AN ANALYSIS OF RAINFALL AND SOIL MOISTURE CHARACTERISTICS IN THE CHILTON VALLEY, CASS

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ABSTRACT

Rainfall and soil-moisture characteristics are analysed for the Chilton Valley, Cass, in the Southern Alps. Methods used to investigate long-period rainfall changes indicate the possibility of a five- or six-year cycle, together with some trend break points — one especially at 1935. Daily rainfall analysis shows a tendency for wet and dry periods to occur in spells of at least two days. A study of soil moisture shows that between sites, vegetation and aspect are important. No relationships between moisture content and slopes or any soil characteristics are revealed. With respect to soil creep, soil moisture is important only in summer, freeze-thaw cycles being dominant in the winter.

INTRODUCTION

This study is part of the larger programme of work being carried out in the micro-climate and geomorphology project in the Chilton Valley, Cass (Soons and Rayner, in press). Rainfall is analysed in terms of long-period data and on a daily basis. Soil moisture records have been taken in association with a study of mass movement, and these show relationships not only with rainfall but also with other climatic parameters.

LONG-PERIOD RAINFALL ANALYSIS

Data for a long-period analysis of rainfall was obtained from records kept at the field station of the Canterbury University Botany Department about a mile from the Chilton Valley. An analysis was made over the 48-year period 1918–65. In this time the average rainfall was 51.23 inches with a variability, following the definition used by Seelye (1940), of 14.91%. The relatively high variability emphasises the fact that the location is in an area of steep annual rainfall gradient from high values in the west to low values in the east. There is only a small variation within the year, ranging from 3.51 inches in February to 5.11 inches in October. There is a gradual increase from mid-summer continuing until late spring, with the months of May and October having significantly higher values. This can be seen from Table 1.

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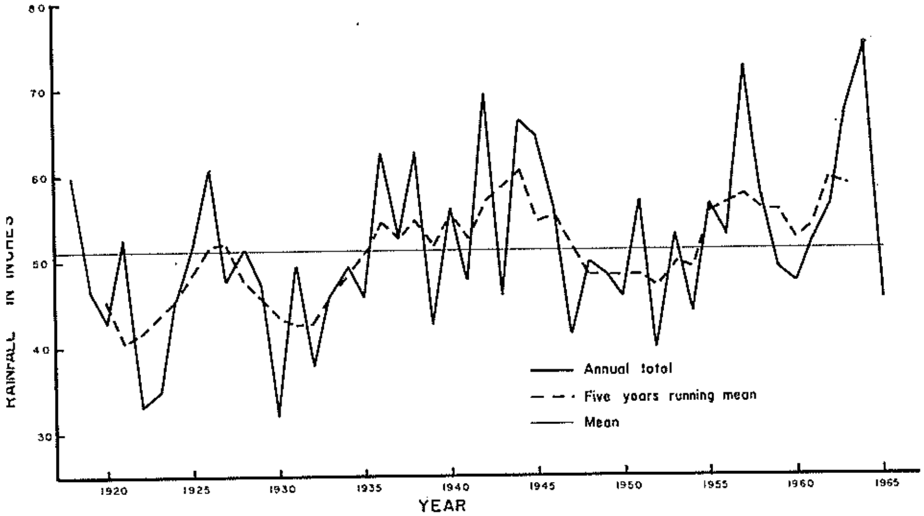

Fig. 1—Annual rainfall at Cass.

TABLE 1 — Monthly average rainfall in inches.

Jan.	4.37	Apr.	4.10	July	4.03	Oct.	5.11
Feb.	3.51	May	4.88	Aug.	4.12	Nov.	4.53
Mar.	3.78	June	4.07	Sept.	4.32	Dec.	4.38

The annual totals over the period are presented in Fig. 1, and the degree of variability can be seen at once. As a first step in searching for some order in the series, five-year running means were taken and these are also shown. They demonstrate two periods of relatively high precipitation between about 1934–47 and 1955–63, but it would be unwise to infer more than this. Harmonic analysis was used to look for periodicities of longer than about ten years, but the low amount of variance of the time series, explained by the harmonics tabulated in Table 2, indicates that this method does not reveal any such periodicities.

