

ASPECTS OF RAINFALL MEASUREMENT IN A NEW ENGLAND LOCATION

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ABSTRACT

An experiment to assess the impact of mounting and site factors on rain-gauge catch is described. When compared with the magnitude of random variations between gauges mounted on a site at a height of 30.5 cm, the influence of mounting and siting was not as great as might have been anticipated.

INTRODUCTION

A number of investigations necessitating rainfall measurement are under way or proposed at the University of New England and it is necessary that an analysis of aspects of the measurement problem be carried out in this location. This preliminary analysis considers the impact of mounting and siting of rain-gauges and serves as a basis for a more extensive analysis of rainfall variations due to meteorological conditions and larger scale relief influence in the area.

The catch of a rain-gauge at a point is determined by a number of factors ranging from small scale influences such as gauge dimensions, mounting and local relief to major relief factors such as mountain ranges and the general meteorological conditions producing the rain. It is important to have some indication of the possible magnitude of the impact of mounting and site factors on rain-gauge catch before analysing rainfall variations over a wider area or utilising data for hydrological and agricultural purposes. Particularly in the case of dense rain-gauge networks over small areas of varied relief it may be impossible to find sufficient sites which satisfy 'normal' specifications and the consequence of this must be evaluated.

A major problem with all such experiments is in the application of results elsewhere since to some extent each situation is unique. Under conditions of low wind-speed and generally high rainfall intensity in a tropical location for example, Jackson (1971) found that the impact of marked differences in siting was of little importance, but there is ample evidence indicating that this is not so elsewhere under different meteorological conditions. It is for this reason that studies over a wide range of meteorological and topographic conditions are necessary. Despite this problem, it is hoped that the results of this analysis may be relevant not only for the general area in which the experiment was situated but also for other areas where conditions may be considered similar.

THE EXPERIMENT

Australian Standard 203 mm non-recording gauges were located at three sites (Fig 1), distances between sites I and II, II and III being 1 and 0.1 km respectively. Site details were as follows:

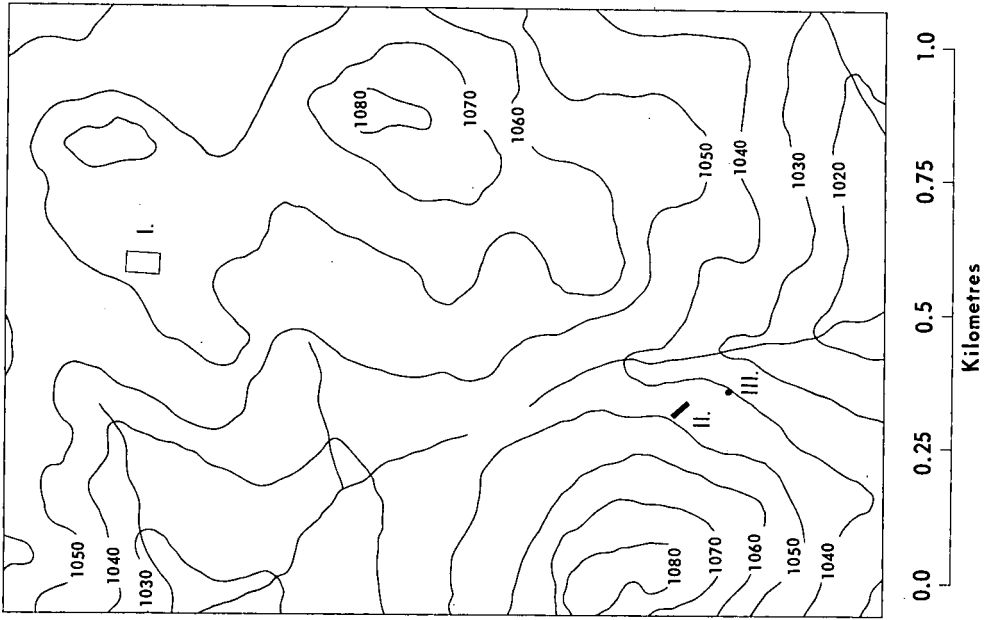


Fig 1 Location of rain gauge sites.

