VARIATIONS OF RAINFALL FREQUENCY IN RELATION TO DROUGHT ON THE EAST COAST

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ABSTRACT

Daily rainfall frequencies were analysed using consecutive-year plots and cumulative-departure curves. It is shown that since the end of the 19th century there have been pronounced periodic changes in the frequencies of the larger daily rains. In spring, summer and autumn — winter was not analysed in detail — periodic mean rainfall, since 1890, is positively related to both frequency and percentage contribution of rains greater than 1.50 inches.

Mean periodic rainfall effectiveness (R.E.) indices are presented. Abrupt decreases of R.E., or increases in drought severity, occurred in spring and summer during 1905–6, and in autumn about 1911. A further abrupt increase in drought severity occurred in spring about 1920. In summer, the most droughty period of this century was 1946–58; for autumn the current period since 1958 is the most droughty.

It is indicated that some of these changes of R.E. probably have practical significance, especially in relation to tree growth and some aspects of stream flow.

The connection between frequency changes of the larger rains and changes of atmospheric circulation is briefly discussed.

INTRODUCTION

Drought conditions exist in humid areas either when there is insufficient moisture in the soil to maintain plant life or when some types of plant become permanently impaired. Considered as an economic phenomenon: "Drought conditions may be said to prevail whenever precipitation is insufficient to meet the needs of established human activities." (Hoyt, 1938). The interpretation of drought is relative to the feature being considered.

Droughts result primarily from a deficiency of effective rainfall. However, wind, temperature and humidity during the drought, as well as the meteorological and soil-moisture characteristics of the antecedent period, may either accentuate or alleviate the effects of rainfall deficiency.

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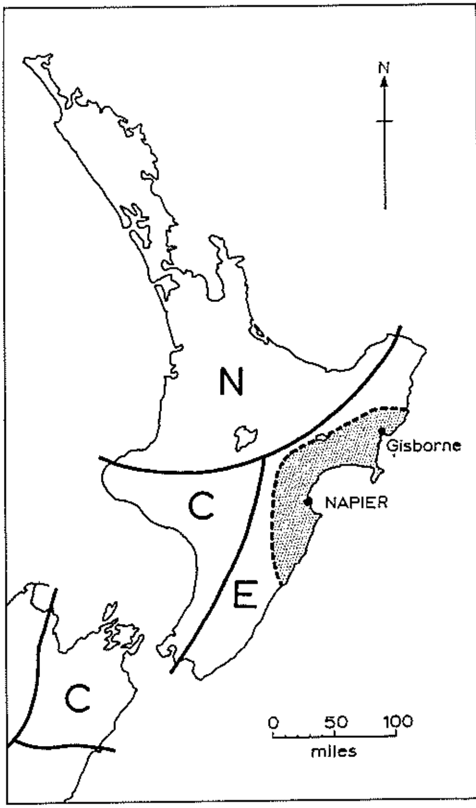

FIG. 1 — The unbroken lines define the areas of de Lisle (1961). These are: Northern (N), Central (C), and East Coast (E). The East Coast for the present study is the stippled area bounded by the Napier isocorrelation line (broken), r_s=0.50.

On the East Coast (Fig. 1) droughts are not uncommon. During 64 years, partial drought — a period of at least 29 consecutive days during which the mean daily rainfall does not exceed 0.01 in. per day (Bondy, 1950) — occurred in 37 years at Napier and 25 years at Gisborne. The average duration per drought year was 56 days at Napier and 54 days at Gisborne. At Napier the longest partial droughts were in 1913–14 (114 days), 1914–15 (150 days), 1945–46 (123 days) and in 1949–50 (107 days). Gisborne records were not available for 1913–15, but other than this 1947–48 (120 days), 1945–46 (101 days) and 1930–31 (103 days) are outstanding.

Because of the high frequency range of days falling within a partial drought (Bondy, 1950) and the great variability of both monthly rainfalls (Seelye, 1946) and annual rainfalls (Seelye, 1940), the East Coast is a marginal or sub-marginal environment for a number of cultural activities and for the sustained healthy growth of many plant species — especially trees.

