135 mm.

At the interception site, total rainfall for the duration of the study was 5340 mm, about 9% more than at Kaharoa. Regression analyses on the sampling period measurements, show there were very close correlations (R^2 > 0.93) between the various raingauges, and also between daily totals from the study area tipping-bucket raingauge and the daily manual totals for the Halls' gauge.

For the analysis of storm data, 87 useable events ranging in size up to nearly 250 mm were identified for the period mid-November 1996 to mid-February 1998. A conservative criterion for separating storm events was 12 hours without rain being measured by the tipping-bucket recorder. This value has been used in a number of other studies (e.g., Jackson, 1975; Rowe, 1983). Although this period is longer than the 3.25 hour interval for drying out of a *P. radlata* canopy found by Kelliher *et al.*

Table I - Total rainfall (Rf in mm) and throughfall (Tf in mm) collected by the troughs for the study period together with 95% confidence limits in parentheses

	Below canopy - above glass (G)	Below canopy - above understorey (C)	Beneath underslorey (U)
Trough ID	W02 W12 WI3 W14 W15	W01 W04 W06 W08 W10	W03 W05 W07 W09 W1 1
Throughfall	3080 2570 2430 3380 2760	3130 3010 3100 2620 2890	3410 4960 2470 2600 3730
Mean	2800 (400)	2950 (260)	3430(1250)
Rainfall	5340	5340	5340
Tf/Rf (%)	58 48 46 60 52	59 56 58 49 54	64 93 46 49 70
MeanTf/Rf (%)	53	55	64

(i 992) using wetness sensors, it goes some way towards ensuring that the canopy had dried out completely, as there may have been low-intensity rainfall after the last raingauge tip for an event and before the first tip of the next event.

Throughfall

Table I summarises throughfall collected by the troughs for the 3 years of the study. Troughs above the grass (Set G) and above the understorey (Set C) are essentially similar sets, both sampling throughfall passing through the kanuka canopy only, but they are considered separately here. Troughs of Set U collected throughfall that passed through both the canopy and the understorey.

The extremely variable nature of throughfall is illustrated by the wide confidence intervals calculated for the means of the sets of troughs. Five troughs were adequate to obtain a reasonable estimate of mean throughfall for Sets G and C, with respective standard errors of the mean being 5.1% and 3.2% of their means. The understorey set was under-sampled, as the standard error of the mean for this set, 13% of the mean, reflected a wider range in throughfall collected in the troughs.

The surprising result is that mean throughfall collected from the understorey troughs (Set U, 3430 mm) was higher than that from the sets above the grass (Set G, 2800 mm) and above the understorey (Set C, 2950 mm) (Table 1). There were no obvious visual differences in the upper canopy above the Set U troughs that could explain this phenomenon. The spread of the throughfall collections from the understorey set was, however, considerably greater than for the other two sets of troughs having both the highest and lowest trough collections in the full suite (Table 1). Two-sample t-tests indicated that the throughfall from any set was not significantly different from another set. Average throughfall, therefore, for this kanuka stand is taken as the average of the 15 troughs — 3060 (± 350) mm or 57 (±7) % of rainfall, and the standard error of the mean of all the troughs was 5.4%. In an average rainfall year, say 1780 mm at the study site, throughfall would be 1020 ± 120 mm.

Linear regression analysis showed a highly significant relationship existed between measurement period (approximately monthly intervals), throughfall (Tf in mm) and rainfall (Rf in mm), the relationship explaining 93% of the variance in the data (Eqn. 1 with 95% confidence limits in parentheses; Fig. I). Almost identical, and not significantly different, equations were derived for summer (October to March) and winter data (a test for common slopes gave F = 0.77, d.f. =32).

$$Tf = 0.73(\pm 0.07)*Rf - 22.0(\pm 12.9) \qquad r = 0.964, n = 34 \text{ pairs (i)}$$

