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THE MEASUREMENT OF CLIMATIC RISK IN THE WESTERN DIVISION OF NEW SOUTH WALES

by

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1. INTRODUCTION.

In western New South Wales farmers are subject to a high level of climatic risk. Wide fluctuations in rainfall conditions are superimposed upon uncertainty as to economic variables. The pattern of variation in rainfall from season to season, and from year to year, in the Western Division has important consequences on the land-use practice and farm organization of the pastoral industry, which relies mostly upon natural grasses and shrubs as sources of fodder supplies. Because of the delicate balance between rainfall and plant life in many parts of the semi-arid areas of New South Wales, relatively small variations in precipitation around a critical point often have important effects upon the success of pastoral operations. However, the main climatic hazard in these areas is not so much the specific variations of rainfall from the average, but the time incidence of variations of a given magnitude and sign. It is the occurrence of protracted sequences of "good" (above long-term average) and "poor" (below long-term average) rainfall conditions of irregular duration, and the widespread incidence of sequences of high or low rainfalls, that imposes severe hardships upon the pastoralist and presses upon his ability to remain in business. Hence, while it is true that an occasional extreme arid year may have long-range repercussions by killing off perennial vegetation, it is usually the length of aridity, rather than the intensity of aridity in a particular year, that constitutes the chief climatic problem of the west.

The history of land settlement in the Western Division has emphasised the important effects of climatic variability on the stability of farm production and farm incomes. It is suggested, therefore, that an assessment of climatic variability, particularly in the light of the time incidence of variability (bunching), may prove of assistance to future farm management and administrative decisions affecting the area. In particular, the accurate determination of carrying capacities of the varied environments in the west, which is basic to the setting up of home-maintenance areas, will be placed upon a realistic and safer footing. An accurate knowledge of climatic variability will enable farmers to plan their farm organization more successfully and so adapt their farm capital structures to the risk element peculiar to their areas; whilst plans to develop co-operative efforts against local droughts will be facilitated by climatic risk studies. Such studies will permit the appraisement of the possibilities of insurance schemes, fodder-conservation programmes, as well as government price-supports and drought-relief schemes.

With a view to throwing more light on the problem of climatic uncertainty in the pastoral occupation of the Western Division, this paper examines various elements of the problem of climatic variability and methods by which it can be adequately measured.

2. CLIMATIC RISK AND ITS MEASUREMENT.

Whilst an analysis of climatic variability and the associated problems of farm survival in the Western Division must necessarily give consideration to a large number of factors, perhaps the most important consideration is the measurement of the climatic risk. It would facilitate treatment of the problem if some measure could be devised which would give an expression to the variability of climate in a form most useful in the analysis of the fluctuations in farm prosperity consequent upon this climatic variability.

Rainfall is the most critical element of the climatic situation in western New South Wales and will, therefore, need primary consideration in the analysis of risk. There are a number of ways in which rainfall and other climatic data may be analysed with the object of studying the incidence and character of moisture conditions and the frequency of occurrence of such conditions. It is considered that climatological studies must be based upon some statistical generalisation, which is sufficiently comprehensive and flexible as to take account of all the facts.

To be most relevant to the problems of farm organization and management in areas of climatic risk, the analysis of climatic variability should treat a number of elements of the risk situation. First, the analysis should provide some expression of rainfall variability over time as it impinges upon the prosperity of each farm unit. This variability analysis should take account of the frequency of occurrence of specific rainfall conditions, with emphasis upon the cumulative effects of variations above and below the "normal" rainfall conditions. The measurement of rainfall variability must be related to a time unit which is significant to the pastoral economy of the Western Division. Some yearly basis of measurement appears to be most useful for a pastoral economy depending upon the annual return from stock. Second, assessment of rainfall conditions, at any point of time, should be made in terms of "influential" rainfall[1] in relation to the growth of fodder supplies. Third, to be of most value, the analysis of rainfall variability should provide a statement of the probability of occurrence of critical rainfall conditions over time. It is proposed to examine the efficacy of some of the existing analytical techniques for treating the problems of climatic variability in the Western Division.

[1] For definition, see page 259.

a. Variability of Rainfall and the Sequential Pattern of Variability.

There are few techniques available which attempt to give consideration to the measurement of the cumulative effects of rainfall variations over time and the incidence of runs of above-average and below-average rainfall conditions. Working in the western United States, which possesses, in its more arid parts, weather risk problems analogous to those of the Western Division, Clawson has attempted to devise an analysis of annual rainfall figures which is relevant to the problems of the sheep and cattle industries in that region[2]. The cumulative effects of good and poor rainfall years have received particular attention. The principles of this analysis have been applied to twenty-five selected rainfall stations in the Western Division of New South Wales for the period 1894-1949. Clawson employed three techniques to examine the pattern of annual rainfall variability. It is proposed to discuss these methods for the analogous situation of the Western Division. They are: (i) correlating one year's rainfall with that of the following year at each recording station, without regard to sign; (ii) counting the number of times that the line showing annual rainfall crossed its own long-term average line at each station; and (iii) applying a coefficient devised on the basis of the accumulation of deficits and surpluses of the annual deviations from the fifty-six-year average.