This study concerns mainly the larger daily rains, i.e. those that are more effective in replenishing deeper soil moisture and total ground water, and the relative periodic changes of rainfall effectiveness (R.E.) since 1890. Rainfalls recorded at Napier are used.

The statistical significance of each change demonstrated has not been considered. It is true that a statistically significant change should have practical significance. But it is also true that a practically significant change need not be statistically significant. The influences of recent short-range changes of climate on agriculture in England (Smith, 1963) stress the importance of statistically insignificant changes even in temperate latitudes. Wallen (1963) has emphasized this point by stating that in marginal areas even a very small change of climate lasting for a short period may have a disastrous influence on, for instance, vegetation.

The East Coast is at least sub-marginal for the present purpose, therefore any changes that constitute negative deviations are likely to have a practical significance that far outweighs the level of statistical significance — if any.

EAST COAST

Napier annual rainfall indices for 1890–1961 (annual rainfalls expressed as percentages of the 1911–40 mean) correlate significantly, $r = 0.84$, with the mean indices for the East Coast region (Fig. 1) of de Lisle (1961) — who did not use Napier rainfalls (pers. comm.) — but it is probable that the regional indices are based largely on records from the eastern portion of the area. Therefore, although the findings and implications of the present study may have valid qualitative application to the entire East Coast of de Lisle, a more specific area in relation to Napier has been determined on the basis of the correlation coefficient between the annual rainfalls of Napier and 24 selected stations for the period 1921–40.

The Spearman rank correlation was used; this is:

$$r_s = 1 - \frac{6\Sigma d^2}{N^3 - N}$$

where Σd^2 is the sum of the squares of the differences between the ranks of the paired annual rainfalls, and N is the number of ranked pairs. This coefficient is conservative in the estimation of r — a property that recommends its use (McDonald and Green, 1960).

For this study the East Coast is taken to be the area enclosed by the coastline and the isocorrelation line $r_s = 0.50$, 95% significant (Fig. 1). To the north of Napier at about 110 miles NE, this correlation line runs from about Tolaga Bay inland to about 8 miles east of Matawai on State Highway No. 2, then SW to Lake Waikaremoana from whence it runs to about Tarawera on State Highway No. 5. From here it continues to about the mid Kaweka Range and then trends generally southwards on the western side of the southern Kaweka Range and along the eastern side of the Ruahine Range to pass about Ormondville and meet the coastline near Akitio, about 80 miles south of Napier.

For Gisborne, $r_s = 0.59$ — a relatively low value — but it was found that over a 64-year period 76% of all partial droughts at Gisborne coincided in time with a partial drought at Napier. This indicates that the East Coast as defined here is a conservative area for the purpose.

DAILY RAINFALL FREQUENCIES

The frequencies of daily rainfalls recorded at Napier have been analysed and related to erosion (Grant, 1966). Napier rainday numbers and rainfall amounts are homogeneous since 1905 and earlier than this the larger daily rainfalls, in excess of 0.50 in., may be reliably accepted.

Napier daily rainfall amounts have been classified into six size groups: (a) 0.01–0.20 in., (b) 0.21–0.50 in., (c) 0.51–1.00 in., (d) 1.01–1.50 in., (e) 1.51–3.00 in., and (f) $>$3.00 in. In each year the frequency of rainfalls in each size group was determined on a seasonal basis, the seasons being: summer (January, February and previous December), autumn (March, April, May), winter (June, July, August), and spring (September, October, November). Because daily rains $>$3.00 in. are infrequent at Napier, this size group was combined for analysis with group (e) to give a group $>$1.50 in. For each season yearly rainfall amounts and frequencies of raindays for each size group were presented graphically (Grant, 1966).