300 1

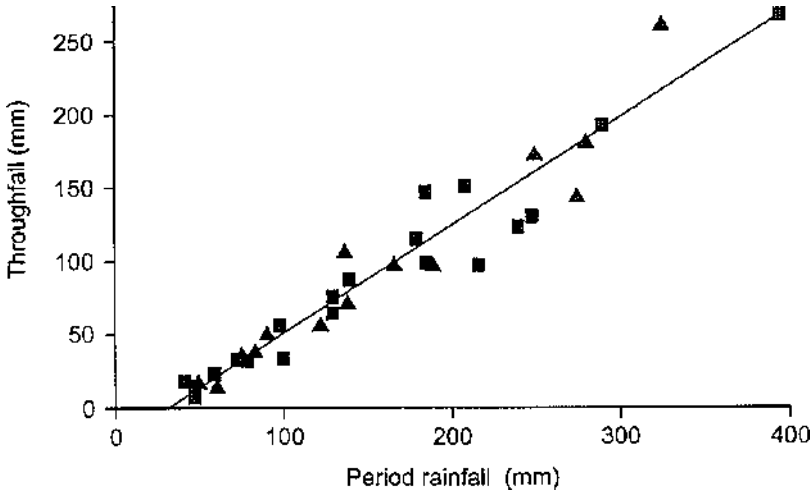

Figure 1 — Relationship between period (approximately monthly intervals) rainfall and throughfall for a kanuka stand at Waimata. Squares = winter; triangles - summer.

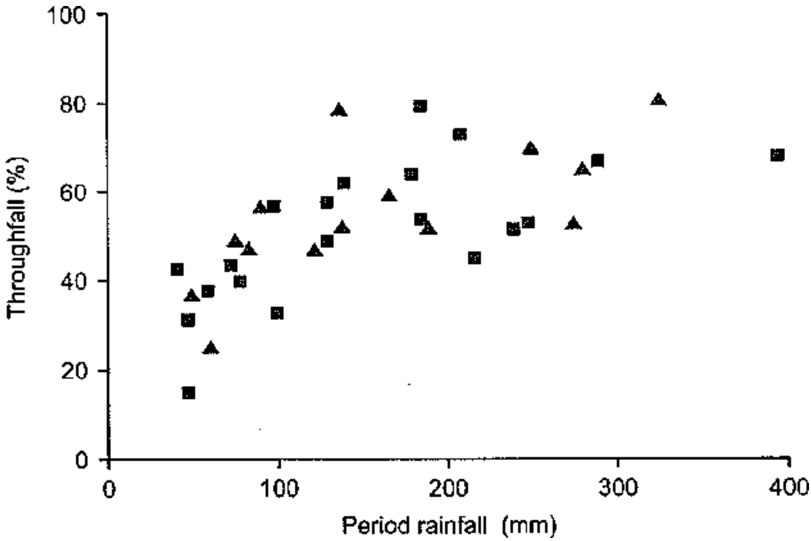

Figure 2 — Relationship between period rainfall and throughfall as a percentage of rainfall for a kanuka stand at Waimata. Squares = winter; triangles - summer

When plotted as a percentage of rainfall, throughfall exhibits the curvilinear pattern typical of other studies (Fig. 2). Again, no seasonal differences were apparent in the data, at least at the time scale of the measurement period.

Storm throughfall

Data are available for 87 storms. Average rainfall in the 46 winter (April—September) storms was 23.7 mm and for the 41 summer storms was 23.0 mm. For various reasons, mainly mechanical, only 3 troughs with tipping- bucket recorders (W03, W09, W13) showed consistent relationships (as demonstrated by mass curve analysis) between storm throughfall and storm rainfall . These 3 troughs under-represented the average plot throughfall by about 7.5%. Regression analyses on the year of data available for each of these troughs showed highly significant relationships between storm throughfall and storm rainfall (Eqns 2 to 4) (Fig. 3 for W09):

Tf =	0.73(±0.02)*Rf - 1,8(±1.0)	W03, r = 0.994, n=80	(2)
Tf =	0.66(±0.02)*Rf- 3.1 (±1.1)	W09, r = 0.988, n=87	(3)
Tf =	0.50(±0.01)*Rf- 1.4(+0.7)	W13, r = 0.993, n=87	(4)

The variable nature of throughfall from point to point is again demonstrated

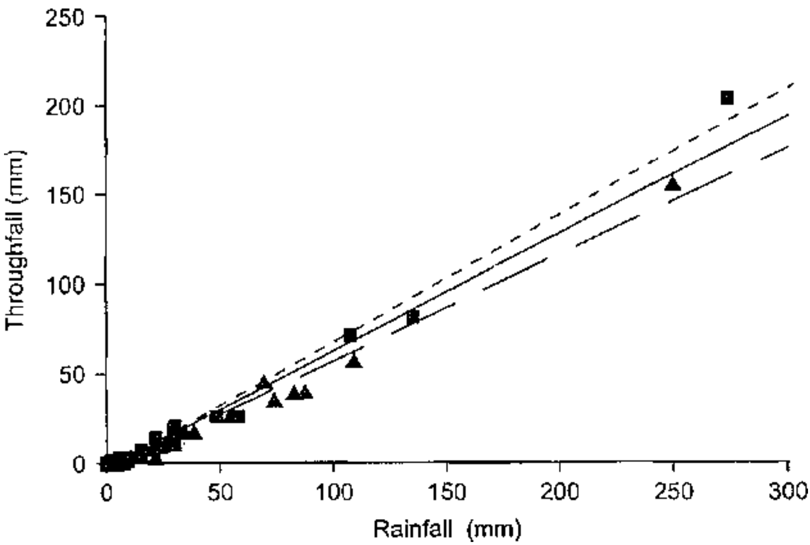

Figure 3 —Relationships between trough W09 storm throughfall and rainfall for a kanuka stand at Waimata. Squares and ------------------ line = winter; trian gles and — —* — line = summer; the solid line represents all data.