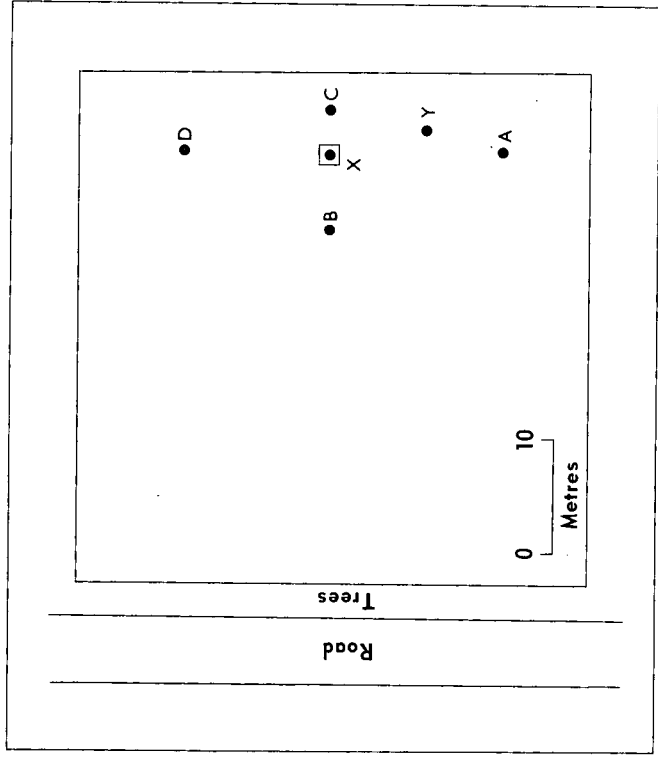


Fig 2 Site I.

Site I (Fig 2)

The site was level and although surrounded by fairly flat country on all sides could not be considered overexposed. A discontinuous line of trees growing to a height of 8 to 9 m were 39 m to the west of the site.

Four 203 mm gauges (Fig 2 A, B, C, D) were mounted at a height of 30.5 cm to detect any possible trend in rainfall across the site or to assess the magnitude of random variations. For a uniform but exposed site in New Zealand, Hutchinson (1969) found that random variations between standard 127 mm gauges at a height of 30.5 cm could be considerable and Huff (1955) in the USA, found that differences between gauges 2 m apart were appreciable for storms greater than 12.5 mm. Allis *et al* (1963) felt that lack of replication of gauges in an experiment assessing the performance of different types was a deficiency because of the possible impact of random variations. Differences between gauges on what are accepted as 'uniform' sites may not be random in the true statistical sense but due to small, undetected irregularities in the site which create differences in windspeed. While Clarkson (1971) suggests that such irregularities would lead to cumulative, systematic differences between gauges, there is no reason to suppose that their effects would necessarily be constant under varying wind and rainfall conditions. Observational errors, discussed below, could also be responsible for small differences between gauges.

For comparison with the gauges at 30.5 cm, a gauge with rim at ground level was located between gauges A, B, C and D (Fig 2). This gauge (X), was surrounded by a grid 2 m x 2 m composed of slats at an angle of 45° to prevent splash into the gauge. In order to evaluate the impact of gauge height further, a 203 mm gauge was mounted at a height of 121.9 cm on a metal stand (gauge Y in Fig 2). Clarkson (1973), in assessing the performance of a tulip shaped gauge mounted at a height of 10 m points out that because of the presence of shallow water or danger of flooding, standard mounting at a height of 30.5 cm may not always be practicable. This may well be the case for some of the proposed investigations at the University of New England.

Site II (Fig 3)

Possible impacts of local site factors are assessed here, the essential contrasts being between a comparatively exposed situation on level ground above a slope of 15.5° (gauge M), on the slope itself (N) and in a more sheltered location below the slope (P). Each site and its surrounding area is unique and hence it is difficult to draw general conclusions. However, the locations of the three gauges represent the kind of sites which in many cases must be accepted for lack of suitable alternatives. In most cases, less 'extreme' sites would probably be available, the aim here being to try and assess how large the differences might possibly be.