At Napier, for the period 1890–1963, rains $>$1.50 in. contributed 22%, rains 1.01–1.50 in. contributed 14%, and rains 0.51–1.00 in. contributed 25% of the average annual rainfall total of 32.8 in. — a total contribution of 61% from rainfalls that represented only 19 of the annual average of 124 raindays.

SEASONAL CHANGES

Cumulative percentage departure curves were plotted for all rain size groups in each season. The weaknesses of the method are many and trend is difficult to interpret — sometimes impossible. However, the diagrams are useful as a check on the chronological determination of major turning points, and therefore for the selection of natural rather than arbitrary periods for subsequent analysis.

Accordingly, both this means and the consecutive-year plots (Grant, 1966) were used to determine natural periods of change for each season.

Spring

About 1905 and 1920 were major change points in spring. Table 1 demonstrates these and indicates that subsequent to 1920 there has been no significant change.

TABLE 1 — Spring rain size frequencies (*f*) and percentage number of years when rains did not occur (*N*).

Rain Group	*1890–1905 (16 yrs)*		*1906–1920 (15 yrs)*		*1921–1943 (23 yrs)*		*1944–1967 (24 yrs)*	
	f	*N*	*f*	*N*	*f*	*N*	*f*	*N*
>1.50 in.	0.75	44	0.40	60	0.13	87	0.17	83
1.01–1.50 in.	0.69	56	0.69	53	0.44	61	0.50	58
0.51–1.00 in.	3.0	6	1.8	20	2.3	26	2.5	4

Rains >1.50 in. decreased markedly in frequency about 1905, and about 1920 a further and more pronounced decrease occurred which has persisted to the present. Frequencies of rains 1.01–1.50 in. did not change until about 1920; after this time there was a decrease which, with some variation, has persisted to the present. Rains 0.51–1.00 in. have not changed appreciably, but 1921–43 is outstanding for having the highest *N* values.

Average annual spring rainfall contributions by the different rain groups have been converted to percentages of the periodic mean rainfalls and are given in Table 2. Because Table 1 indicated that no significant change has occurred since 1920, the period 1921–67 is taken as a whole in Table 2.

TABLE 2 — Spring rain size percentage contributions.

Rain Group	*1890–1905 (16 yrs)*	*1906–1920 (15 yrs)*	*1921–1967 (47 yrs)*
	Rainfall as a percentage of period mean		
>1.50 in.	18	12	7
1.01–1.50 in.	11	15	9
0.51–1.00 in.	27	21	30
0.01–0.50 in.	44	52	54
Period Mean (in.)	7.63	6.01	5.85

Average spring rainfall has decreased about 23% since 1905, and this reduced amount (5.85 in.) is composed of much smaller contributions from rains >1.00 in. Periodic mean rainfall is positively related both to the frequencies (Table 1) and to the contributions of rains >1.50 in., and negatively related to the 0.01–0.50 in. rain contributions.

In terms of drought, larger rains (>1.00 in.) are more effective for ground-water replenishment. Therefore, the level of rainfall effectiveness (R.E.) has been lowered since 1905 by more than 23% because of the pronounced diminution in the contributions of the larger rains. For truer comparison of periodic levels of R.E. an index is used. This is:

$$\text{R.E. Index} = \frac{\text{Large}}{\text{Small}} \times \text{Mean}$$

where Large is percentage contribution of rains >1.00 in.
Small is percentage contribution of rains $\leqslant 1.00$ in.
Mean is period mean rainfall.

Spring R.E. indices are:

Period	*R.E. Index*
1890–1905	3.1
1906–1920	2.2
1921–1967	1.1

R.E. indices have recognized limitations, and may tend to exaggerate the relative drought changes, but in relation to deeper-rooted plants and ground-water replenishment they should give a more reliable comparative measure of R.E. than the simple use of rainfall amounts. Rainfall effectiveness is approximately proportional to the R.E. index. The spring R.E. indices suggest a lowering of R.E. or an increase in drought stringency, from 1905 to the present, of up to 64%. The greatest change occurred about 1920 when an abrupt increase in drought severity of up to 50% took place, and this state has persisted to the present.