by the wide range in the regression coefficients: 0.50 to 0.73. These equations all adequately represented their respective locations, explaining over 97% of the variance in their data sets, but were statistically significantly different from each other. Notwithstanding the high level of explained variance, multiple-regression analyses were carried out to try to improve the relationship between throughfall and storm rainfall by adding either the storm duration ora sine function representing the date of the year. These additions made no improvement to the R^2 value nor to the confidence limits on the intercept or slope factor. Therefore, the simpler equations were retained.

Note that the regression slopes in these relationships, Eqns. 2—4, have different values than those given in Table 1 for comparable throughfalls expressed as the % of throughfall over rainfall. For example, at W03, Tf/Rf = 0.64 (= 64%) compared to the regression slope of 0.73 in Eqn. 2. These differences reflect the number of storms in the year and, therefore, the number of limes interception storage is filled by rainfall and emptied by evaporation.

Seasonal throughfall

Even though seasonal differences could not be picked up in the monthly data, and average storm rainfall was similar for both seasons, for the three recording troughs throughfall was higher in winter than summer: trough W03 throughfall was 69% of rainfall in winter, 62% in summer; trough W09, 57% in winter, 48% in summer; trough W13, 45% in winter, 43% in summer.

Troughs W03 and W09 each had significantly different through fall-rainfall relationships for winter and summer, with winter having the higher regression slope, and hence, higher throughfall (W03: Eqns 5 and 6, test for common slopes F ~ 20, d.f. = 77; W09: Eqns 7 and 8, test for common slopes F = 40, d.f. = 84, Fig. 3). Regression equations for W13 indicated that the slope factor for summer was less than winter, as for W03 and W09, but the relationships were not significantly different (test for common slopes F = 0.67, d.f. = 84; test for single regression F = 0.47, d.f. = 85) and are not presented here.

Tf = 0.77(±0.02);I:Rf- !.7(±1.1) W03, Winter r = 0.997, n=41 (5) r
Tf = 0.69(±0.03)*Rf~ 1.7(±1.4) W03, Summer = 0.993, n=39 (6) r
Tf = 0.71 (±0.03):1;Rf- 3.4(±1.6) W09, Winter = 0.992, n=41 (7) r
Tf = 0,59(±0.02)*Rf-2.5(±l.l) W09, Summer = 0.992, n=46 (8)

Throughfall data as a percentage of rainfall for W09 on a storm and seasonal basis (Fig. 4) show an overlapping scatter of points similar to data for the measurement period (Fig. 2). Points plot at the low end of the rainfall spectrum, reflecting individual storms rather than lumped events, but still no discernable seasonal effect is apparent.

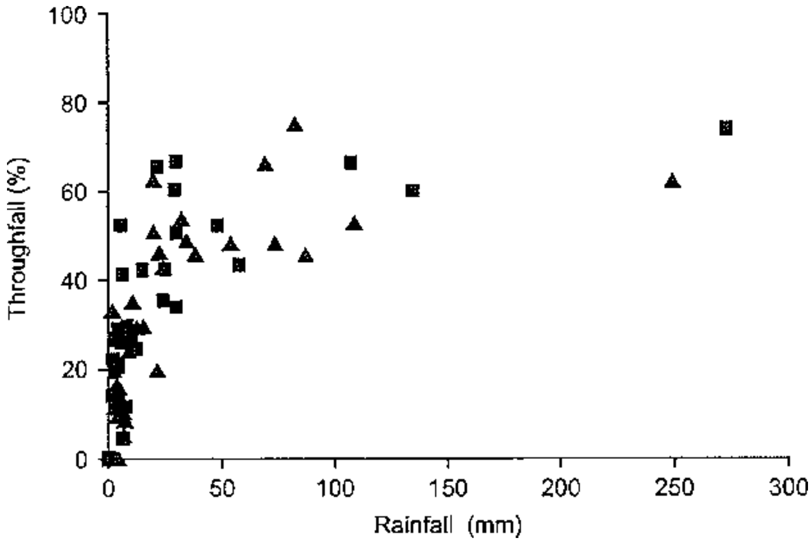

Figure 4 — Relationships between trough W09 storm through fall as a percentage of storm rainfall for a kanuka stand at Waimata. Squares = winter; triangles = summer.