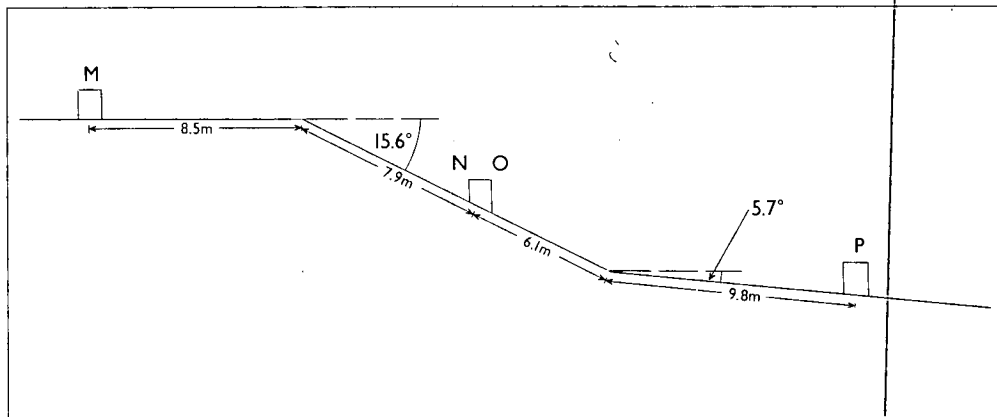


Fig 3 Site II.

The question of differences between gauges mounted with their rim horizontal and with the rim parallel to the ground surface has been the subject of considerable study, aspects being reviewed by Corbett (1967). For comparison, a gauge O was mounted alongside N but 2 m from it with the rim parallel to the slope.

Site III

Two 203 mm gauges, one with rim horizontal (K), the other with rim parallel to the slope (L) were mounted 2 m apart. This site had an easterly aspect, the same as the slope at site II, but the slope angle was less (9.5°). Sites II and III were only 100 m apart.

During the period from 19 January 1973 to 16 July 1973 readings were taken daily, usually beginning at 0900 hours at site I, the whole sequence taking about 30 minutes. Reading was postponed if it was raining at that time, however. Individual readings might therefore be composed of a number of storms (*ie*, single rain periods) of different character and this has implications in terms of differences between gauges. Since most gauges are read on a daily basis, however, comparability may be useful and furthermore, even during a single rain period, characteristics such as rainfall intensity, windspeed and direction may vary considerably.

Factors other than mounting and site could produce variations between the gauges. Variations in the collecting area of gauges should not exceed 0.25% (Handcock 1960) and therefore this factor can be ignored. Evaporation from gauges is only likely to be serious in dry climates where the catch is measured infrequently (WMO 1971) and in any case over this small experimental area variation between gauges would be negligible.

While the World Meteorological Organization (1971) states that, provided reasonable care is taken, errors in reading the catch will be small compared with uncertainty due to the effects of exposure of the gauge, for an experiment of this nature this aspect must be considered. Failure to transfer all water from the gauge to the measure or not completely emptying the measure before refilling are possible sources of error. Given care with the procedure, this is unlikely to cause appreciable error and in any case the error could be expected to be reasonably constant between gauges. The World Meteorological Organization (1971) states that accurate measures should have a maximum calibration error of 0.02 mm up to the 2 mm mark and 0.05 mm above the 2 mm mark. Any calibration error is likely to be constant (*eg*, all readings 0.03 mm too high) and since the same measure was used for all gauges this would not create variations between gauge readings. If the calibration error was not constant then small differences could result.

Errors in reading the measuring cylinder may be wholly random or partly random and partly systematic; one observer, for example, reading consistently high (Handcock 1960). Since all gauges were read by one person, the systematic error can be neglected.