(i) The method of correlating a yearly rainfall with that of the following year would, at first sight, suggest a possible measure of bunching. If a high correlation existed, then it could be inferred that the rainfall station in question had experienced a marked tendency towards bunching of deviations of like sign. The correlation would be

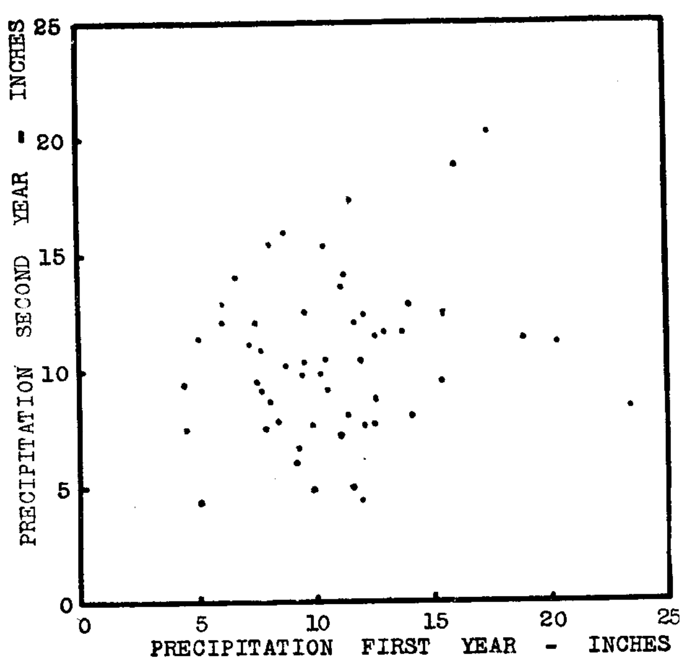


Fig. I.—Correlation Between Annual Precipitation in One Year and in the Following Year at Wentworth, 1894 to 1949.

[2] Marion Clawson, "Sequence in Variation of Annual Precipitation in the Western United States," *The Journal of Land and Public Utility Economics*. Vol. XXIII (August, 1947), pp. 271-287.

greatest if a high degree of bunching occurred and each sequence was separated by a lengthy transition period. In practice, as illustrated in Figure 1 for Wentworth (1894-1949), the method would reveal a low correlation with little meaning, because annual rainfall figures are usually characterized by marked variations from year to year. Even with a station such as Wentworth, where bunching is very evident (see Figure 2), fortuitous and relatively infrequent crossings of the long-term average by the line of annual rainfall make for a low correlation.

(ii) The number of times the curve of annual rainfall crosses the line of long-term average rainfall (1894-1949) might provide some indication of the degree of bunching. The less frequent the crossings and the longer the interval between each crossing, the greater the bunching. Again, because of the variable character of annual rainfall figures, this method has little value when applied to annual precipitation data. In addition, the method ignores the magnitude of the variations, which is very important to the long-term effects of such variations. This shortcoming can be seen by examining the stations shown in Figure 2. The graph of annual deviations from the long-term average will serve to indicate the nature of the graph of annual rainfall. The number of crossings for the four stations are: Wentworth 22, Wilcannia 30, Broken Hill 32, Collarenebri 22. It is obvious, when the magnitude of variations is taken into account, that, whereas Collarenebri has experienced a marked overall lack of significant bunching of the greater variations, Wentworth has revealed a definite tendency towards bunching for most of the period (*i.e.*, overlooking the smaller deviations). A count of the number of crossings by the line of annual rainfall over the line of long-term average rainfall does not reveal this. This demonstrates that it is inaccurate to confuse the significance of the frequency of variations in annual rainfall with the magnitude of the variations.

(iii) Marion Clawson, in his study of annual rainfall for seventeen western states of the United States, has devised a new technique for analysing annual rainfall figures. This technique aims at describing the existing sequence of variations at each recording station, but, at the same time, aims not to dominate the results. Clawson has devised a coefficient for measuring the frequency of sequence of variations in annual precipitation (Coef*vs*) which will take account of the cumulative "deficits and excesses of moisture" considered to be significant to a pastoral economy, similar in many of its parts to that of the Western Division. The coefficient uses the amount of cumulative surpluses and deficits of the annual deviation from the long-term average rainfall for each rainfall station.

The technique for calculating the Coef*vs* can be described with reference to Table I. The Coef*vs* is calculated as follows: The average of the fifty-six-year total annual precipitations and the yearly deviations from this average are calculated. The total of these deviations is obtained, without regard to sign. The cumulative deviation is calculated year by year, with regard to sign. The coefficient is then obtained by dividing the total of the cumulative deviations (without regard to sign) by the total of the yearly deviations from the average annual rainfall, without regard to sign. In the case of Wentworth, for the period 1894-1949, the Coef*vs* is 6.57. When regard is taken of sign throughout, the total of the annual deviations should be zero if sufficient decimal places have been considered. This can be used as a check on the calculations. Likewise, the last item in the list of cumulative deviations should be zero (or near it) and hence equal to the sum of the annual deviations, with regard to sign. This provides an additional check.

TABLE I.

Annual Precipitation, Deviations in Annual Precipitation, and Calculation of $Coef_{vs}$ *for Wentworth,* 1894–1949.