TABLE 2 — Variance explained by the first five harmonics.

Harmonic number	1	2	3	4	5
% variance explained	7.29	12.01	5.73	1.56	16.32

The autocorrelation method was used to investigate shorter periodicities. Autocorrelation coefficients were computed for the time series using the formula given by Lambe (1967). This formula differs slightly from that of Brooks and Carruthers (1953), the difference being in the term which allows for the decrease in data with increased lag values. The correlogram from the correlation coefficients is shown in Fig. 2. The diagram is difficult to interpret, but following the example of the latter two authors, peaks at lags

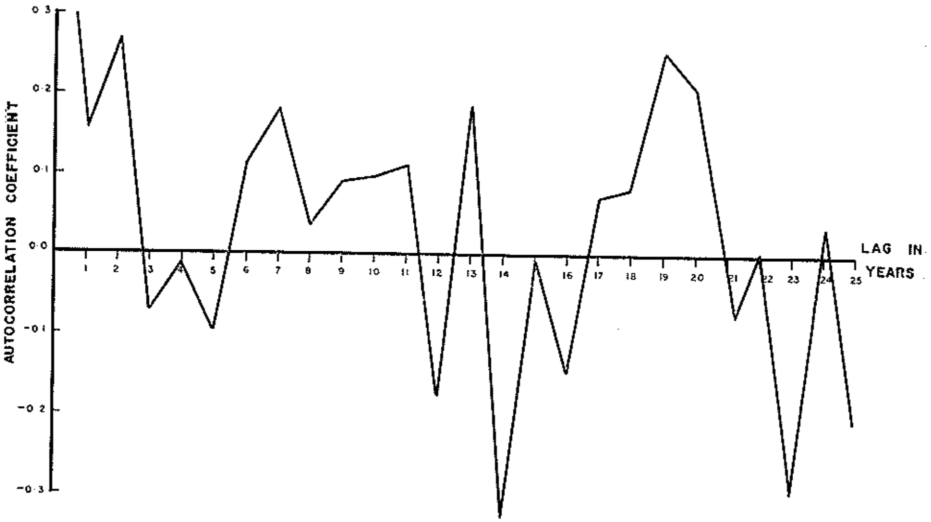

Fig. 2—Correlogram of autocorrelation coefficients.

of 2, 7, 13 and 19 years point to a periodicity of about five or six years. The amount of data used here greatly restricts the significance of the diagram after lags of about ten years. Thus it must be concluded that, although there is some evidence for a periodicity of this order, it has not been definitely proved. Such proof awaits power-spectrum analysis of this and other, preferably longer, time series from nearby locations. This will be the subject of a later paper.

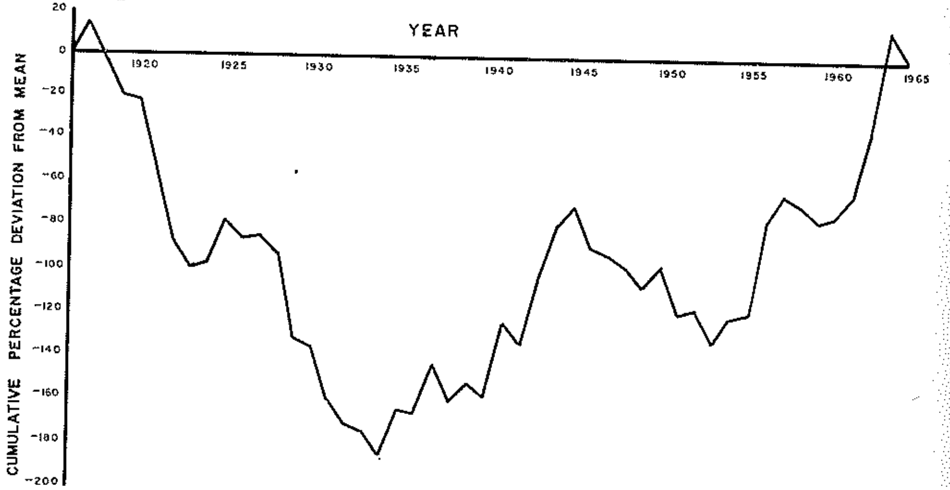

Fig. 3—Residual mass curve.