The measuring cylinder had a capacity of 10 mm, the first millimetre being graduated at 0.1 mm intervals and the remainder at intervals of 0.2 mm. Reading errors could be taken as being 0.05 mm up to 1 mm and 0.1 mm above 1 mm. In terms of the difference between two gauges, these errors could cancel out or could be additive. Thus, for a fall of up to 1 mm, the error in the difference between two gauges could be up to 0.1 mm, and up to 0.2 mm for falls of 1 mm to 10 mm. For falls greater than 10 mm errors could cancel out or be additive. Handcock (1960) states that the larger the number of observations, the more likely that random reading errors will cancel and Learmonth (1960) classifies them as self correcting with zero cumulative effect. It is possible however that, say for a fall of 20 to 30 mm, the extreme error in the difference between two gauges could be 0.6 mm. However, the higher the fall, the more likely it is that errors would tend to cancel. While above 1 mm the measuring cylinder was graduated at 0.2 mm intervals, for consistency readings were estimated at 0.1 mm.

For very small falls, say < 1 mm, measurement errors discussed above and factors such as dew could result in considerable differences between gauges in relative terms. For example, the difference between two gauges could be subject to a reading error of 0.1 mm for a fall of 0.3 mm. Differences for such small falls are of no practical significance however and this was considered when discussing the results.

RESULTS

Gauges A, B, C and D

Monthly totals (Table 1) in most cases differed little, the exception being the July figures. The latter differences were due to exceptionally variable readings at all three sites on 16 July (Table 2). In Table 2 differences are clearly greater than possible observational errors previously discussed. Much of the difference between totals for the whole period is due to this single reading. Unfortunately, no wind data for this individual reading were available but the considerable variations between gauges apparent at all three sites tend to suggest high, possibly gusty winds. Since considerable differences were found at all three sites, mis-reading or interference with gauges can safely be ruled out.

Table 1 Monthly rainfall (mm) 1973, Gauges A to D

Gauges	Jan*	Feb	Mar	Apr	May	Jun	Jul†	Total
A	48.0	109.9	44.6	23.8	26.4	31.4	26.3	310.4
B	48.6	106.9	45.8	24.4	27.2	33.3	31.1	317.3
C	49.6	111.4	46.9	24.5	26.7	31.8	34.3	325.2
D	49.3	110.5	46.9	24.0	26.2	31.3	29.9	318.1
(A,B,C,D)	48.88	109.68	46.05	24.18	26.63	31.95	30.40	317.75

* 19 to 31 January

† 1 to 16 July

(A,B,C,D) = mean of gauges A, B, C, D.

Table 2 Readings on 16 July 1973 (mm)

Gauge	A	B	C	D	X	Y	M	N	O	P	K	L
Rainfall	19.3	24.6	27.4	23.1	27.8	18.0	20.9	13.4	21.8	22.0	10.7	18.2

While gauge C had the highest total overall, this was not always the case even for monthly readings and certainly not in the case of individual daily figures. Even monthly readings (Table 1) indicate something of the lack of consistency in readings in the sense that one particular gauge did not always read more or less than any other. For individual days, readings often varied considerably between gauges, there being a general, although not close, relation between variations, expressed by the standard deviation, and daily totals (Table 3). The complexity of the situation is illustrated in Table 4, which shows the lack of consistency in the ranking of gauges and that while variations in general increase with storm size, this is not always so. Some of the differences are greater than possible observational errors. To see if there was a particular sequence in gauge ranking, the Friedman two way analysis of variance by ranks (Siegel 1956) was applied to the daily readings. No significant difference was found, indicating that the ranking of the gauges was not consistent.

Table 3 Relationship between standard deviation and storm size, gauges A to D and New Zealand data.