S tem flow

Stem flow is a small component of rainfall reaching the ground, about \% of gross rainfall, or 15—20 mm in an average rainfall year. Although sampled approximately monthly, in no period do stem flow totals exceed 3 mm. Total stem flow (as a % of rainfall) measured for each sampling period showed no significant correlation with gross rainfall and no cyclical patterns were evident during the 1 year of measurements. This may be a consequence of the different magnitudes of stemflow and rainfall. There were no significant relationships between the proportion of total stemflow measured for the individual trees and tree parameters such as stem diameter, stem cross-section area, and the tree canopy area. This may reflect overlapping and intermingling tree canopies allowing transfer of throughfall from one plant to another and thereby influencing stemflow yields.

interception storage capacity

Interception storage capacity is often calculated as the storm rainfall that falls before throughfall begins i.e., Rf at Tf= 0 (Singh, 1977; Rowe, i979; Prebble and Stirk, 1980). Calculations using the storm-derived regression equations above (Eqns 4-8) result in interception storage capacity estimates of: W03-2.2 mm in summer, 2.4 mm in winter; W09 -4.8 mm in summer, 4.3 mm winter; W13 -2.8 mm over the entire year. Estimates for interception storage capacity obtained using this method tend to be high, as the regression relationship uses all storms, including those with low average rainfall intensities in which storage may be filled and partly emptied a number of times.

An alternative method for estimating interception storage capacity is to extend the upper envelope of the throughfall/storm rainfall data points back to the rainfall axis and read off the rainfall value (e.g., Rogerson and Byrnes, 1968; Pearce and Rowe, 1981; Whitehead and Kelliher, 1991; Kelliher *et cii*, 1992). This method tends to emphasise short-duration, higher-intensity storms where evaporation from the storage is small before it is filled. Results were variable, with estimates for interception storage capacity ranging from 0 to 1.9 mm. Inspection of the data from the three troughs with reliable records indicates that only two storms at W03 had throughfali for events less than 2 mm, suggesting that 2 mm is likely to be a reasonable estimate for the interception storage capacity of this kanuka stand.

Interception loss

Interception loss (II) is calculated as the residual in the equation:

Interception loss = rainfall - throughfali - stemflow (9).

Because stemflow is so small, interception loss approximates the difference between rainfall and throughfali. Making an allowance for stemflow of I %, interception loss for this stand would be about 42% of rainfall, i.e. 740 ±110 mm in an average rainfall year. Note that the error estimate here is the same magnitude in absolute terms (i.e., in mm) as for throughfali. This is because interception loss is a calculated quantity, and all variability inherent in the throughfali and stemflow measurements will How through in absolute terms into the error band for loss. Therefore, in % terms, because interception loss is smaller than throughfali, the absolute error band translates into a higher percentage value.

Because interception loss approximates the complement of throughfali, on a monthly basis, the complement of Eqn. 1, adjusted for stemflow of 1 % of rainfall, becomes Eqn. 10. Throughfali at the monthly timescale showed no significant seasonal variation, so the estimated interception losses will not either.

$$II = 0.26^{:I:}Rf + 22 \qquad (10).$$

For storms, if we take all the storm data for troughs W03, W09, and W] 3 and calculate one relationship we can get the equation:

II = 0.36·I·Rf + 2.1 n - 254, r ~ 0.936 ( ] j) .

As mean throughfall for these 3 troughs underestimates the stand average by nearly 8%, this equation will overestimate the stand interception loss by about 10%. Therefore, a better estimate of storm interception loss is likely to be closer to Eqn. S2.

$$II = 0.32*Rf + 2 \qquad (12).$$

Throughfall had showed seasonal variations for two of the troughs, indicating that there will also be some seasonal variation in storm interception loss. This variation can be calculated as complementary relationships to Eqns. 5- 8.

Discussion

Published New Zealand data are available for a number of types of woody vegetation including gorse (Aldridge, 1968), manuka (Blake, 1965, Aldridge and Jackson, 1968), regenerating kamahi (Jackson and Aldridge, 1973), various forms of beech forest (Aldridge and Jackson, 1973; Rowe, 1975, 1979, 1983), and *Pinus radiata* (Fahey, 1964; Pearce *et al*, 1987; Kelli her *et al.*, 1992; Duncan, 1995; Rowe, unpubl. data for Chaneys and Eyreweil Forests). To enable comparisons to be made, the data from these studies have generally had to be converted from the values for study periods to annual estimates, and there were uncertainties over study period lengths in some cases. Blake (1975) has presented regression equations for the various facets of interception (interception loss, throughfall, stem How) and storm rainfall for these and other vegetation types, but provides no indication of total amounts. Without knowledge of the storm rainfall distribution and the number of storms it is not possible to calculate throughfall and interception loss totals for comparisons with the other studies.