Summer

In summer the first marked change in the frequencies of rains >1.50 in. occurred in 1906 — continuous with the change already demonstrated for spring of 1905. Five natural change periods have been adopted for summer (Table 3).

TABLE 3 — Summer rain size frequencies (f) and percentage number of years when rains did not occur (N).

Rain Group	*1890–1906 (17 yrs)*		*1907–1933 (27 yrs)*		*1934–1945 (12 yrs)*		*1946–1958 (13 yrs)*		*1959–1967 (9 yrs)*	
	f	*N*	*f*	*N*	*f*	*N*	*f*	*N*	*f*	*N*
>1.50 in.	1.2	29	0.22	81	1.2	17	0.23	77	1.2	33
1.01–1.50 in.	1.0	35	0.81	48	0.92	50	0.38	69	0.67	44
0.51–1.00 in.	3.1	0	2.8	11	3.2	8	2.2	15	2.6	11

The values demonstrate a fluctuation, with minima in 1907–33 and 1946–58. Of the maximal periods if only rains >1.00 in. are considered it is seen that there is a progressive slight reduction of f value, with corresponding increase in N, from 1890–1906 to 1934–45 to 1959–67.

Overall frequency values were lowest during 1946–58 when there was also the highest percentage number of years during which the larger rains failed to occur.

Rain size group contributions to the periodic mean rainfalls appear in Table 4.

TABLE 4 — Summer rain size percentage contributions.

Rain Group	*1890–1906* (*17 yrs*)	*1907–1933* (*27 yrs*)	*1934–1945* (*12 yrs*)	*1946–1958* (*13 yrs*)	*1959–1967* (*9 yrs*)
	Rainfall as a percentage of the period mean				
>1.50 in.	29	9	33	12	33
1.01–1.50 in.	16	15	12	8	9
0.51–1.00 in.	28	31	23	29	24
0.01–0.50 in.	27	45	32	51	34
Period Mean (in.)	8.14	6.32	9.74	5.29	8.40

The values demonstrate that a strong positive relationship exists between periodic summer rainfall amount and the contribution of the rains >1.50 in. — this applies also to their frequencies (Table 3). However, the smaller rains (0.01–1.00 in.) are negatively related. The contribution of the 1.01–1.50 in. rains progressively decreased to 1946–58.

In the three wetter periods, rains >1.00 in. contributed about 44% of the summer mean rainfall, while in the two drier periods 1907–33 and 1946–58 they contributed only 22% on average. The driest summer period since 1890 was 1946–58, and during this rains 0.01–1.00 in. contributed 80% and rains >1.00 in. contributed 20% to the periodic mean rainfall.

The summer R.E. indices for the periods are:

Period	*R.E. Index*
1890–1906	6.7
1907–1933	2.0
1934–1945	8.0
1946–1958	1.3
1959–1967	6.1

The lower the R.E. index, the more stringent is the drought factor; 1946–58 was therefore the most droughty summer period since 1890. It is interesting, and may be important in some fields of application, that the most droughty period immediately followed the least droughty period, 1934–45 — the decrease of periodic mean rainfall was nearly 46%, but R.E. indices suggest a difference of the order of 80%.

Autumn

Judged by both the consecutive-year and the cumulative-departure plots, frequency changes of autumn rains have been less pronounced than those demonstrated for spring and summer. The natural change periods adopted, which agree closely with those for summer, are shown in Table 5.

TABLE 5 — Autumn rain size frequencies (*f*) and percentage number of years when rains did not occur (*N*).