Gauges A to D

$$Y = 0.0199 + 0.0319x$$

where Y = standard deviation (A,B,C,D), $x = \overline{(A,B,C,D)}$

$r^2 = 0.4406$ (0.01% significance level), r = correlation coefficient

Mean storm size (mm)	2.54	5.08	7.62	10.16
Standard deviation -				
New Zealand*	0.127	0.229	0.406	0.635
New England (A to D)	0.101	0.182	0.263	0.344

*Data from Hutchinson (1969)

Table 4 Gauges A to D, examples of daily readings (mm), 1973

Gauge	26 Jan	29 Jan	12 Feb	17 Feb	27 Feb	14 Mar	16 May	24 May	16 Jul
A	9.7	13.5	57.2	2.3	24.1	33.8	1.8	0.2	19.3
B	9.9	13.5	55.6	2.3	23.1	34.8	1.8	0.2	24.6
C	9.9	14.0	58.9	2.3	23.6	35.6	1.7	0.4	27.4
D	9.9	13.5	58.2	2.3	24.4	35.8	1.8	0.1	23.1
$\overline{(A,B,C,D)}$	9.85	13.63	57.5	2.3	23.8	35.0	1.78	0.23	23.60
S.D. $\overline{(A,B,C,D)}$	0.10	0.25	1.43	0.00	0.57	0.91	0.05	0.13	3.38

Where $\overline{(A,B,C,D)}$ = mean of gauges A,B,C,D and

S.D.
 $\overline{(A,B,C,D)}$ = standard deviation between gauges A,B,C,D.

The readings from a single gauge for individual days on a 'normal' site may therefore be subject to considerable uncertainty even as indicators of rainfall over a uniform small area. This substantiates the findings of Huff (1955) and Hutchinson (1969) referred to earlier. Comparative data from the latter for 12 gauges in New Zealand are presented in Table 3. Variations, expressed by the standard deviation, are greater for the New Zealand data, this perhaps being attributable to the exposed nature of the site. Table 2, however, does indicate just how large variations could be at the New England site.

Differences between the four gauges A to D may therefore be considerable although variable in relative or absolute terms. They cannot be accounted for simply by observational errors such as those involved in reading. Since no significant difference was found in the ranking of gauges, differences may be regarded as 'random' in nature. They are perhaps indicative of the limitations of gauges mounted above the ground which lead to a disturbance of the airflow. Their magnitude is relevant not only in terms of the representativeness of a single gauge but also in analysing the impact of mounting and siting of the other gauges in the experiment.

Gauges A to D and X

The mean of gauges A to D, designated by $(\overline{A,B,C,D})$, is used in comparison with gauge X but the variation between gauges A to D must be borne in mind. Monthly values (Table 5) illustrate the general principle that readings for the grid gauge (X) are higher than those for gauges at a height of 30.5 cm. Such consistency rules out the possibility of differences being due to random observational errors even if the latter had been of sufficient magnitude. Ratios $\frac{X}{(\overline{A,B,C,D})} \%$ for monthly readings range from 103% to 116% with an overall figure for the whole period of 107%. Since differences vary with wind and rainfall parameters, however, individual readings show considerable fluctuations. For a few cases where falls were very small, the grid gauge had a value slightly less than $(\overline{A,B,C,D})$. Problems associated with small storms have already been referred to. In the case of the reading on 16 July, $\frac{X}{(\overline{A,B,C,D})} \% = 118\%$. On this occasion however, it should be noted that gauge C had a value almost equal to X (Table 2), the difference being within possible reading error.

Table 5 Monthly rainfall 1973 $(\overline{A,B,C,D})$, X, Y

Gauge	Jan*	Feb	Mar	Apr	May	Jun	Jul†	Total
$(\overline{A,B,C,D})$	46.88	109.68	46.05	24.18	26.63	31.95	30.40	317.75
X	52.1	114.2	51.7	25.3	27.5	34.2	35.2	340.2
X/ $(\overline{A,B,C,D})$ %	107	104	112	105	103	109	116	107
Y	49.6	110.0	47.4	23.9	26.9	31.4	24.8	314.0
Y/ $(\overline{A,B,C,D})$ %	101	100	103	99	101	98	82	99

