THROUGHFALL AND INTERCEPTION OF RAINFALL IN A STAND OF RADIATA PINE

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SUMMARY

Some interception values are determined for **Pinus radiata** in the Silverstream catchment, Otago. Both net rainfall and pattern of throughfall are correlated with a number of factors. Individual storm total appears to be the main factor in the determination of throughfall and interception loss.

Over the 9-month recording period a total rainfall of 36.21in. was measured in the open. Of this total, on the average, only 48% (17.38in.) reached the forest floor as throughfall; 49% (17.74in.) being attributed to the average interception loss. Stemflow was accounted for by the 3% (1.09in.) deficit.

INTRODUCTION

It is generally accepted that trees provide shelter from rainfall. To the hydrologist and the soil conservator the interception of precipitation by trees is an important factor in the hydrological cycle. Removal of the vegetative cover, especially the forest cover, may result in a higher frequency of flooding, and accelerated soil erosion.

Since the turn of the century, workers in several countries have attempted to determine the effect of vegetation on rainfall. However it is only over the last 15 years that literature on the subject has grown appreciably. Strangely enough, in New Zealand where flooding and soil erosion are relatively common phenomena, little has been written on the subject. Some of the concepts are presented, and some problems concerned with the collection and analysis of data on throughfall and interception under New Zealand conditions are examined. A glossary of terms used, and their definitions, is appended.

THE STUDY AREA

Precipitation falling through the canopy was measured with 16 standard daily 5-in. rain gauges placed under a portion of the Dunedin City Council's exotic plantation. This plantation is situated 5 miles west of Dunedin (Fig. 1) and consists of a number of species the most common being *Pinus radiata*.

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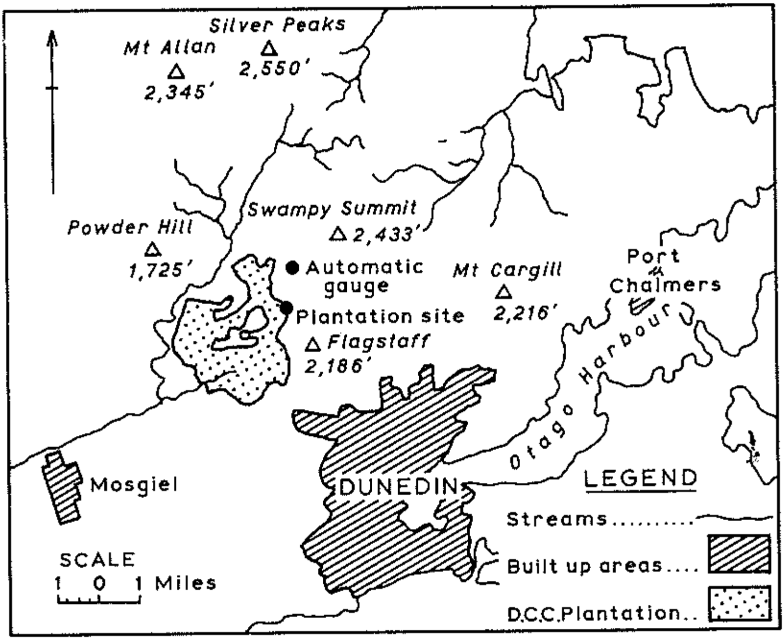

Fig. 1 — LOCALITY MAP

A site was chosen for the study of throughfall under *P. radiata* on the west-facing flank of the Silverstream catchment.

At the site, the trees are approximately 30 years old with an average tree height of 70ft and an average trunk diameter of 10in. The average distance between trees is 6ft 10in. giving a density of about 840 trees to the acre. Canopy coverage is roughly 40 to 50%.

The gauges were positioned as shown in Figure 2. This allowed various factors which determine the net rainfall beneath a forest cover to be separated out and their relative importance discussed. In order to obtain interception values that represent a large area, other workers have suggested that gauges should be moved after each rainfall period. Wilm and Niederhof (1941) found that stationary gauges were subject to large standard errors of throughfall estimates. Reynolds and Leyton (1963) concluded that random positioning following each storm was the most suitable procedure if the recorded interception was to be a representative figure. It is interesting to note that gauges 1 to 8 (Fig. 2) are oriented NE-SW and thus parallel tree alignment. This alignment of the trees is fortuitous in that SW storms predominate.