Throughfall and interception loss data from the studies referred to above have been plotted together with data from this study in Figures 5 and 6. Throughfall and interception loss for kanuka found in this study fall within the general trends for other taller woody vegetation studied in New Zealand.

The rate of evaporation from a wet plant canopy depends strongly on the boundary-layer conductance, which in turn is influenced by the vegetation characteristics, especially height (Kelliher and Scotter, 1992). Thus, it might be expected that the rale of evaporation from this kanuka stand, which is 13m

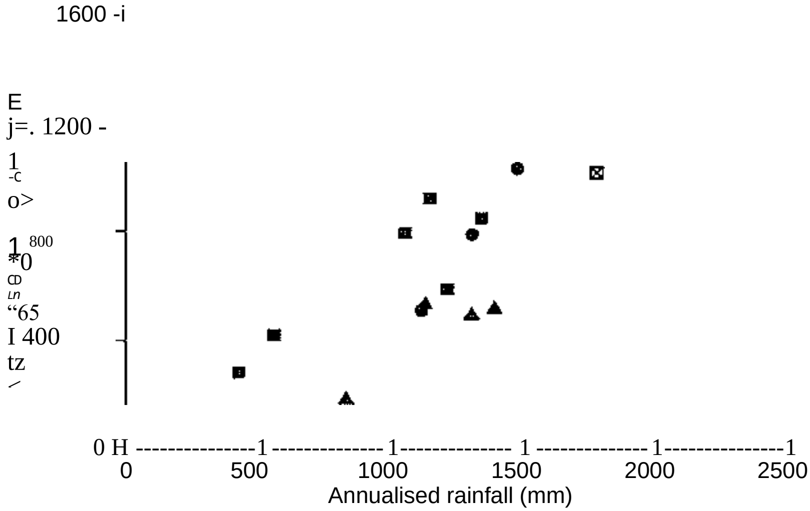

Figure 5 — Annual rainfall-throughfall relationships for a number of New Zealand studies with differing vegetation types. Triangles = scrub; dots = native forest; squares = *P. rcidicita;* crossed box = kanuka (this study).

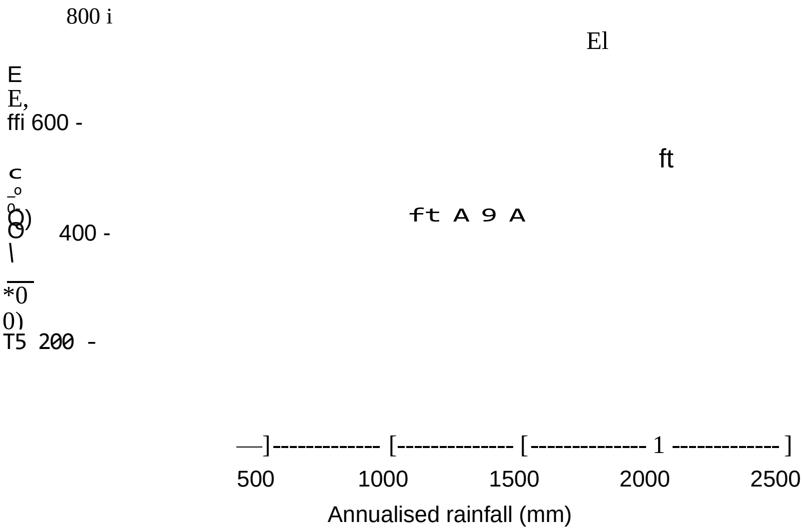

Figure 6 —Annual rainfall-interception loss relationships for a number of New Zealand studies with differing vegetation types. Triangles = scrub; dots = native forest; squares = *P. rcidicita;* crossed box = kanuka (this study).

tail, would be similar to that for forest, given similar rainfall characteristics. The Waimata environment is wetter than most other study areas, and presumably the canopy will be wetter longer, with more opportunity for wet canopy evaporation. Total interception loss will be high, and has been estimated to be of the order of 740 mm per year.