Apart from periodicities, secular changes or trends were investigated by plotting the residual-mass curve, as used by Kraus (1955) in Australia and de Lisle (1956) in New Zealand. The curve of the present series is shown in Fig. 3. Again, care has been urged in the use of this method (W.M.O., 1966) but it is still considered by some workers to be able to demonstrate major trends or break points in a time series. The curve for Cass indicates periods of below-average rainfall from 1918–35 and 1946–54 and above-average from 1936–45 and 1955–64, with significant turning points at 1935, 1946 and 1954. It is difficult to compare these results with those of de Lisle for the West Coast as his data were analysed on a seasonal basis. However, the present findings agree in general with those of Finkelstein (1962) for the whole of the country.

Summarizing the above discussion it appears that — using the methods described — no long periodicities are present, but that there is the possibility of a cycle of the order of five or six years. Secular trend changes appear to have occurred in 1935, 1946, and 1954. The results for the Botany Department Field Station data were related to the Chilton Valley rainfall by means of a regression line using 15 monthly values of rainfall. The correlation coefficient between the two series is 0.98. The regression of the Chilton Valley figures (Y) on the station data (X), to two places of decimals, is very close indeed, namely:

$$Y = X \qquad (1)$$

DAILY RAINFALL ANALYSIS

Daily rainfall records, obtained from a Lambrecht rain gauge, for the periods 1 August 1964 to 31 August 1965 and 1 March 1966 to 7 July 1967 have been analysed. Perhaps the most signicant point about these records is that wet and dry periods tend to occur in groups of two days or longer. This is common to many parts of New Zealand. One measure of this fact is that persistence forecasts for the valley would have given verification figures of 63.0% and 70.6% of the time for wet and dry days respectively. Another measure, the persistence indices R and r_B (Brooks and Carruthers, 1953), gives values of 1.24 and 0.35. These are of the same order as figures quoted by Finkelstein (1967) for other parts of the country, but they are not directly comparable owing to the shorter data period and the different definition of a rain day used here (0.01 cm instead of 0.01 in.).

Frequency distributions of different lengths of dry and wet periods have been drawn and the results are shown in Table 3. It can be seen that fewer than one third of wet and dry periods occurred as single days. This has considerable significance in the wetting and drying of the soil. It should be noted, however, that if rain days had been defined as having greater than 0.5 cm, a figure ensuring that the soil would be well wetted, then the distribution of wet periods would have tended heavily to periods of one day, and that of dry periods towards longer durations.

TABLE 3 — Percentage of periods of specified length of the total number of periods observed

Length of periods (days)	1	2	3	4	5	6	7	8	9	10 and above
Wet periods (% of total)	30.5	29.7	14.1	11.7	8.6	3.1	0.8	0.8	0.0	0.8
Dry periods (% of total)	30.2	19.1	11.1	15.1	8.7	3.2	4.8	2.4	0.0	5.6

TABLE 4 — Percentage of rainfall periods of specified amounts of the total number of periods observed

Amount (cm)	0.0–0.4	0.5–0.9	1.0–1.4	1.5–1.9	2.0–2.4	2.5–2.9	3.0–3.4	3.5–3.9	4.0–4.4	4.5–4.9	5.0 and above
% of total	27.3	20.3	10.9	11.7	5.5	3.1	5.5	3.9	2.3	0.8	8.6

A similar analysis of the rainfall amounts in any one period is shown in Table 4 and indicates that most wet periods had light rainfalls. Half of them were less than 1.5 cm. This is of importance to soil and plants in geomorphic processes. Rainfall intensities are also small and have been discussed elsewhere (Soons, 1966). This is also shown for the maximum expected intensities which have been calculated using the work of Robertson (1963) and which are given in Table 5. Figures quoted here have an estimated accuracy of plus or minus 10% because of interpolations that had to be made from the original work.