Year.	Annual Precipitation.	Deviation from 56-Year Average.	Cumulative Deviation.	Year.	Annual Precipitation.	Deviation from 56-Year Average.	Cumulative Deviation.
	Inches.	Inches.	Inches.		Inches.	Inches.	Inches.
1894	23·41	+ 12·67	+ 12·67	1930	11·16	+ 0·42	+ 27·51
95	8·44	— 2·30	+ 10·37	31	13·64	+ 2·90	+ 30·41
96	7·84	— 2·90	+ 7·47	32	11·79	+ 1·05	+ 31·46
97	7·54	— 3·20	+ 4·27	33	12·04	+ 1·30	+ 32·76
98	9·56	— 1·18	+ 3·09	34	7·69	— 3·05	+ 29·71
99	10·40	— 0·34	+ 2·75	35	6·01	— 4·73	+ 24·98
1900	10·50	— 0·24	+ 2·51	36	12·82	+ 2·08	+ 27·06
01	9·36	— 1·38	+ 1·13	37	11·65	+ 0·91	+ 27·97
02	6·69	— 4·05	— 2·92	38	5·01	— 5·73	+ 22·24
03	14·04	+ 3·30	+ 0·38	39	11·82	+ 1·08	+ 23·32
04	12·95	+ 2·21	+ 2·59	1940	4·46	— 6·28	+ 17·04
05	10·42	— 0·32	+ 2·27	41	9·46	— 1·28	+ 15·76
06	15·40	+ 4·66	+ 6·93	42	9·82	— 0·92	+ 14·84
07	9·69	— 1·05	+ 5·88	43	4·95	— 5·79	+ 9·05
08	12·51	+ 1·77	+ 7·65	44	4·46	— 6·28	+ 2·77
09	11·50	+ 0·76	+ 8·41	45	7·41	— 3·33	— 0·56
1910	17·45	+ 6·71	+ 15·12	46	12·19	+ 1·45	+ 0·89
11	20·33	+ 9·59	+ 24·71	47	12·47	+ 1·73	+ 2·62
12	11·28	+ 0·54	+ 25·25	48	7·73	— 3·01	— 0·39
13	14·19	+ 3·45	+ 28·70	49	10·91	+ 0·17	— 0·22
14	8·05	— 2·69	+ 26·01	Total considering signs ...	601·22	0·22	...
15	8·70	— 2·04	+ 23·97	Total disregarding signs ...	601·22	161·60	1062·20
16	16·00	+ 5·26	+ 29·23	Average considering signs ...	10·74	...	...
17	18·80	+ 8·06	+ 37·29	$Coef_{vs}$ ...	...	...	6·57
18	11·40	+ 0·66	+ 37·95				
19	8·03	— 2·71	+ 35·24				
1920	15·55	+ 4·81	+ 40·05				
21	12·49	+ 1·75	+ 41·80				
22	8·77	— 1·97	+ 39·83				
23	10·26	— 0·48	+ 39·35				
24	9·87	— 0·87	+ 38·48				
25	7·71	— 3·03	+ 35·45				
26	9·24	— 1·50	+ 33·95				
27	6·03	— 4·71	+ 29·24				
28	12·14	+ 1·40	+ 30·64				
29	7·19	— 3·55	+ 27·09				

Clawson has outlined certain characteristics of the Coef*vs* and certain of the obvious drawbacks. These can be summarised as follows:

(i) The Coef*vs* is affected by the size of the cumulative surpluses and deficits and by the amount of the deviations from the long-term average. The sum of the cumulative deviations (ignoring signs) will be greater, in relation to the sum of the deviations from the average (again ignoring signs), the greater is the tendency for deviations of like sign to occur in sequence, *i.e.*, the greater the bunching. *Therefore, the larger the Coef*vs *the greater the tendency towards bunching.*

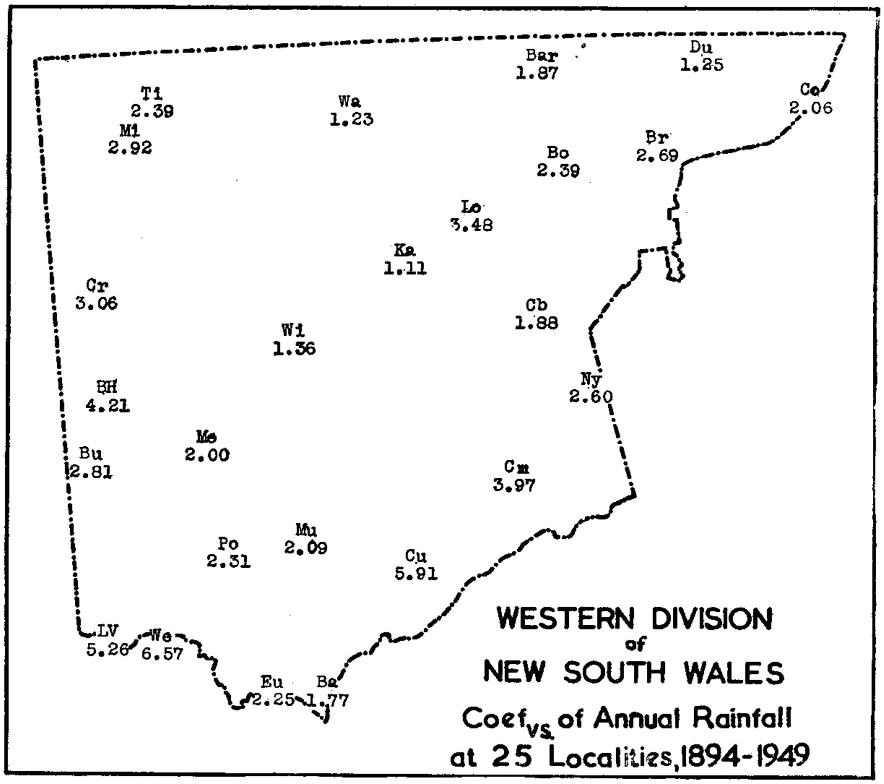
(ii) As a measure of bunching, the Coef*vs* does not depend on assumptions as to the nature of the sequences whether they be random, cyclical or otherwise.

