RAINFALL MEASUREMENTS AT TAITA EXPERIMENTAL STATION, NEW ZEALAND

1 — Vertical Raingauges

R. J. Jackson* and R. Aldridge*

ABSTRACT

Three networks of vertical raingauges were used to study the variability of rainfall in a 90-ha area of hilly and steep land, most of which is covered by scrub and forest. For individual storms, the standard deviation of gauge catch ranged from slightly over 10% of the network mean for storms smaller than 7.5 mm to around 5% of the network mean for storms greater than 40 mm. For monthly totals of catch the standard deviation was usually between 3% and 7% of the network mean. An unbiassed and sufficiently precise estimate of the network mean could be obtained from a selected single gauge.

Patterns of gauge catch associated with wind direction or with altitude were observed for some storms.

INTRODUCTION

The Taita Experimental Station (Fig. 1) consists of several small catchments having a total area of 90 ha and is situated on the hills to the east of the Hutt Valley near Wellington (latitude 41°S, longitude 175°E). Altitude ranges from about 30 m above mean sea level on the floor of the Hutt Valley (near N1 in Fig. 1) to 230 m on the crest of the main ridge (near G in Fig. 1).

The land surface is finely dissected, gullies with steep sides (slopes over 30°) being separated by rounded ridges and spurs. A mixture of scrub and forest covers much of the Experimental Station, although small areas of grassland occur on the lower slopes and on firebreaks. Four catchments are being used for hydrological investigations, and these make up the Taita IHD Experimental Basin.

The climate of the Wellington region has been described by Garnier (1958). Snow has not been recorded at the Experimental Station and fog is insignificant, although occasionally cloud may extend as low as 150 m above sea level and influences raingauges

* Soil Bureau, Department of Scientific and Industrial Research, Lower Hutt.

above this height (see below). In relation to rainfall measurement three points are important:

(1) The rainfall is mainly frontal; convective storms giving intense rainfall over a small area are rare.

(2) The rainfall may come from a north-westerly or southerly quarter. However, the onset of a southerly as a cold front passes may be abrupt, and rainfall from the two directions may come in quick succession so that they cannot always be separated.

(3) The rainfall may be accompanied by strong and often gusty winds. In combination with the steep and broken terrain having