TABLE 5 — Expected maximum rainfall intensities.

Duration of rain (hours)	*Depth in inches for a given return period in years*					*% chance of recording in an area 5 sq. miles around collecting point*
	2	*5*	*10*	*20*	*100*	
½	0.4	0.6	0.7	0.8	1.1	80
1	—	0.9	1.0	—	1.4	87
2	1.2	1.4	1.6	1.7	2.0	—
6	—	2.3	2.8	—	3.8	96
12	—	3.1	3.8	—	5.2	—
24	3.1	4.2	4.9	5.7	7.1	98

Examination of daily rainfall therefore reveals a tendency for both wet and dry periods to come in runs of at least two days, and the storms themselves to be relatively light. At this point it should be briefly noted that a dense network of rain gauges is now in operation in the valley in order to investigate the spatial variation. So far, over a period of six months, no clear pattern has emerged.

SOIL MOISTURE

A soil-moisture study was undertaken as part of an investigation into the causes and rates of soil creep. Previous quantitative work on the causes of creep is limited to that of Young (1958) and Kirkby (1965). Kirkby developed a theory of soil creep in which movement was caused by cyclic changes in soil moisture. He then tested this theory by correlating measured creep and moisture changes. As several methods of measuring soil moisture proved unsatisfactory, he relied on a theoretical model of moisture change analogous to the unit hydrograph. A significant correlation between moisture changes and measured creep appears to be the main justification for the model. In this study the influence of soil moisture changes on soil creep was also examined, but the problem of obtaining a day-to-day record of soil moisture changes was approached in a different manner.

METHODS

Soil samples were taken from four sites at depths of 0–3, 7.5–10.5, and 15–18 cm, over a period of ten months. Determination of moisture content was made by normal gravimetric methods and computed on a dry-weight basis. The change of tilt of ten tilt-bars (see Selby, 1966) at each site was recorded at the same time. In an attempt to establish a record of daily moisture changes, the observed moisture values were correlated with rainfall and radiation data from the micro-climate station (Soons and Rayner, in press). Several different periods of rainfall and radiation were tested and the most significant used in equations to predict moisture content at the four sites. Further analysis involved correlating accumulated soil moisture (the sum of moisture increases for a given period) with tilt-bar measurements.

RESULTS

Some of the general characteristics of the four sites are shown in Table 6, while Table 7 summarizes the soil-moisture and tilt-bar measurements. Within sites moisture content tended to increase with depth while variations decreased with depth, as could be expected. The most significant features of the tilt-bar measurements were their great variability and the fact that significant downslope movements were recorded at only two sites.

TABLE 6 — Site characteristics

Site	*Aspect (degrees)*	*Slope (degrees)*	*Particle size (φ units)* M_z*	δ_I*	*% clay*	*% Bare area*
1	121	27	−1.13	−2.56	1.0	54.0
2	143	34	−1.66	−2.73	0.5	2.0
3	312	27	2.63	−3.99	11.0	100.0
4	205	16	0.23	−2.94	6.2	19.0

* Folk parameters (Folk, 1965).

TABLE 7 — Soil moisture and tilt-bar measurements.

	Soil moisture (% dry weight)						*Total tilt-bar movements*	
	Mean			*s. d.*				
Site	*0–3*	*7.5–10.5*	*15–18*	*0–3*	*7.5–10.5*	*15–18*	*Mean*	*s d.*
1	32.4	37.2	33.0	11.9	7.8	8.5	141.2	89.9
2	40.1	42.7	46.5	10.6	5.9	5.6	2.8	30.7
3	18.3	25.4	25.6	5.7	4.9	4.2	217.6	197.6
4	34.4	38.6	32.7	10.8	7.8	5.6	4.4	30.1

The results of an analysis of variance on the moisture contents for six pairs of sites is shown in Table 8. This showed significant differences between all sites at the 0.05 level except between sites 1 and 4. All other differences were significant at the 0.01 level, except for the top two samples at sites 2 and 4.