(iii) The Coef*vs* is a pure number, since its magnitude does not depend on the unit of measurement of rainfall.

(iv) In practice it is unusual to find Coef*vs* values outside the range 1.5 to 7.0.

(v) The Coef*vs* is influenced, perhaps unduly, by the place of the initial year in the cycle if a cycle exists, and this cycle is fairly regular. In a similar manner, the Coef*vs* is greatly influenced by the presence of one or two very abnormal years in a sequence of rainfall years.

The appended map indicates the values of the Coef*vs* for twenty-five recording stations in the Western Division for the period 1894 to 1949. These represent those recording stations with continuous records over this period, as published by the Commonwealth Meteorological Bureau.



INDEX TO STATIONS SHOWN ON THE MAP.

Balranald—Ba.	Cobar—Cb.	Euston—Eu.	Mulurulu—Mu.
Barringun—Bar.	Collarenebri—Co.	Kallara—Ka.	Nyngan—Ny.
Bourke—Bo.	Coombie—Cm.	Lake Victoria—L.V.	Pooncarie—Po.
Brewarrina—Br.	Corona—Cr.	Louth—Lo.	Wanaaring—Wa.
Broken Hill—B.H.	Culpotaro—Cu.	Menindie—Me.	Wentworth—We.
Burta—Bu.	Dumble—Du.	Milparinka—Mi.	Wilcannia—Wi.

For the western United States, Clawson differentiates several zones of magnitudes of Coef*vs* within the arbitary groups: "high" above 4.0, "medium" 2.5 to 4.0, and "low" below 2.5. Applying these terms to the values shown on the map for the Western Division, it will be seen that the area has had a variety of experience in the sequence pattern of rainfall over the period 1894 to 1949. The number of stations, for which it has been possible to determine the Coef*vs* values, is too small to permit any worthwhile zonal differentiation. However, on the basis of the limited number of values shown on the map, the following observations can be made. "Low" values are found in two groups: (*a*) in the far north including Wanaaring, Barringun and Dumble, and (*b*) in the central area including Cobar, Kallara and Wilcannia. For all of these localities, the overall time incidence of negative and positive variations in annual rainfall from the fifty-six-year average has been characterised by a lack of protracted sequences of variations of a like sign. "High" values are found at Culpotaro in the south-east, Lake Victoria and Wentworth in the south-west, and at Broken Hill in the far west. By contrast with those stations with "low" values, the stations with "high" values have experienced, over the period 1894 to 1949, a pronounced tendency for variations of like sign to occur in protracted sequences. This is especially the case if attention is focussed upon the variations with greatest magnitude and minor intermediate exceptions are overlooked. The remaining selected stations have "medium" values, with sequence patterns intermediate in character to those stations with "high" and "low" values.

The types of rainfall patterns experienced over the period 1894 to 1949 at stations with Coef*vs* values of the "high," "medium" and "low" orders are demonstrated on Figure 2. Three major sequences are demonstrated by the graphs for Wentworth and Broken Hill, both with "high" Coef*vs* values. First, after the well-above-average year of 1894, the period 1895-1902 was marked, in both cases, by a distinct sequence of below-average years, this tendency being more pronounced at Wentworth. Second, the period 1903-1921, for both localities, was marked by a protracted sequence of predominantly above-average years, especially 1910, 1911 and 1917. Third, the period from 1922-1949 was, in both cases, characterised by a sequence of predominantly below-average values. As with the initial sequence, the latter two sequences were more pronounced at Wentworth than at Broken Hill. The cumulative impact of these two rainfall histories is signified by the Coef*vs* values shown for the two stations, namely, Wentworth 6.57 and Broken Hill 4.21.

The rainfall pattern for Wilcannia, on close inspection, contrasts with those for Wentworth and Broken Hill as described above. This contrast is borne out by the "low" Coef*vs* (1.36). Apart from the sequence of below-average values over the period 1896-1905 and several subsequent shorter sequences, Wilcannia experienced frequent alternations in the sign of deviations from the long-term average annual rainfall. With the exception of the above-average sequence, 1930-33, no protracted sequences of above-average or below-average years were experienced between 1905 and 1949.

For the period 1894-1949, Collarenebri experienced marked yearly variations from the long-term average, but, for the period as a whole, the time incidence of variations was intermediate in character to the patterns described above. This contrast is reflected in the "medium" Coef*vs* for this station (2.06).