The gauges are situated approximately 180ft inside the plantation. All throughfall recorded in these gauges has been

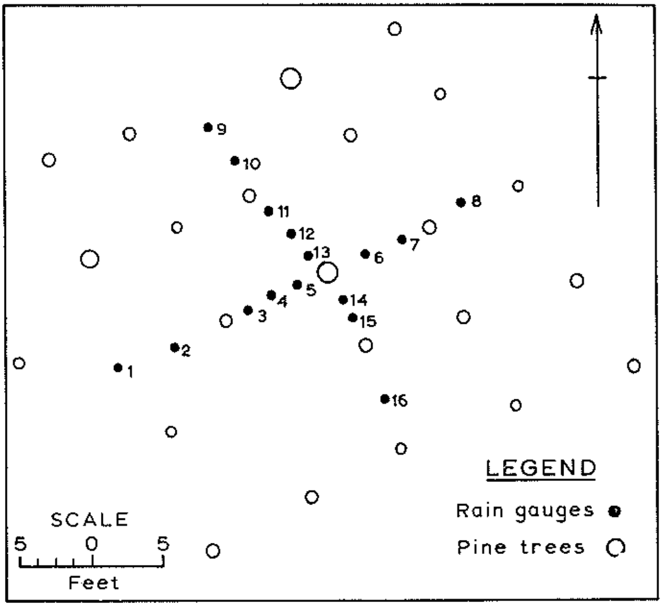

Fig. 2 — DISTRIBUTION of the 16 rain gauges in the plantation, in relation to the pine trees.

compared with records from an open-sited gauge also 180ft away from the edge of the plantation (Fig. 3). Originally two standard 5-inch gauges 20ft apart were employed at the open site. However, because the difference in rainfall between the two gauges seldom exceeded 0.01in., one was discontinued.

For want of a better term, "storm" has been used in the present discussion to represent a recorded amount of rainfall. Wherever possible individual periods of rainfall have been used as a basis for throughfall values. However this has not always proved practicable due to the distance to be travelled to the area as well as the conditions under which storms occur. Cold fronts dominate the local weather and consequently there is often a brief period of heavy rainfall followed by showery weather. Further difficulties arise when one cold front rapidly follows another without any distinct break.

Over the 9-month period from the end of July, 1963, until the end of April, 1964, a total of 53 storms was recorded; the rainfall at the open site varying from 0.02in to 3.37in. The spacing within this range was reasonably uniform up to 1.3in., with 47 storms being recorded below this figure; while for storms above 1.3in., the spacing was far wider.

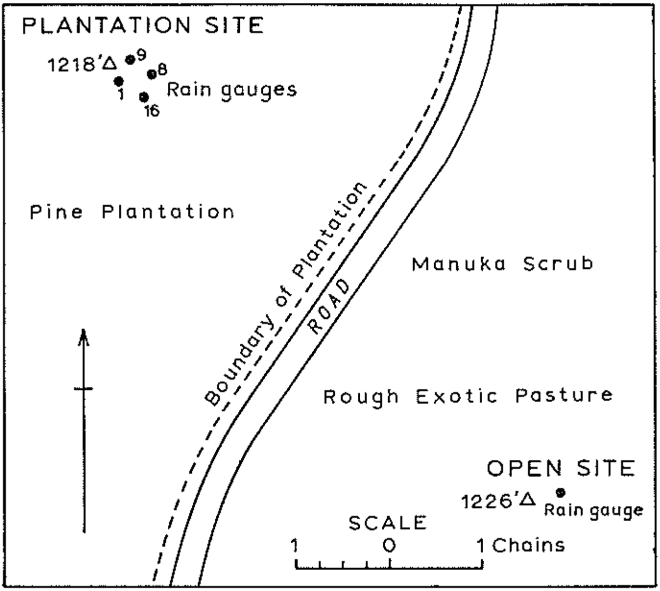

Fig. 3 — RELATION of the plantation site to the open site.