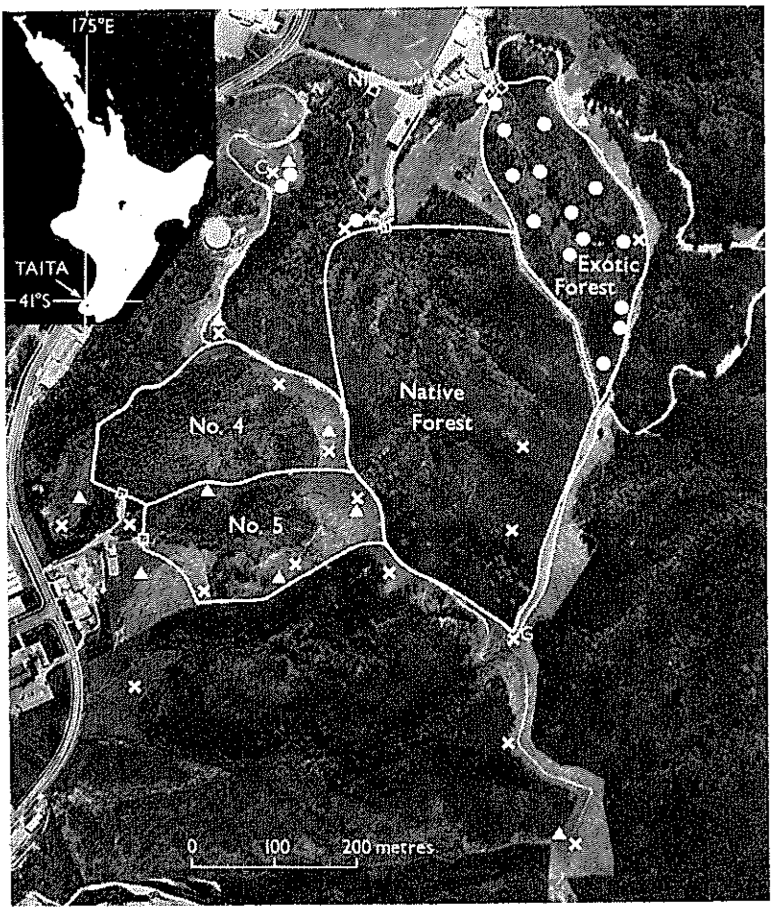

FIG. 1 – Taita Experimental Station, showing location of raingauges. (Network 1, ●; Network 2, ✕; Network 3, ▲.)

scrub or forest vegetation these winds may pose serious problems for rainfall measurement.

While several sites on firebreaks and on the lower pasture areas are suitable as permanent sites for measurement of rainfall, the continual growth of vegetation in the scrub and forest catchments prevents the use of permanent sites over the greater part of the Experimental Station. The present work was undertaken to investigate variation of rainfall over the Station and to establish to what extent a network of permanent gauges on or near the perimeters of the catchments should be supplemented by gauges within the catchments.

In interpreting the results of any study of rainfall measurement it must be recognized that the catch of a raingauge may differ from the true rainfall at the site of the gauge. Studies such as those of Rodda (1967) and Green (1970) have shown that even on a level site a standard gauge with its orifice 0.30 m (1 ft) above the ground can give a catch less than that of a ground-level gauge, which is assumed to give a good measurement of true rainfall. Exposure effects of this type generally increase with increasing wind speed. In the present case additional problems arise as a result of the scrub or forest vegetation covering most of the area. Exposure of gauges above the canopy cannot be precisely controlled since the surface is uneven and liable to be deformed by wind, while check measurements of 'true' (ground-level) rainfall are not possible on the actual site. Thus the present paper is concerned with the catch of gauges rather than with true rainfall. Work with tilted gauges, directional gauges (vectopluviometers) and ground-level gauges will be reported in subsequent papers.

EXPERIMENTAL

Three networks of vertical gauges have been used in studies of rainfall variation at Taita. Some details of the networks are given in Table 1, while the location of the gauges is shown in Fig. 1. Network 1 was concentrated in and around the 4.0-ha Exotic Forest Catchment, and was also used in a comparative study of the performance of vertical and tilted gauges (Jackson and Aldridge, 1972). Network 2 was used in an initial survey of the variation of the catch of vertical gauges over the entire Station, while Network 3 is essentially a reduced version of Network 2. Three vectopluviometers (directional gauges) were also included in each network, and were read at the same time as the vertical gauges.

The sites used in Network 1 covered a wide range of site conditions. Level ground is almost entirely absent from the Exotic

TABLE 1 – Size of networks and duration of readings.

Network	*Number of gauges*	*Duration of readings*	*Number of readings*
1	18	Oct 1965–Dec 1966	74
2	23	Feb 1967–Aug 1967	28
3	13	Oct 1968–Mar 1970	49

Forest Catchment, and most of the gauges were located over scrub 0.5 m to 4 m tall on slopes of up to 40°. Although the normal standards for gauge exposure (N.Z. Meteorological Service, 1971; WMO, 1969) could not be followed, sites close to trees projecting above the general level of the canopy were avoided, as were obviously over-exposed sites near the crests of the main confining ridges. On sites having a scrub cover, the gauges were mounted on masts to have their orifices just above the general level of the canopy. On pasture, gauges were placed with their orifices 0.3 m (1 ft) from the surface of the ground.

Most sites in Network 2 and all sites in Network 3 were on pasture areas on the gentle footslopes or on the crests of broad ridges, and they are thus closer to the usual standards for gauge location than were the sites for Network 1.