On the basis of the Coef*vs* values shown on the map and a close inspection of the rainfall data for the twenty-five selected stations, it is evident that these localities, for the period 1894-1949, have had a variety of experience in both the magnitude and sign of the yearly variation from the average rainfall and in the time incidence of such variations. This suggests that the component parts of the Western Division have not experienced a common climatic history; both "drought" and "good" rainfall conditions have had a differential effect throughout the Division, both in point of time and in geographical distribution. In certain cases, marked differences have occurred between

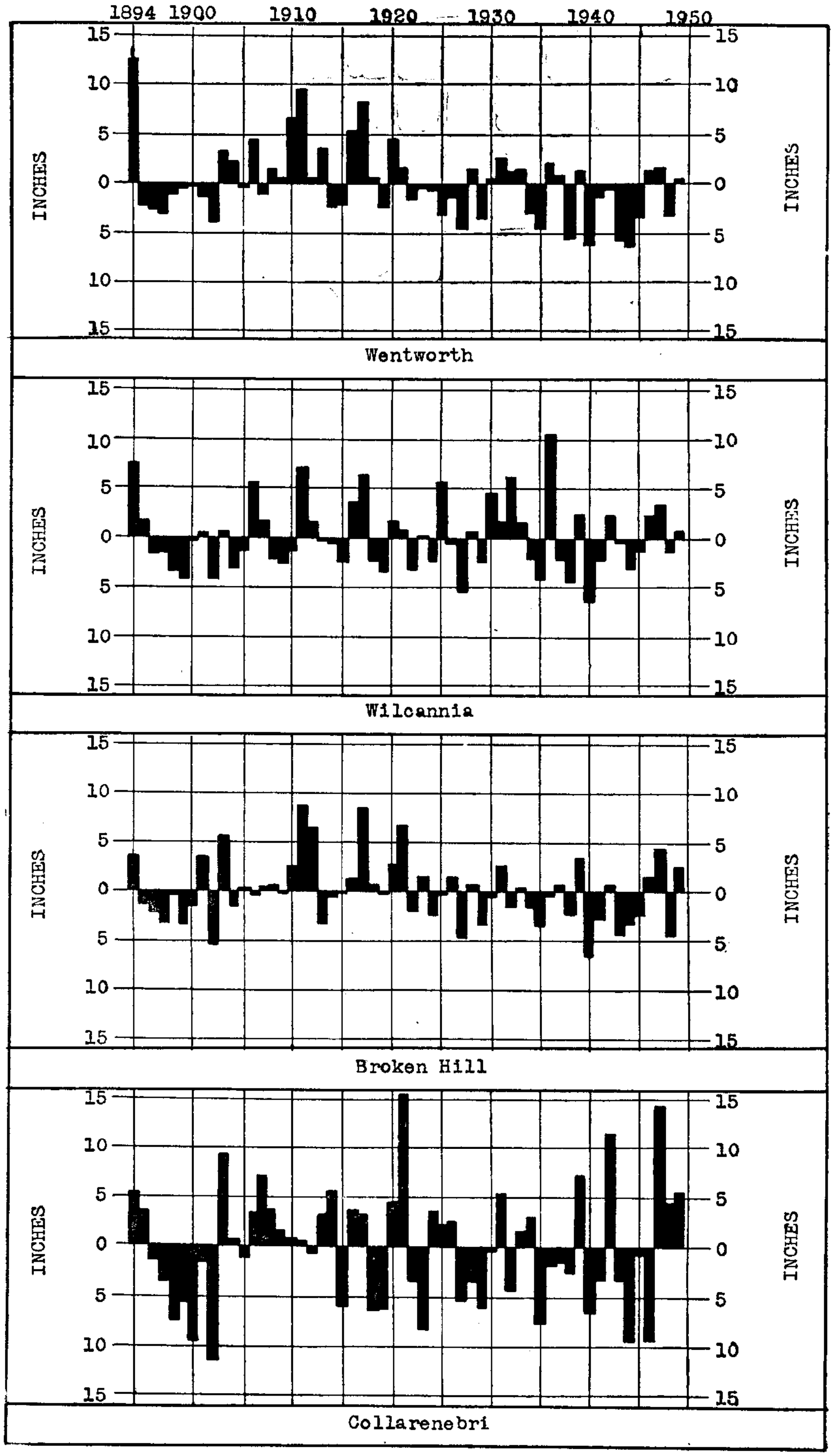


Fig. 2.—Annual Deviation from 1894–1949 Average Annual Precipitation for Four Selected Localities in the Western Division.

places in close proximity to each other, *e.g.*, Louth with a Coef*vs* of 3.48 which contrasts markedly with Kallara (Coef*vs* 1.11) less than fifty miles away. Again, severe drought sequences such as the pre-1903 drought had a universal effect throughout the Division as a whole.

The aim of the Coef*vs* is to provide a formula to assist in the measurement and forecasting of variations in precipitation so that farming may be contracted and expanded with a minimum of risk. At first sight, the concept of the Coef*vs* might offer one possible means of approach to the problem of climatic risk in the Western Division. A region with low Coef*vs* values might be regarded as an area of comparative high climatic risk, in so far as it is subject to frequent and possibly extreme fluctuations from average rainfall conditions. It is commonly held that frequency of variations of rainfall conditions constitutes the chief element of climatic risk to agricultural prosperity. However, for a pastoral industry at least, frequent rainfall variations, even if they be large, often do not present grave economic problems. An area experiencing a low Coef*vs* is usually one in which a pastoralist is capable of conserving sufficient assets, both in the form of money and in kind, to tide him over the fairly short periods of drought or near-drought conditions. Also, in such an area, premium rates for any insurance covering farm operations would be more amenable to actuarial determination. In areas where a dry season of short duration follows a period of good rainfall conditions, again of short duration, grazing on the dried grasses left from the previous good seasons has enabled many pastoralists to increase their stock numbers even in the dry period. This has been especially the case when the dry year was marked by light but opportune falls of rain at critical stages throughout the year[3]. Such practices may often be practicable in areas marked by a low Coef*vs*, but they would usually prove extremely difficult in an area with a high Coef*vs*.