The factors which determine the percentage of net rainfall on the forest floor can be divided into climatological and vegetational factors. These are listed and considered below.

CLIMATOLOGICAL FACTORS

The throughfall values for each storm were converted to a percentage of the gross rainfall recorded at the open site.

Aggregate Amount

The 16 percentages, one for each rain gauge, were averaged for each storm, and the average values were correlated with gross rainfall for each storm. Using the method of least squares, the linear correlation coefficient relating the percentage throughfall (excluding stemflow) to rainfall was +0.569. This is significant at the 1% level. The square of the linear correlation coefficient showed that 26% of the variance of the throughfall during various storms is accounted for by the storm aggregates.

In other words, although there is a linear relationship between average throughfall and storm size, other factors are also important in determining the average throughfall. One storm of 0.10in., for instance, resulted in a throughfall of 42% yet during a storm of 1.19in. the average on the forest floor was only 41%.

Hamilton and Rowe (1949) working in chaparral shrub vegetation in California found a much closer relationship between throughfall and gross rainfall. Reynolds and Leyton (1963), working with 17-year old Norway spruce (*Picea abies*) near Oxford found a similar relationship to that revealed in the chaparral study.

Reynolds and Leyton (1963) extrapolated their regression line to determine the critical rainfall in any one storm which would result in net rainfall on the forest floor. This value they termed "canopy saturation" and estimated that under the existing conditions no throughfall would occur until the total exceeded 0.05in.

Initially, rainfall may be completely intercepted, but once maximum storage of the tree has been reached, drops will accumulate on the leaf and branch surfaces and begin falling to the forest floor. In the present study it seems doubtful whether any one value can be given as a minimum below which gross rainfall will be completely intercepted. One storm of 0.04in., for example, resulted in an average throughfall of 33% while two storms of 0.05in. produced throughfalls of 6% and 19%. The average for storms ranging from 0.02in. to 0.10in. was 22%.

Other factors must also play a part in determining whether or net rainfall is recorded on the forest floor. Horton (1919) pointed out that wind, by causing movement in the foliage, may result in a higher throughfall.

The tree species will also help determine what gross rainfall can be expected before throughfall is recorded. Ovington (1954) stated that for any given storm the canopies of conifers may retain up to 5 times the amount of water retained by hardwood canopies. The free flow of water is apparently hindered by the large number of needle-like leaves.

It must be remembered also that under field conditions, any error incurred during readings may well be magnified with storms of less than 0.10in. A few drops of rain left in a gauge from a previous storm may increase a reading of 0.04in. by up to 20%.

At the other extreme, analysis of data suggests that as the storm aggregate increases, the average throughfall tends towards a constant. This is shown in Table 1 where the 53 recorded storm totals and their associated throughfalls were divided arbitrarily into 5 classes. Calculated interception loss is also shown.

Similar results have been found by both Horton (1919) and Kittredge (1949).

TABLE 1 — Trend of Throughfall and Interception Loss with Storm Class

Rainfall per Storm Class (inches)	0.0-0.10	0.11-0.30	0.31-0.78	0.79-1.29	1.48-3.37
Average Throughfall (%)	22	40	54	56	62
Interception Loss (%)	78	60	46	44	38

Correlation coefficients were calculated for throughfall recorded in 4 of the 16 gauges. Two are situated between tree canopies (gauges 1 and 2) while the other two (gauges 6 and 13) lie beneath a tree canopy, within two feet of the trunk (Fig. 2). For gauges 1 and 2, the linear correlation coefficient relating the throughfall to the storm aggregates was +0.249 and +0.205 respectively. However, neither of these figures are significant at the 5% level and it can be seen that only 6% of the variance of throughfall would be accounted for by the storm totals for gauge 1, and 4% for gauge 2. On the other hand the correlation coefficient for gauge 6 is +0.704, and +0.583 for gauge 13, both being significant at the 1% level. In this case the storm totals account for 50% of the throughfall variance for gauge 6 and 34% for gauge 13. These results suggest that throughfall in relatively exposed positions is not directly related to storm totals, whereas closer to individual trees storm totals appear to be more important in determining average throughfall.