Table 1 gives the number of gauges in each network, although as a result of the usual field hazards (interference by farm animals, vandalism, gauge malfunction, etc.) readings were not always obtained from all gauges.

Networks 1 and 2 were usually read on a 'storm' basis, i.e. after each period of continuous rain, but some of the data are for two or three days of intermittent rain. Network 3 was read approximately weekly. All rainfall measurements were made to the nearest 0.25 mm (0.01 inch).

RESULTS

Variation within Networks

The first hypothesis considered was that there was no definite pattern of rainfall over the Experimental Station and that for each set of readings the measured catches of the vertical raingauges were a random sample from a parent population that is normally distributed. The mean and standard deviation of the catches of the gauges were calculated for each set of readings, and in Table 2 they have been grouped into five convenient size classes.

The results in Table 2 show that the three networks have similar variation of catch among gauges. The standard deviation increases with storm size, although there is a considerable range of

TABLE 2 – Average values, for specified size classes, of variability of catch in individual storms for three networks of vertical raingauges.

*Size class** *(mm)*	*Average network mean (mm)*	*Std. deviation of catch in individual storms (mm)*		*Average coeff. of variation (%)*	*No. of storms in size class*	*No. of storms with coeff. of variation greater than 10%*
		Average	*Range*			
Network 1						
0– 7.5	3.3	0.41	0–1.46	12.4	16	10
7.6–15.1	10.4	1.18	0.49–2.80	11.2	20	12
15.2–22.8	18.8	1.58	0.42–3.94	8.4	14	5
22.9–43.2	30.2	2.49	0.78–3.75	8.3	15	6
>43.2	79.0	4.54	1.36–9.73	5.7	9	1
Network 2						
0– 7.5	3.8	0.40	0.06–1.01	10.7	13	7
7.6–15.1	13.7	0.83	0.68–1.04	6.1	3	0
15.2–22.8	18.5	1.76	0.78–2.66	9.5	3	2
22.9–43.2	33.3	2.09	1.36–3.06	6.3	4	0
>43.2	68.3	3.64	1.14–5.67	5.3	5	0
Network 3						
0– 7.5	4.6	0.46	0.15–0.90	10.3	6	2
7.6–15.1	11.9	0.91	0.51–2.67	7.6	13	1
15.2–22.8	19.1	1.08	0.76–1.55	5.7	8	0
22.9–43.2	28.2	1.58	0.53–3.05	5.6	12	1
>43.2	72.4	2.73	0.60–5.07	3.8	10	0

* Boundaries between classes were originally 0.30, 0.60, 0.90 and 1.70 inches.

values of standard deviation in each size class. However, for each network the average coefficient of variation (standard deviation as percentage of mean) decreases from a little over 10% in the smallest size class to close to 5% in the largest size class. High values of the coefficient of variation (greater than 10%) were more common for Network 1 than for the other networks – probably reflecting the wide range of site conditions in the Exotic Forest Catchment.

Monthly Totals

The data were grouped into approximately monthly periods and the total catch was obtained for each gauge for which there were no missing data during the month. However, even for the analysis of monthly totals missing data rarely caused the omission of more than three gauges from Networks 1 or 2, and data were never missing from more than one gauge in Network 3. Figure 2