Rain Group	*1890–1911 (22 yrs)*		*1912–1933 (22 yrs)*		*1934–1946 (13 yrs)*		*1947–1958 (12 yrs)*		*1959–1967 (9 yrs)*	
	f	*N*	*f*	*N*	*f*	*N*	*f*	*N*	*f*	*N*
>1.50 in.	1.4	32	0.6	59	1.2	38	0.9	42	0.6	55
1.01–1.50 in.	1.5	27	1.3	32	0.7	54	1.5	17	0.8	33
0.51–1.00 in.	3.6	5	2.3	9	2.8	0	2.2	17	2.1	0

Fluctuations are demonstrated by both the *f* and *N* values, but the most distinctive change is between the 1890–1911 period and the subsequent periods. Frequencies both for rains >1.00 in. and for all rains >0.50 in. decreased abruptly after 1911 and the reduced frequencies were sustained to 1959, when a further reduction resulted in 1959–67 having the lowest overall *f* values since 1911.

Table 6 shows the contributions of the various rain size groups to the periodic mean rainfalls for autumn.

TABLE 6 — Autumn rain size percentage contributions.

Rain Group	*1890–1911 (22 yrs)*	*1912–1933 (22 yrs)*	*1934–1946 (13 yrs)*	*1947–1958 (12 yrs)*	*1959–1967 (9 yrs)*
	Rainfall as a percentage of the period mean				
>1.50 in.	33	19	36	27	15
1.01–1.50 in.	17	19	10	22	14
0.51–1.00 in.	25	23	21	18	21
0.01–0.50 in.	25	39	33	33	50
Period Mean (in.)	11.12	8.04	8.81	8.27	7.31

For the larger rains, percentage contributions follow the frequency patterns fairly closely and, as for spring and summer, a good positive relationship exists between periodic autumn rainfall mean and the contribution of rains >1.50 in.

As with frequencies, a fairly marked change took place after about 1911 in the contributions of the larger (>1.00 in.) and smaller rains which, after some fluctuation, culminated during 1959–67 in the lowest percentage contribution for rains >1.00 in.

The autumn R.E. indices for the periods are:

Period	*R.E. Index*
1890–1911	11.1
1912–1933	4.9
1934–1946	7.5
1947–1958	7.9
1959–1967	3.0

The most droughty autumn period since 1890 was the last (1959–67), and 1912–33 ranks next.

Winter

In winter a decrease in the frequency of rains >1.50 in. occurred about 1920. The years 1942–54 had the lowest periodic frequency value. Frequency values (f) for rains >1.50 in. are:

Period	*Frequency Value*
1890–1920	1.40
1921–1967	0.94
1942–1954	0.69

Rains 1.01–1.50 in. failed to occur more often and attained their lowest average frequency during 1920–33 ($f=0.64$). However, for the 0.51–1.00 in. rains, about 1905 marked an abrupt decrease in frequency.

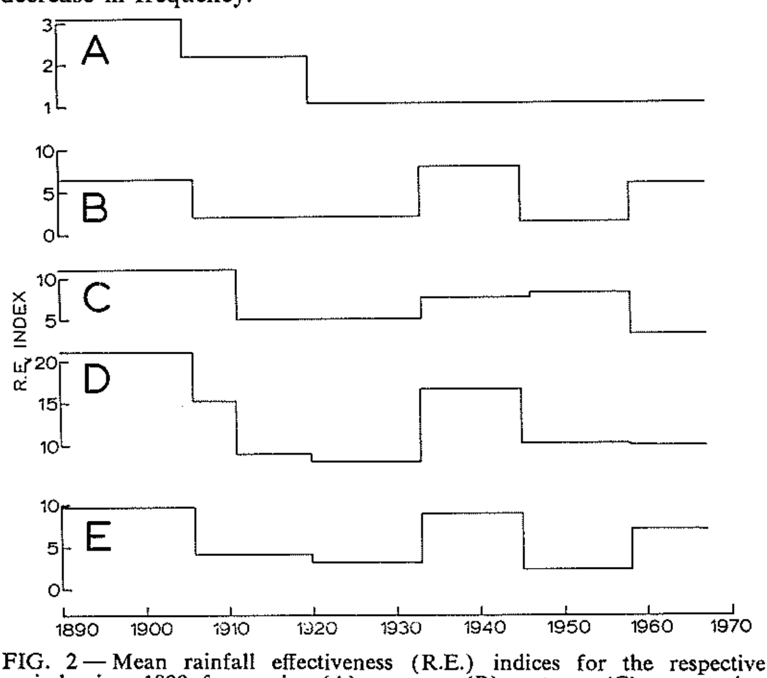

FIG. 2 — Mean rainfall effectiveness (R.E.) indices for the respective periods, since 1890, for: spring (A); summer (B); autumn (C); summation of spring, summer and autumn (D); summation of spring and summer (E).