Intensity of Rainfall

One of the factors that operates against an extremely close correlation between aggregate amount and throughfall is the intensity of the gross rainfall. This varies not only from storm to storm but also within each storm. To determine the effect of intensity on net rainfall, an automatic rain gauge was installed in December, 1963, on a farm property approximately one mile north of the main site. Charts were changed daily by the farmer who also maintained a manual gauge. Despite the distance between the two sites, the correlation coefficient between the manual gauge records at the open site and the manual gauge on the farm property was high (+0.970). Prior to its installation on the farm property the automatic gauge was situated two miles to the west, in the Silverstream valley. Although storm totals are often considerably lower in the valley than at the farm site, 11 storm intensities from the valley site were added to the record taken at the farm. In each case the storm total was close to that recorded at the open site near the plantation.

In all, the intensities of 28 storms were determined. When the intensity figures were related to the average throughfall the correlation coefficient was +0.376 (significant at the 5% level); rainfall intensity thus accounting for only 14% of the throughfall variance. In some cases, therefore, the intensity of rainfall during a storm determines the net rainfall on the forest floor. However, because the intensity may vary greatly in individual storms, the relationship is not highly significant.

Duration of the Rainfall

Statistical analysis has also revealed a correlation between throughfall and storm duration. The coefficient of correlation was found to be +0.440 (significant at the 5% level), thus 19% of the variance is explained by the duration of the storm.

Type of Rainfall

Both Ovington (1954) and Rutter (1963) were in agreement that throughfall is less when a storm occurs as a series of small showers than when it consists of a continuous downpour. Since July 1963 five storms of continuous rainfall, rather than showers, have been recorded and these are shown in Table 2.

TABLE 2 — Average Throughfall Percentage Associated with Continuous Periods of Rainfall

Rainfall per storm (inches)	0.22	0.42	0.43	0.78	0.79
Average throughfall (%)	55	55	59	57	74

The above averages of individual storms are considerably higher than the 47% average for all storms.

Wind

It has already been stated that, in the initial stages, wind probably affects net rainfall by decreasing the time taken for canopy saturation to occur during a storm. However, it is the variation in the pattern of throughfall, caused by different wind directions, as recorded by the 16 gauges that is the most striking feature. If all patterns are graphed, that associated with a SW wind is found to be totally different from that associated with a NE storm. Similarly, patterns for southerly and westerly storms can be delineated. As would be expected, individual throughfall values are generally higher on the windward side of the trees.

Wind strength may also be an important variable. Seven storms with little or no wind have been recorded and their results are set out, with their appropriate throughfalls, in Table 3.

TABLE 3 — Average Throughfall and Rainfall per Storm with No Wind

Rainfall per Storm (inches)	0.02	0.10	0.13	0.26	0.32	0.84	1.01
Average Throughfall (%)	33	42	41	57	55	70	63

Table 4 shows figures for four storms which were accompanied by strong winds.

TABLE 4 — Average Throughfall and Rainfall per Storm Associated with Strong Winds

Rainfall per Storm (inches)	0.21	0.72	0.82	1.19
Average Throughfall (%)	27	49	46	41

In comparing these two tables it is found that throughfalls associated with strong winds are consistently lower than those associated with no wind.

VEGETATIONAL FACTORS

Throughfall totals will vary with different species due to the variation in the type of foliage, the shape of the canopy, and whether the species is deciduous or evergreen. With deciduous types, seasonal changes may also have to be considered due to the loss of foliage during the cold season. This results in a reduction of surface area which in turn causes reduced interception and evaporation from the vegetation.

On six occasions a throughfall equal to, or greater than, the rainfall at the open site was recorded in one of the 16 gauges. Gauge No. 5 recorded 100%, or over, on four of the 6 occasions; while on the remaining occasions, the two gauges involved were Nos. 13 and 14. All three gauges were situated less than 20in. from a tree stem (Fig. 2) and not, as might be expected, in a relatively exposed position. This may be explained by the type of branching in *P. radiata* which occurs at an acute angle to the direction of growth. Hence, any concentration of rainfall caused through the funnelling effect of the branches, would be more likely to occur close to the base of the trunk rather than towards the edge of the crown.