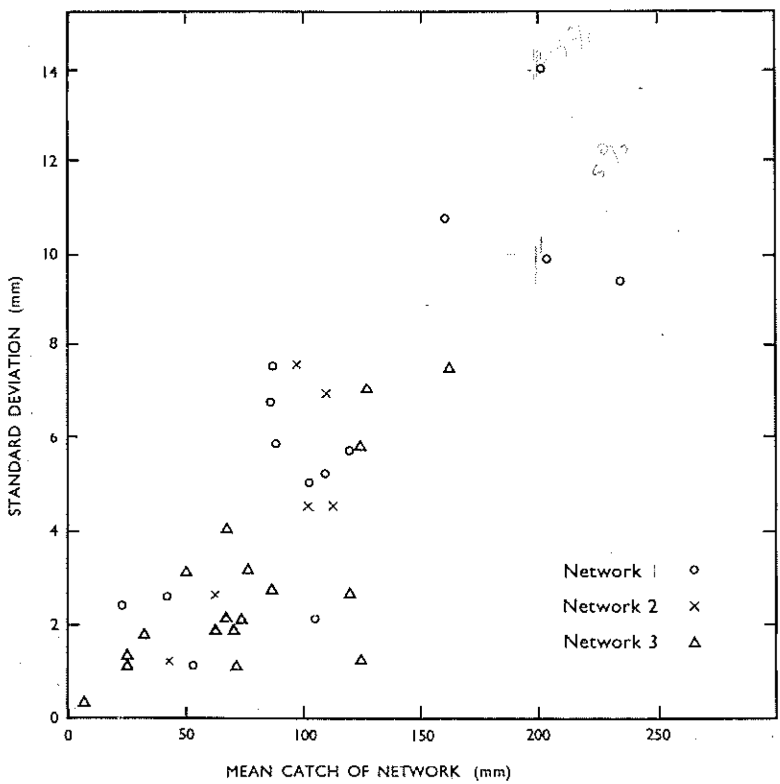

FIG. 2 – Relation, for monthly totals, between standard deviation of gauge catch and the mean catch of the network.

shows the standard deviation of monthly totals in relation to the mean catch for the network. For most months the standard deviation is close to 5% of the mean and exceeds 7% in only 4 of the 38 months.

Relation of Mean Catch of Network to Catch of Individual Gauges

In order to test to what extent a single gauge provides a good estimate of the mean, the relation between the mean catch of the network and the catch of each individual gauge in Networks 1 and 2 was calculated by linear regression, using the data for individual storms. The correlation coefficients were greater than 0.990 for all but two gauges, both of which were located over scrub. The slope of the regression line was nearly always between 0.95 and 1.05, while intercepts were mainly between −0.5 mm and +0.5 mm. A few gauges were consistently biassed, under- or over-estimating the mean catch by 5 to 10%. Estimates of the network mean that were not significantly biassed (slope of regression line not significantly different from 1.00) could be obtained from several gauges. One of these, the standard manual gauge in the climatological station (C in Fig. 1), is of particular interest as this is the only site that has been used continuously since 1957, and data have been used in a number of hydrological publications (e.g. Toebes, 1962; Ministry of Works, 1968). The regression results for this site for all three networks are given in Table 3.

TABLE 3 – Relation, for storms, between mean catch of network (M) and catch of standard manual gauge in climatological station (C) (mm).

Network	*Linear regression equation*	*Correlation coefficient*	*Standard deviation from regression (mm)*
1	$M = 0.21 + 0.9951C$	0.9988	1.21
2	$M = 0.30 + 0.9866C$	0.9991	1.04
3	$M = -0.09 + 0.9857C$	0.9995	0.89

Fig. 3 shows the errors that arise if the catch of the standard gauge in the climatological station is used as an estimate of the mean catch of the network. The errors are approximately evenly distributed either side of zero, so that the gauge in the climatological station gives an unbiassed estimate of the mean. The percentage error decreased with storm size and exceeded 5% for only 6 of the 51 storms greater than 25.4 mm (1.00 in.), but exceeded 10% for 20 of the 100 storms smaller than this size. However, in spite of these large percentage errors in storms smaller than 25.4 mm the errors in actual rainfall exceeded 1.3 mm (0.05 in.) in only 11 of