An area with high values of the Coef*vs* generally experiences protracted runs of poor conditions separated by protracted runs of above-average conditions. These circumstances impose severe strains upon the ability of farm survival, especially for the relatively small and often heavily-encumbered pastoralist. This is particularly the case when sequences are of irregular occurrence and length, thereby making efficient planning very difficult. Hence, while frequent variations of rainfall may constitute a risk factor, the main climatic risk consideration will be the time incidence of sequences of good and poor years. The economic repercussions of protracted sequences of poor years often have widespread effects in the Western Division. Also the land use of the area is primarily monocultural with only limited scope for diversification except in restricted areas. These characteristics of the area make difficult the implementation of some of the accepted methods of reducing the undesirable effects of climatic variability including crop insurance, the shifting of stock to nearby agistment areas, and quick changes in the dominant enterprise. To the extent that it provides some measure of the cumulative effects of the peculiar time incidence of poor years and good years in the Western Division, the Coef*vs* might prove of some value in the study of climatic risk.

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[3] N. C. W. Beadle, *The Vegetation and Pastures of Western New South Wales with Special Reference to Soil Erosion*, (Sydney: Government Printer, 1948), p. 91.

Although Clawson schematically devised several major zonal groupings of Coef*vs* magnitudes, his study took into account 211 recording stations and each of the zones included a number of atypical values. The number of recording stations with continuous rainfall records over a long period is very limited in the Western Division. It is known that a number of the stations in the area are situated in unsatisfactory sites from the point of view of local geographic conditions, hence the possibility of erroneous recording is present at these stations. For these reasons, it is suggested that too few stations have been considered in this study to permit any significant implications being attached to the various Coef*vs* values shown. To permit a worthwhile application of this analysis to the Western Division, a much larger number of stations with data over a lengthier period of time would be desirable.

It is considered that Clawson's coefficient has a number of shortcomings. The Coef*vs* makes undue emphasis upon the significance of the average rainfall. In semi-arid areas, especially, the mean rainfall is very sensitive to a few extremely heavy falls and a few heavy showers may cause the average to be unrepresentative of the usual experience[4]. As a more suitable measure of the central tendency, the mode might provide a more realistic basis for calculating the Coef*vs*. However, the rainfall patterns of many localities in the semi-arid portions of the state are characterised by widely dispersed records of greatly varying values. In these cases there are no really representative modal values. As a measure of central tendency, the median is perhaps more satisfactory. An inspection of the distribution of values for a sample of the recording stations in the west suggests that the area is characterised, in many cases, by asymetrical distributions in which the average is higher than the median. Because of certain major shortcomings of the Coef*vs* as a practical measure of climatic variability, no attempt has been made to calculate the values shown on the map, on the basis of median values instead of mean values.

Clawson's coefficient attempts to show that high rainfall years will have repercussions upon subsequent low rainfall years. This is a valuable concept in the analysis of the climatic risk problem. However, it may be inadequately measured in many cases by the Coef*vs*. The degree to which a residual effect of rainfall effectiveness occurs, requires close examination for each individual area. Many of the Coef*vs* calculated for the Western Division have been substantially influenced by protracted sequences of low rainfall years, such as that which occurred prior to 1903. It is impossible to determine accurately, on the basis of existing evidence, for what period of time, and to what extent, pastures and production levels in years subsequent to 1903 were affected by the pre-1903 drought. This will be a matter governed by the complex of factors influencing rainfall effectiveness and the retention of soil moisture. Conditions will have varied considerably from one area of the Western Division to another, and such variations are not merely a direct function of annual rainfall totals. Apart from the effect of the various natural factors (rainfall, temperatures and soil conditions, etc.),

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[4] See P. R. Crowe, "The Rainfall Regime of the Western Plains," *The Geographical Review*, Vol. XXVI (1936), p. 465; also H. A. Mathews, "A New View of Some Familiar Indian Rainfalls," *The Scottish Geographical Magazine*, Vol. LII, No. 2 (March, 1936), pp. 84-97.

the economic effects of drought and above-average rainfall periods, including their residual effect, will be influenced considerably by management practices such as stocking rates, and also by destruction of plant cover by rabbits, leading to soil erosion. For example, the residual effect of drought conditions in the west, prior to 1903, was amplified in certain areas, by overstocking and an infestation of rabbits which reduced the land's capacity to react favourably to subsequent increased rainfall conditions. It can be seen, therefore, that the assumptions implicit in the Coef*vs* require a closer examination than existing data will allow.

Clawson has suggested, that, in certain cases (particularly where the Coef*vs* is high), the annual deviations of rainfall, upon which the index is based, could be calculated with reference to a base which is more significant to agricultural prosperity than is the long-term average rainfall. He suggests the use of a long-term moving average supplemented by observations on the condition of subsoil moisture[5]. Such a procedure would have the effect of providing a measure of the variations in influential rainfall which would be more accurate than mere variations in total rainfall from the long-term average.