The maturity of the stand will also affect the percentage of throughfall. Obviously, net rainfall will be greater under young stands where the canopy cover is not so extensive. Variations in the density of the stand will also affect net rainfall.

STEMFLOW

No mention has yet been made of that percentage of the gross rainfall that reaches the ground via the tree stem. Horton's investigations showed that it seldom exceeded 6% of the gross rainfall for deciduous species. Under pine forests, Kittredge, Loughead, and Mazurak (1941) concluded that stemflow rarely exceeded 3% and with storms less than 0.20in. may be reduced to zero.

Aranda and Coutts (1963) suggested that stemflow may be neglected, while Ovington (1954) found that it does not exceed 1% with conifers but may reach 15% with hardwoods. The rough bark of conifers hinders the movement of droplets, hence there is more chance of rainfall retention and subsequent evaporation.

As no stemflow measurements were taken in this study, in the final analysis (Table 5) an arbitrary value of 3% has been subtracted from each individual throughfall to allow for stemflow.

CONCLUSIONS

The individual storm total seems to be the main factor determining throughfall and interception loss. Storm totals are, however, determined by the duration and intensity of the storm. Linear correlation analyses suggest that, assuming a given storm aggregate, any increase in the duration (with a consequent decrease in intensity) will result in a higher average throughfall; but, if there is an increase in intensity, accompanied by a decrease in duration, the result is a lower throughfall. This suggests that the inter-related factors of storm total, intensity, and duration must all be considered in determining net rainfall. In some cases only one of these factors may be important; in others, all may affect the final total. If rainfall is continuous rather than showery, less precipitation will be intercepted and a greater throughfall will be recorded. During rainfall with which there is no wind, throughfall will also be relatively high. Throughfall generally increases away from the stems. However this is dependent upon wind direction and strength. Gauges exposed to the wind will record relatively high throughfalls. Total stemflow is probably small especially in storms less than 0.50in. However it should not be ignored.

In Table 5 the average throughfall of the 53 storms as recorded by each gauge is set out, together with the losses caused through interception.

TABLE 5 — Total Average Throughfall and Interception Loss (corrected for Stemflow) from July, 1963, to April, 1964

Gauge No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Average Throughfall (%)	60	56	48	59	57	31	30	26	51	53	55	54	34	56	52	40
Interception Loss (%) corrected for Stemflow	37	41	49	38	40	66	67	71	46	44	52	43	63	41	45	57

Over the 9-month recording period a total rainfall of 36.21in. was recorded in the open. Of this total only 48% on the average (or 17.38in.) reached the forest floor as throughfall, 49% (or 17.74in.) being attributed to the average interception loss. Stemflow was accounted for by the 3% (or 1.09in.) deficit.

In conclusion it should be pointed out that these figures can be applied to a wider area only with the greatest caution. However, they do show how important a forest cover can be both in acting as a protection against soil erosion during periods of heavy rainfall, and in modifying stream flow.

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GLOSSARY OF TERMS USED AND THEIR DEFINITIONS

Where possible terms adopted by the Hydrology Section, Soil Conservation and Rivers Control Branch, Ministry of Works, have been used.

Interception* is the precipitation caught and stored by vegetation. It consists of interception loss, stemflow, throughfall, and drip.

Interception Storage* is the volume of precipitation intercepted by vegetation.

Interception Loss* is the volume of precipitation stored on vegetation and evaporated before reaching the ground.

Throughfall is the precipitation which reaches the ground under the trees through inter-tree spaces in the canopy, and as drip from the leaves, twigs, and stems.

Stemflow is the precipitation that reaches the ground by running down the stems.

Gross Rainfall is the total rainfall that would reach the ground if there was no vegetation to intercept it.

Net Rainfall is the total rainfall beneath the forest consisting of throughfall, drip, and stemflow.

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*Refer: Toebes, C. 1963: Glossary of Terms. **Handbk. of Hydrol. Proc.** Prov. Proc. 19. S.C.R.C.C. Wellington.