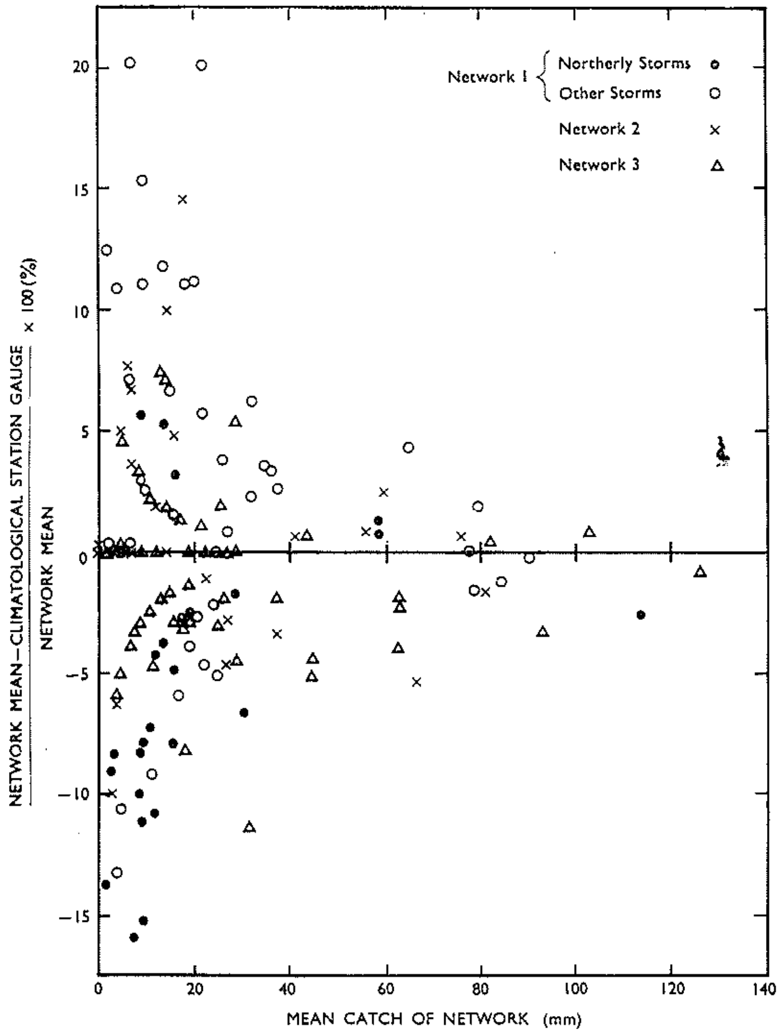

FIG. 3 – Differences between mean catch of network and catch by gauge in climatological station.

these 100 storms. Errors exceeding 2.5 mm (0.10 in.) occurred for only 6 of the 151 storms. It can be seen, both from the regression equations in Table 3 and the distribution of points in Figure 3, that results for Network 1 are similar to those for the other networks, indicating that the gauge in the climatological station provides as good an estimate for the steep sites covered with scrub as for the pasture sites.

The total catches for monthly periods were also examined and it was found that the gauge in the climatological station was within 5% of the mean of the network for all but 5 of the 38 months. The largest error in any month occurred for Network 1 in August 1966, the catch of the gauge in the climatological station being 153.9 mm compared with a mean for the network of 163.1 mm.

Patterns of Vertical Gauge Catch

It has been assumed that for each storm the catches of the gauges varied randomly about the mean over the area covered by the networks. However, when the data were examined in detail it was found that for some storms there were patterns of catch related either to wind direction or to altitude.