Whilst the concept of the cumulative impact of sequence in climatic experience is of a great significance to the problems of climatic risk, the Coef*vs* as a measure of this tendency has two major limitations. First, the Coef*vs* does not provide a measure of climatic experience year by year but merely a summation of experience for a long period. Hence, it does not provide a means of measuring the universality of a particular above-average or below-average climatic experience. This is necessary if the climatic variability study is to have value as a basis for social action. Second, the use of annual rainfall data, whether related to the long-term average or to a moving average, appears to have only a limited value in the measurement of influential rainfall conditions at any locality.

b. The Mapping of Climatic Years in Variability Studies.

The most comprehensive account of annual variability of climate in New South Wales has been made by Elizabeth Lawrence. Based upon a modification of Koppen's world classification of climate, the regional incidence of "desert," "steppe" and "humid" climatic years, the yearly movement of their boundaries and frequency of occurrence of these climatic types has been mapped for the period 1900-1935[6]. Lawrence's analysis provides an approach to the problem of climatic risk based upon the concept of the expansion and contraction of climatic

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[5] Clawson, *op. cit.*, pp. 284-285.

[6] Elizabeth F. Lawrence, "A Climatic Analysis of New South Wales," *The Australian Geographer*, Vol. III, No. 3 (November, 1937), pp. 3-24. The mapping of climatic years to show variability of climate has been made for the United States along similar lines to those adopted by Lawrence. See R. J. Russell, "Climatic Years," *Geographical Review*, Vol. XXIV (1934), pp. 92-103; R. J. Russell, "Frequency of Dry and Desert Years, 1901-1920," *University of California Publications in Geography*, Vol. V, No. 5 (1932), also H. M. Kendall, "Notes on Climatic Boundaries in the Eastern United States," *The Geographical Review*, Vol. XXV, pp. 117-124.

C. W. Thornthwaite employs an actuarial method of forecasting the probable recurrence of drought conditions using climatic year maps. See his chapter on the Great Plains in Carter Goodrich *et al.*, *Migration and Economic Opportunity*, (Wharton School of Finance and Commerce, University of Pennsylvania, 1936).

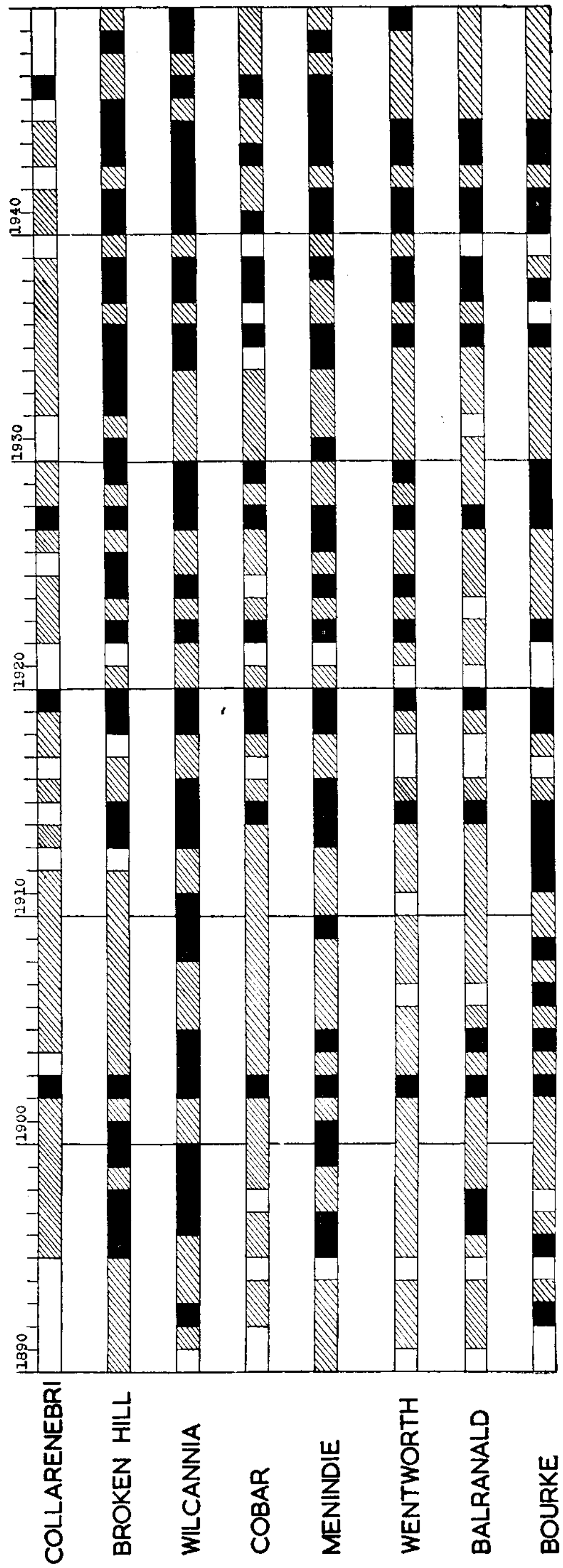

Fig. 3.—Climatic Years at Eight Localities in the Western Division, 1894 to 1949.

Black indicates *desert* years, crosslines indicate *dry* years, and white indicates *humid* years.

areas. In any year, the climatic type for an area has been defined in terms of specific average relationships between moisture and temperature, expressed according to the seasonal pattern. Climatic zones are usually most stable in their central parts; transitional belts between the central parts of two dissimilar adjacent climatic zones are marked by the element of uncertainty. Such areas experience fluctuations, sometimes severe, in climatic conditions from one year to another, which can be measured by the oscillations of climatic boundaries.