For this study, the interception loss for kanuka as a percentage of rainfall (42%) is at the top end of losses reported in other New Zealand studies. Two studies have reported interception losses for manuka scrub of 37% and 31% of rainfall, respectively (Aldridge and Jackson, 1968; Blake, 1965). Because the kanuka in the present study is taller than the manuka in those stands, we would expect the losses in this study to be higher, as they are. However, most interception studies in New Zealand report lower values, ranging between 26% (Rowe, 1979) and 30-40% (Aldridge and Jackson, 1973) for native forests, and about 27% for a regenerating native stand of kamahi (Jackson and Aldridge, 1973).

The relationship between interception loss and storm rainfall (Eqn. 12) is consistent with other studies. The slope of the equation, 0.32, is close to the median slope for 12 New Zealand scrub and forest communities (Blake, 1975), the range of slopes in those studies being 0.14 to 0.64. While the intercept, 2.1 mm, is larger than that from all but one of those studies, this probably reflects canopy drying processes during storms rather than the size of the canopy interception storage capacity.

The magnitude of the interception loss estimated for this kanuka stand has significant implications for retaining kanuka on site as an agent for mitigating soil erosion. Previous research has shown that, for *P. radicita* stands, the interception of rainfall by the canopy and the efficient use of soil-water (Pearce *ei ctl*., 1987), and the interlocking and overlap between adjacent tree-root networks (Forest Research Institute, 1990) combine to modify the hydrology of the slopes, reinforcing the upper soil horizons sufficiently to reduce the likely occurrence of shallow landsliding. During normal climatic conditions, the generally lower soil water content and the shorter annual period of high water content under closed-canopy forest are considered to be important in reducing the incidence of landsliding (Pearce *etai*, 1987). Conversely, where there is little or scattered forest cover, soils tend to be wetter for longer periods and are more prone to landsliding during rain events with return periods of less than 5 years.

Based on measurements from this one stand of kanuka, and for the range of storm magnitudes during the study period, soils under a dense kanuka canopy will be considerably drier than those at an equivalent pasture site, because the amount of rainfall reaching the soil will be reduced by interception and wet canopy evaporation. Soils under kanuka will therefore be less prone to rainfall-induced landslides than similar soils under pasture.

Most of the major incidences of shallow landsliding in the North Island's East Coast region have, however, been associated with infrequent, heavy rainfall events with about a 10-year return period (Keiliher *et al.*, 1995). It is during these larger storms that shallow soils under a forest cover are most likely to reach near saturation, a condition conducive to the triggering of translational landslides (Fourie, 1996). Following Cyclone Boia it was noted that where areas of regenerating scrub and *P. mcliata* had attained canopy closure, both species were effective in reducing landslide initiation. When compared with pasture, there was a 4-16 fold reduction in storm-initiated landslides associated with areas of closed- canopy forest, including kanuka (Marden and Rowan, 3993). For the most common planting regime for *P. mcliata* (1000-1250 stems per ha), canopy closure occurs within 6-8 years of planting whereas for regenerating kanuka in the absence of browsing animals, it can occur within 5 years of establishment. In areas of younger pine and kanuka (< 6 years old) and older scattered scrub, where the canopy had not yet closed, the levels of landslide damage were similar to that on pastoral hill country (Phillips *et al.*, 1990; Marden and Rowan, 1993).

Within forested areas, and particularly during extreme rainfall events, factors additional to the soil-water regime are likely to influence landslide initiation. These include stand density, root system dimensions and the magnitude of root-soil reinforcement. The excavation of root systems of kanuka and *P. mcliata* revealed that, although the roots of individual kanuka were smaller than those of *P. mcliata* at all stages of growth, the difference in total root mass was more than compensated for by the higher stand densities of the kanuka. Thus, the annual rate of root production of stands of regenerating kanuka exceeds that of P. *mcliata* for the first 9 years of growth (Watson *et ciL,* 1995). As a consequence, the calculation of slope safety factors (a measure of a slope's resistance to failure) using the relationships between the shear strength of the soil-root system, the specific root cross- sectional area and slope angle, showed that slopes with a dense stand of regenerating kanuka were less likely to fail than similar slopes in P. *mcliata*, at least for the first 9 years after establishment. In addition, older aged stands of both species afforded a high and comparable level of protection against landslide initiation (Ekanayake *et al.,* 1997). This finding is supported by previous research in which landslide frequency in areas of pines > 8-years-old and in 16-year-oid, fully-stocked stands of kanuka was found to be similar to that in areas of indigenous forest (Marden and Rowan, 1993; Bergin *et al.*, 1993).

Because of its substantial rainfall interception and below-ground biomass, kanuka provides a high level of protection against the initiation of shallow landslides during major storms, comparable to or better than that provided by a closed-canopy stand of *Pinus radictta.* For areas of landslide-prone, steep, hill country of the eastern North Island, existing areas of kanuka should be retained and severely eroding farmland allowed to passively revert to kanuka. As kanuka is endemic to New Zealand and an early coloniser of harsh sites, it could be a cost-effective land-use option for hill country areas in need of soil conservation and erosion prevention measures.