The pattern related to wind direction consisted of lower catches on windward slopes than on level or leeward slopes. For Networks 2 and 3 the gauges located in or near Catchments 4 and 5 (see Fig. 1) formed a definite subgroup which had lower catches than the remaining gauges for storms that came from a southerly or westerly direction and higher catches for storms from a northerly or easterly direction. However, the difference between the mean catch of these gauges and that of the remaining gauges was less than 5% for two-thirds of the storms and exceeded 10% in only 8 out of the 77 storms. For the whole period of observations storms from various directions tend to compensate and the overall difference between the means of the two subgroups was less than 1% for both Network 2 and Network 3. A similar phenomenon occurred in Network 1 – the catch of the gauges on slopes being lower than that of gauges on level sites for storms from the north. One consequence of this is to be seen in Fig. 3, where the mean catch of Network 1 is lower than that of the gauge in the climatological station for most northerly storms. For all northerly storms combined the catch of the gauge in the climatological station was 4.8% greater than the mean of the network. There was, however, a compensation by storms from other directions, and for the whole period of measurements the gauge in the climatological station caught 0.4% more than the mean catch of Network 1.

A pattern related to altitude was observed for a few storms for which it was also known that low cloud had blanketed the higher parts of the hills (over 150 m above sea level). High catches were obtained in gauges on the upper ridge and also in a directional gauge on this ridge (near G, Fig. 1). Such conditions are not common, and it is not known to what extent a raingauge simulates the ability of vegetation to intercept drifting cloud.

DISCUSSION

The variation of catch of the vertical gauges over the 90-ha Experimental Station could include random errors, variation due to the gauge performance, and real variation of rainfall. Hutchinson (1969) gives some indication of the possible magnitude of random errors, using data from 12 gauges placed at random on a site which measured 9 × 15 m. Most of his data are for storms in the smallest size class (0–7.5 mm) used in Table 2, and he reports standard deviations in the range 0–0.4 mm. His data indicate an average coefficient of variation for these storms of about 5%, which is approximately half that given for the smallest size class in Table 2. For monthly totals Hutchinson found coefficients of variation of 1.0 to 2.1%, whereas most of the values in the present work fall in the range 3 to 7% (see Fig. 2).

Comparisons of standard gauges at the height of 0.3 mm above ground level with gauges at ground level have shown the catch of the standard gauge to be deficient. On level sites Green (1970) found an average deficiency over a 5-year period of 3%, while Rodda (1967) found an average deficiency of 6.6% over 5 years and monthly deficiencies of up to 15%. The variation of catch among gauges at Taita is of similar magnitude to the deficiency of catch reported by Rodda (1967) and Green (1970). Much of the variation within the network may result from variation of gauge performance as a result of site conditions rather than any real variation of rainfall. The differences between catches on windward and leeward slopes are similar to those reported by others (e.g. Geiger, 1966, p. 419; James, 1964; Hovind, 1965), but – as Rodda (1966) suggests – these differences may also reflect the effect of wind on gauge catch. A real variation probably occurs when the cloud base is below about 250 m above sea level, but this is infrequent and the area involved is small; an investigation of interception by the vegetation would be needed to evaluate its hydrological significance.

The variation of catch among gauges is quite small, and for most purposes an adequate estimate of the mean catch of the network is obtained from a single gauge, the gauge in the climatological station, which is in error by less than 5% for about 90% of large storms (greater than 25 mm) and monthly totals. As the coefficient of variation of catch averages about 6% for these storms (Table 2) or monthly totals (Fig. 2), at least four randomly located gauges would be needed to achieve a similar precision in estimating the mean for the network. Although the precision of the estimate of the mean catch is improved by using more gauges, as in the three networks used in this study, the possibility of significant systematic errors in actual rainfall measurement needs further examination. One source of error, the deficiency of catch of a standard gauge compared to a ground-level gauge, has been mentioned above. A second concerns gauge wetting losses (Finkelstein, 1971; Waugh, 1971; Rapier and Grant, 1971). There is a third source of systematic error, which needs consideration when individual small steep catchments are being studied in a region where rainfall is strongly inclined, since the effective rainfall on each catchment depends on its slope and aspect. At Taita, studies with tilted gauges in conjunction with the vertical gauges of Network 1 indicated that in the Exotic Forest Catchment this error is about 5% for long-term totals and up to 10% in some storms (Jackson and Aldridge, 1972).

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