* 19 to 31 January

† 1 to 16 July

$(\overline{A,B,C,D})$ = mean of gauges A,B,C,D

These results in general therefore confirm those of previous studies. Thus Green (1958) suggested that particularly in comparing rainfall with potential evaporation values, it was necessary to increase rain-gauge readings at 30.5 cm by 5%. The overall figure for this experiment is fairly close to this (7%) but individual daily readings varied considerably. Furthermore, the difference between gauge X and $(\overline{A,B,C,D})$ should be compared with the variation between gauges A to D. The maximum difference between gauges A, B, C, D, denoted by $(\overline{A,B,C,D})_{\max}$ was compared with $X - (\overline{A,B,C,D})$ using a paired t test of daily values. The difference was not significant, suggesting therefore that while gauge X invariably gave a higher reading than gauges at 30.5 cm, the difference was no greater than might be expected between gauges mounted in the standard way. This itself however may simply further indicate the unreliability of measurements involving gauges mounted above the ground. Since only a small number of gauges was used in the analysis, the comparison may not be valid although it might be expected that if the number of gauges at 30.5 cm was increased, the maximum difference between them would also increase.

Gauges A to D and Y

Monthly values (Table 5) indicate the differences between gauge Y, at a height of 121.9 cm, and $(\overline{A,B,C,D})$ are small and inconsistent. For readings > 1 mm, $\frac{Y}{(\overline{A,B,C,D})} \%$ ranged from 76% to 103%. The value 76% was for the exceptional reading of 16 July referred to previously, the next lowest value being 91%. $(\overline{A,B,C,D})_{\max}$ values were significantly greater than Y - $(\overline{A,B,C,D})$ values (5% significance level), reinforcing

the point that differences between gauges at 121.9 cm and 30.5 cm are of little importance. Clarkson (1973) found that a tulip shaped gauge at a height of 10 m under-read by less than 2% compared with a normal gauge.

Gauges M, N and P

The Friedman analysis of variance test indicated an overall significant difference in the ranking of the three gauges (0.01% level), with P in the more sheltered position tending to have the highest figure in many, but not all cases. This consistency again means that random reading errors could not be responsible for the differences. Paired t tests however indicated that the difference between gauges M and N was not significant. Monthly values are shown in Table 6. Again, the marked impact of the 16 July figure on both the July and overall totals is apparent. Differences between the three gauges were less than (A,B,C,D)_{max} although not significantly so.

The paired t test used may not be completely valid in this case because on a few occasions there was a marked difference in storm size between site I and site II. Despite this, the general inference that differences between gauges M, N and P are no more than those between gauges A to D is justifiable.

Table 6 Monthly rainfall (mm) 1973, gauges M, N, P

Gauge	Jan*	Feb	Mar	Apr	May	Jun	Jul†	Total
M	47.9	120.5	45.0	22.7	25.3	34.7	28.2	324.3
N	47.4	115.7	43.4	22.9	25.4	35.5	20.9	311.2
P	48.6	120.5	45.6	24.1	26.1	35.6	30.0	330.4

* 19 to 31 January † 1 to 16 July

Gauges N, O, K and L

Since both pairs of gauges were on slopes with the same aspect and the two sites close together, relationships between horizontal and parallel gauges would be expected to be similar in nature, differing only in magnitude in response to slope differences. In less than 7% of cases the relationships at the two sites were opposite, although on 18% of occasions, gauges at one site were equal and the pair at the other site different. The nature of the relationships, depending on wind and rainfall characteristics, as would be expected, was extremely variable, examples being shown in Table 7. Since the relationships between horizontal and parallel gauges were in most cases the same at both sites, random reading errors could not be responsible. In any case the magnitude of differences could not be accounted for solely by observational errors. Neither pair of gauges was significantly different, monthly totals being shown in Table 8. Again the impact of 16 July is apparent.