Conclusions

The magnitude of interception loss, as a percentage of rainfall, estimated for the kanuka stand in this study is high compared to other interception studies of woody vegetation in New Zealand. However, the results are consistent with other studies if the annual losses are viewed in terms of annual rainfall, and the relationship between storm interception ioss and rainfall is comparable with relationship for other vegetation communities. There is also some evidence for throughfall being higher in winter than in summer.

For the 3 years of the study, an annual interception balance for the kanuka stand at Waimata would be:

Rainfall (1780 mm) = Throughfall (1020 mm) + Stemflow (20 mm) + Interception Loss (740 mm).

An estimate of interception loss for individual storms (in mm) is:

Interception loss = 0.32*Rainfall + 2.

There will also be seasonal differences, with higher interception losses in summer than in winter.

Because of kanuka's substantial rainfall interception and below-ground biomass, the retention of existing areas of kanuka and the passive reversion of severely eroding farmland to kanuka could provide a level of landslide protection comparable to that of a closed-canopy stand of *Pinus radiata,* and be an alternative land-use option for hill country areas in need of soil conservation and erosion-prevention measures.

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References

Aldridge, R. 1968: Through fall under gorse *(Ulex europaeus)* at Taita, New Zealand. *New Zealand Journal of Science II:* 447-451.

Aldridge, R.; Jackson, R.J. 1968: Interception of rainfall by manuka *{Leptospennum scopciriuni)* at Taita, New Zealand. *New Zealand Journal of Science II:* 301-317.

Aldridge, R.; Jackson, R.J. 1973: Interception of rainfall by hard beech *(Nothofagus trunccita)* at Taita, New Zealand. *New Zealand Journal of Science 16:* 185-198.

Bergin, D.O.; Kimberley, M.O.; Marden, M. 1993: How soon does regenerating scrub control erosion? *New Zealand Forestry 38(2):* 38-40.

Bergin, D.O.; Kimberley, M.O.; Marden, M. 1995: Protective value of regenerating tea tree stands on erosion-prone hill country, East Coast, North Island, New Zealand. *New Zealand Journal of Forestry Science 25:* 3-19.

Blake, G.J. 1965: Measurement of interception loss in teatree. Abstract. *Journal of Hydrology (New Zealand) 4:* 87.

Blake, G.J. 1975: The interception process. *In:* T.G. Chapman; F.X. Dunin *(eds.) Prediction in catchment hydrology*. Australian Academy of Science, Canberra: 59-81.

Czarnowski, M.S.; Olszewski, J.L. 1970: Number and spacing of rainfall-gauges in a deciduous forest stand. *Oikos 21:* 48-51.

Duncan, M.J. 1995: Hydrological impacts of converting pasture and gorse to pine plantation, and forest harvesting, Nelson, New Zealand. *Journal of Hydrology (New Zealand) 34:* 15-41.

Ekanayake, J.C.; Marden, M.; Watson, A.J.; Rowan, D. 1997: Tree roots and slope stability: a comparison between *Pinits radiata* and kanuka. *New Zealand Journal of Forestry Science 27:* 216-233.

Fahey, B.D. 1964: Throughfall and interception of rainfall in a stand of radiata pine. *Journal of Hydrology (New Zealand) 3:* 17-26.

Forest Research Institute. 1990: Contribution of tree roots to slope stability. New Zealand Ministry of Forestry, Forest Research Institute, What's New in Forest Research No. 196.

Fourie, A.B. 1996: Predicting rainfall-induced slope instability. *Proceedings of Institution of Civil Engineers, Geoteclmique Engineering 119:* 21 1-218

Freese, F. 1967: Elementary statistical methods for foresters. United States Department of Agriculture, Agriculture Handbook 317. Washington D.C. 87p.

Hewitt, A.E. 1992: New Zealand soil classification. DSIR Land Resources Scientific Report No. 19. 133 p.

Jackson, IJ. 1975: Relationships between rainfall parameters and interception by tropical forest. *Journal of Hydrology 24:* 215-238.