DROUGHT PATTERNS

The R.E. indices derived for spring, summer and autumn are intra-seasonal and cannot be compared among seasons; however, for any year they may be summed to give the yearly R.E. index.

Fig. 2 shows the mean R.E. indices for the respective periods. Summation of spring, summer and autumn values produced curve D. Compared with the period 1890–1905 this indicates a marked decrease in R.E. indices, i.e. an increase in drought severity, from 1906 to 1933. The period 1934–45 was less droughty, but from 1946 to the present the drought factor again became more severe. The period 1920–33 was the most droughty since the turn of the century, although the present period is little better.

Consideration of the frequency changes of the larger rains in winter serves to emphasize the reduction of R.E. about 1905, as well as the very low R.E. levels during both 1920–33 and the period mid 1940s–1950s.

Summations of spring and summer R.E. indices are shown by curve E (Fig. 2) which demonstrates the same general pattern as curve D except that 1946–58 appears as the most droughty period of this century.

In relation to pasture and crop growth, the important patterns are probably either spring or summer alone (curves A and B), or in combination (curve E).

Tree growth is likely to be related either to spring and summer combined (curve E) or to spring, summer and autumn combined (curve D). The relationship will depend on tree species and site conditions.

Changes of stream flow-duration patterns in the lower discharge range, together with minimal flow values, may follow the general pattern of curve D for spring, summer and autumn. For some purposes a combination of the summer and autumn curves may be most pertinent.

All data presented demonstrate that the average level of rainfall effectiveness (R.E.) decreased abruptly about 1905–6 and became even lower after 1920, except for a period of amelioration (1934–45) which, however, remained below the 1890–1905 level.

In summer there has been some amelioration of drought severity since 1958 which for pastures and other shallow-rooted plants has probably been beneficial — the same change could have been unfavourable in terms of plant, and perhaps animal, diseases. However, for spring, drought has remained at its more intense post-1920 level to the present, and in autumn from 1958 to the present, drought has reached its most stringent level since 1890–1905.

Pronounced negative changes of R.E. have taken place since the turn of this century and, even if the periodic R.E. indices presented are only approximately correct, it is probable that some of these changes have a high practical significance. In particular they are likely to have influenced adversely the vigour and health of some tree species, and those facets of stream flow that are dependent on ground-water storage. These implications are to be considered in follow-up communications.

CIRCULATION CHANGES

By far the majority of rains >1.50 in. at Napier are produced by depressions. Major periodic frequency changes of these rains therefore reflect changes in the frequency of depressions affecting the East Coast. Such circulation changes should be reflected elsewhere and in other ways. There is agreement with Kraus (1955) that a widespread abrupt change occurred about the end of the 19th century. In spring and autumn this was manifest by a considerable decrease in rainfall on the East Coast and in SE Australia (Kraus, 1954).

General agreement is reached with de Lisle (1956, 1957) for spring circulation changes about 1918–20, and for summer changes about 1930. With this measure of chronological agreement for major changes, the results of the present study are not likely to be analytical accidents.

De Lisle (1961) found that in the three northern areas, which comprise the North Island and the north-eastern portion of the South Island (Fig. 1), the long-period annual fluctuations are correlated, ". . . so there is probably some long-period circulation change affecting all three districts". Because Napier annual rainfalls correlate highly with his East Coast values there is a reasonable basis for suggesting that changes similar to those demonstrated have affected the North Island and possibly the north-eastern portion of the South Island.

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