Table 7 Daily readings (mm) 1973, gauges K, L, N, O

Gauge	28 Jan	29 Jan	12 Feb	27 Feb	14 Mar	24 Mar	9 Apr	16 Jul
K	16.3	15.0	58.9	33.8	34.0	1.2	3.6	10.7
L	16.3	14.7	61.0	33.3	30.5	1.8	3.6	18.2
N	16.3	15.0	57.9	29.7	33.8	1.6	3.6	13.4
O	16.3	13.2	62.0	30.0	29.7	2.0	3.6	21.8

Table 8 Monthly rainfall (mm) 1973, gauges K, L, N, O

Gauge	Jan*	Feb	Mar	Apr	May	Jun	Jul†	Total
K	47.4	120.2	43.4	22.2	25.9	35.6	17.8	312.5
L	48.3	122.6	40.1	22.2	25.3	34.0	25.0	317.5
N	47.4	115.7	43.4	22.9	25.4	35.5	20.9	311.2
O	47.5	120.2	39.5	22.7	24.5	33.3	29.5	317.2

* 19 to 31 January † 1 to 16 July

As would be expected, gauges on the smaller slope (K,L) differ less than N and O. Differences between K and L were less than $(A,B,C,D)_{max}$ although not significantly so. There was no significant difference between (N,O) and $(A,B,C,D)_{max}$. As in the comparison involving M, N, P, the paired t test used may not be completely valid because of variations between sites, but the general inference that differences between horizontal and parallel gauges, while existing, are no greater than those between gauges A to D is acceptable.

Differences between sites I, II and III

For comparison, site I was represented by (A,B,C,D) , site II by the mean of gauges M, N and P, (M,N,P) and site III by gauge K. A significant difference (0.01% level) existed in the ranking of the three sites (Friedman analysis of variance test) with a general increase from site III to site I, although there were exceptions to this. A paired t test showed that differences between sites III and II were not significantly greater than $(A,B,C,D)_{max}$, however. Differences between sites I and II fell just short of being significantly greater than $(A,B,C,D)_{max}$. Differences between sites I and III were significantly greater than $(A,B,C,D)_{max}$ (significant at 0.5% level).

Choice of sites was dictated by the aims of the experiment, which was not concerned with local rainfall variations. Generalisations from site differences are not really possible but it is of interest that although there was a significant difference between the three sites, only between I and III was this significantly greater than $(A,B,C,D)_{max}$.

DISCUSSION AND CONCLUSIONS

The problems of generalising from an individual experiment have already been referred to. Deficiencies in the experiment include lack of wind data and lack of replication of gauges, the variation between gauges A to D highlighting the latter aspect. Despite these problems, a number of points emerge.

Random variations between gauges A to D were often considerable, supporting the findings of Huff (1955) and Hutchinson (1969). They could not be solely due to observational errors involved in reading. These may indicate the problems resulting from turbulence and eddies created by gauges with rims above ground level. The magnitude of the variations has implications in terms of differences in readings due to mounting and siting. While the gauge with rim at ground level (X) gave readings averaging 7% higher than those at 30.5 cm, the difference was not significantly greater than $(A,B,C,D)_{max}$. Differences between the gauge at 121.9 cm and those at 30.5 cm were small, inconsistent and significantly less than $(A,B,C,D)_{max}$. There was

a significant difference in the ranking of gauges M, N, and P, but the differences between individual pairs of these gauges were not significantly different from $(A,B,C,D)_{\max}$.

Differences between gauges mounted with their rims horizontal and parallel to the slope varied considerably in magnitude and sign but again were not significantly different from $(A,B,C,D)_{\max}$. While there was a significant difference between the three sites, only that between I and III was significantly greater than $(A,B,C,D)_{\max}$.

The individual reading on 16 July illustrated the possible magnitude of differences between gauges, but even in this case the random variations between A, B, C and D matched those of the other gauges under a variety of mounting and siting conditions.

Although mounting and site factors produce differences, when compared with the magnitude of 'random' variations in this area they may not be of such importance as might be anticipated. While it is dangerous to generalise from a single experiment this fact may be important, particularly if normally acceptable sites are unavailable. If the variation between gauges A to D indicates the impact of turbulence around the gauges then it suggests that mounting with rims level with the ground may be advantageous not only because their increased catch is perhaps more realistic but also because variations between gauges may be less. The latter could only be tested by an experiment involving a number of such gauges.

ACKNOWLEDGMENT

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