TABLE 8 — Analysis of variance of moisture content, between sites.

Sites tested	*d.f.*	*Within-sample mean square*	*Between-sample mean square*	*F*	*Significance*
1 and 2					
a	82/1	112.33	1412.864	12.578	99.99
b	78/1	50.244	542.155	10.79	99.99
c	76/1	57.919	3326.774	57.438	99.99
1 and 3					
a	82/1	72.952	3750.685	51.413	99.99
b	78/1	45.272	2784.8	61.513	99.99
c	76/1	46.257	1067.08	23.069	99.99
1 and 4					
a	82/1	116.033	188.7	1.626	NS
b	78/1	64.036	47.586	0.743	NS
c	76/1	52.981	0.862	0.016	NS
2 and 3					
a	82/1	73.865	9750.086	131.998	99.99
b	78/1	30.92	5861.888	189.582	99.99
c	76/1	30.097	8162.107	271.913	99.99
2 and 4					
a	82/1	116.945	568.88	4.865	99.95
b	78/1	49.683	261.034	5.254	99.95
c	76/1	36.821	3434.74	93.282	99.99
3 and 4					
a	82/1	77.566	5621.955	72.48	99.99
b	78/1	44.703	3554.039	79.503	99.99
c	76/1	25.159	1007.288	40.037	99.99

a=0–3 cm. b=7.5–10.5 cm, c=15–18 cm.

Correlation analysis between moisture content and rainfall and radiation for various periods revealed that the 84 hours before sampling was the most significant period. This agrees with the analysis of the frequency of wet periods and with the lack of high intensity rainfall already noted. Logarithmic transformations of the data considerably improved correlations. The resulting equations for moisture content from 0–3 cm at the four sites were:

$$\log_e M_1 = 0.074331 \log_e Rl - 0.00326026 \log_e Rn\ 4.027187 \quad . \quad (2)$$
$$\log_e M_2 = 0.065275 \log_e Rl - 0.00224495 \log_e Rn\ 4.070848 \quad . \quad (3)$$
$$\log_e M_3 = 0.084413 \log_e Rl - 0.00255368 \log_e Rn\ 3.331627 \quad . \quad (4)$$
$$\log_e M_4 = 0.048115 \log_e Rl - 0.00253706 \log_e Rn\ 3.993316 \quad . \quad (5)$$

where Mn = percentage moisture content at site n,
Rl = rainfall in preceding 84 hours in cm, and
Rn = radiation in preceding 84 hours in cal/cm.^{2}.

The values of the coefficient of determination (R^2) for these equations were 56.84%, 62.51%, 60.77% and 51.8% for sites 1 to 4 respectively.

In the analysis of the relationship between accumulated moisture content and tilt-bar movement, only site 3 gave significant results. This was probably the result of the great variability of tilt-bar measurements and the small amounts of tilt recorded at the other sites. For site 3 the analysis was split into a consideration of the periods that were and were not affected by freezing and thawing of soil moisture (designated winter and summer). Table 9 shows the results of this analysis for site 3.

TABLE 9 — Relation between tilt and moisture changes and freezing and thawing of the soil moisture, site 3.

	Tilts measured in winter period	*Tilts measured in summer period*	*Tilts measured over while period*
Accumulated moisture content	− 0.11504	0.5219	− 0.10694
Number of freeze-thaw cycles	0.77795	—	0.74533

(Relation expressed as Pearson's product-moment correlation.)

DISCUSSION

Because of the small number of sample sites the causes of variations in moisture content between sites can only be discussed qualitatively. A most important control would appear to be the amount of vegetation, while aspect also seems to be important. No relationships between moisture content and slope or any soil characteristics are apparent from the data. The analysis of the influence of moisture changes in causing soil creep shows that this is important only in summer and that its overall contribution is small compared to the action of freezing and thawing of soil moisture.

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