Jackson, R.J; Aldridge, R, 1973: Interception of rainfall by kamahi *(Weinmannia mcemosa)* atTaita, New Zealand. *New Zealand Journal of Science 16:* 573-590.
Kelliher, F.M.; Marden, M.; Watson, A.J.; Arulchelvam, I.M. 1995: Estimating the risk of landsliding using historical extreme river flood data. *Journal of Hydrology (New Zealand) 33* (2): 123-129.
Kelliher, F.M.; Scotter, D.R. 1992: Evaporation, soil and water. *In:* M.R Mosley *(ed.) Waters of New Zealand.* New Zealand Hydrological Society, Wellington: 135-145.
Kelliher, F.M.; Whitehead, D.; Pollock, D.S. 1992: Rainfall interception by trees and slash in a young *Pi tuts radiata* D.Don stand. *Journal of Hydrology 131:* 187-204.
Marden, M.; Phillips, C.J.; Rowan, D. 1991: Declining soil loss with increasing age of plantation forests in the Uawa Catchment, East Coast Region, North Island, New Zealand. In: *Proceedings of International Conference on Sustainable Land Management, 18-23 November*; *Napier, New Zealand:* 358-361.
Marden, M; Rowan, D. 1993: Protective value of vegetation on tertiary terrain before and during Cyclone Bola, East Coast, North Island, New Zealand. *New Zealand Journal of Forestry Science 23:* 255-263.
New Zealand Meteorological Service. 1984: Rainfall normals for New Zealand 1951-1980. New Zealand Meteorological Service Misc. Publ. 185.
O'Loughlin, C.L. 1984: Effectiveness of introduced forest vegetation for protection against landslides and erosion in New Zealand's steeplands. In: Symposium on *Effects of forest land use on erosion and slope stability, Honolulu, Hawaii.* University of Hawaii: 275-280.
O'Loughlin, C.L.; Zhang, X.B. 1986: The influence of fast-growing conifer plantations on shallow landsliding and earthflow movement in New Zealand steepland. *In:* Proceedings of the International Union of Forest Research Organisations 18lh World Congress, September 1986, Ljubljana, Yugoslavia: 217-226.
Pearce, A.J.; OXoughlin, C.L.; Jackson, R.J.; Zhang, X.B. 1987: Reforestation: on-site effects on hydrology and erosion, eastern Raukumara Range, New Zealand. International Association of Hydrological Sciences Publication 167:489-497.
Pearce, A.J.; Rowe, L.K. 1981: Rainfall interception in a multi-storied, mixed evergreen forest: Estimates using Gash's analytical model. *Journal of Hydrology 49:* 341-353
Peterson, D.L.; Rolfe, G.L. 1979: Determining sample size in throughfall studies. *Forest Science 25:* 582-584.
Phillips, C.J.; Marden, M.; Pearce, A.J. 1990: Effectiveness of reforestation in prevention and control of landsliding during large cyclonic

storms, *In:* Proceedings IUFRO XIX World Congress, United States: 340-350.

Prebble, R.E.; Stirk, G.B. 1980: Throughfall and stemflow on silverleal' ironbark *(Eucalyptus melanophloia)* trees. *Australian Journal of Ecology 5:* 419-427.'

Rogerson, T.L.; Byrnes, W.R. 1968: Net rainfall under hardwoods and red pine in central Pennsylvania. *Water Resources Research 4:* 55-57.

Rowe, L.K. 1975: Rainfall interception by mountain beech. *New Zealand Journal of Forestry Science 5:* 45-61.

Rowe L.K. 1979: Rainfall interception by a beech-podocarp-hardwood forest near Reefton, North Westland, New Zealand. *Journal of Hydrology (New Zealand) 18:* 63-72.

Rowe, L.K. 1983: Rainfall interception by an evergreen beech forest, Nelson, New Zealand. *Journal of Hydrology 66:* 143-158.

Singh, B. 1977: The effect of rainfall characteristics and post-wetting synoptic conditions on evaporation rates from a wetted hardwood canopy. *Climatological Bulletin 21:* 12-33.

Soil Survey Staff. 1992: Keys to soil taxonomy. *SMSS Technical Monograph.* No. 19, 541 p,

Tomlinson, A.I.; Sansom, J. 1994: Rainfall normals for New Zealand for the period 1961 to 1990. *NIWA Science and Technology Series* No.3. 20 p.

Watson, A. J.; Marden, M,; Rowan, D. 1995: Tree species performance and slope stability. *In:* D. H. Barker (*ed*.), *Vegetation and slope stabilisation, protection and ecology.* Thomas Tel ford Press: 161-171.

Watson, A.J; Marden, M.; Rowan, D. 1997: Root-wood strength deterioration in kanuka after clearfelling. *New Zealand Journal of Forestry Science 27:* 205-215.

Whitehead, D.; Kelliher, F.M. 3991: A canopy water balance model for a *Pinus radiata* stand before and after thinning. *Agricultural and Forest Meteorology 55:* 109-126.