Figure 3 demonstrates the character of each climatic year at eight selected localities in the Western Division for the period 1890-1949[7]. The frequency of occurrence of climatic types at each of these localities can be summarised as follows:

Collarenebri.—20 humid, 36 dry, and 4 desert years. The dry years occurred usually in protracted sequences, separated by a single desert or humid year. The longest sequences of humid years occurred from 1890 to 1894 and from 1947 to 1949.

Broken Hill.—3 humid, 29 dry, and 28 desert years. A marked feature was the preponderance of desert years after 1921.

Wilcannia.—1 humid, 26 dry, and 33 desert years. These occurred mainly as short alternating groups of desert and dry years.

Cobar.—10 humid, 37 dry, and 13 desert years. There was a preponderance of dry years. The humid and desert years occurred for the most part singly.

Menindie.—2 humid, 31 dry, and 27 desert years. The distribution is comparable with that for Wilcannia with a greater number of dry years and less desert years.

Wentworth.—7 humid, 38 dry, and 15 desert years. The period prior to 1915 was marked by long sequences of dry years separated by isolated desert or humid years. By contrast, the second period (1916-1949) experienced eighteen dry years and thirteen desert years, with each type occurring usually in short groups. As with Broken Hill, the marked increase in desert years since 1920 was a feature.

Balranald.—9 humid, 37 dry, and 14 desert years. The distribution was made up of a preponderance of dry years. Humid and desert years occurred mostly as single units.

Bourke.—9 humid, 29 dry, and 22 desert years. Both dry and desert years have occurred either as protracted sequences or as alternating single units. Humid years occurred at widely-spaced intervals.

For much of the sixty-year period, the eight selected localities experienced a variety of climatic types in any year. However, the incidence of certain climatic years was universal to the selected stations; this applies particularly to the drought years of 1902, 1919 and 1927. A preponderance of desert years over the period 1935-1944 was a feature of all stations except Collarenebri. With the exception of Collarenebri, Bourke, Wilcannia and Balranald, the second half of the period (*i.e.*, 1920-1949) saw a marked increase in the number of desert years by comparison with the first half of the period (1890-1919). Collarenebri experienced few desert years, whilst Bourke and Wilcannia had numerous desert years throughout the whole sixty-year period.

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[7] Each of these climatic years has been defined in terms of the formulae employed by Lawrence, *op. cit.*, pp. 3-4.

It is suggested that the mapping of expansion and contraction of climatic areas provides a valuable approach to the measurement of climatic risk. Such an approach portrays climatic boundaries in their true role "as indicators of direction of change . . . . An expression of variability, rather than rigidity, is made possible through specific representation of zones of transition and areas of climax climatic types"[8].

The chief problem, however, is to devise an index, or set of indices, which will give the most effective expression to the variety of climatic experience in an area such as the Western Division. The writer believes that Lawrence's climatic year maps are not entirely satisfactory for this purpose for two reasons: (*a*) The mapping of the climatic zones for each year is essentially schematic. A comparatively small number of stations within the Western Division has been used in the analysis, precluding a detailed treatment of this area, which seems to be necessary for a climatic risk study. (*b*) Lawrence's choice of terms purports to be related to vegetation and landform types, expressing conditions characteristic of New South Wales. Although this may be true in a broad regional sense, it is doubtful whether the modified Koppen formulae make adequate allowance for the variety of local geographic conditions in the area to which they are applied.

It may be true that the average relationships obtaining between moisture and temperature, and classified by Lawrence as constituting a "dry" year, may actually represent dry conditions (in terms of plant requirements) at one or a number of places throughout the Western Division. Such relationships may even serve to indicate, in general terms, the approximate position of the boundary between one major soil or plant type and another. It is not to be expected, however, that these relationships will give adequate expression to aridity for the large variety of environments throughout an area as large as the Western Division. However, the mapping of the frequency of occurrence of climatic types appears to provide a sound basis for approaching the problem of climatic risk. The main task will be to evolve a suitable measure of climate which takes sufficient account of the factors relevant to the success or failure of pastoral operations in varied environments.

c. Measurement of Influential Rainfall.

In discussing the shortcomings of the Coef*vs*, as developed by Clawson, it was stated that variations in annual rainfall at a particular locality may not necessarily reflect important fluctuations in the carrying capacity of the holdings in that area. Because of the sporadic occurrence and variable duration of rainfall in the Western Division, annual rainfall figures will often disguise considerable differences in influential rainfall between areas.

For agronomic purposes, the most realistic measure of climatic experience is one which appraises climatic conditions in terms of the soil moisture conditions necessary for the maintenance of a desired level of plant growth, namely, a measure of *influential rainfall*. The latter attempts to make allowance for all those factors which govern the effect of rainfall on the level of crop or pasture growth. Such factors include the amount, duration and frequency of occurrence of rainfalls; wind occurrence; the frequency and length of dry spells; local

[8] Kendall, *op. cit.*, p. 124.

variations in soil and plant conditions; and the rate of loss of soil moisture through evaporation (with particular emphasis on sub-surface soil-moisture conditions).

Whilst Koppen's climatic formulae, as adopted by Lawrence, make some attempt to evaluate rainfall in certain of the abovementioned terms, it is thought that a much more efficient approach could be achieved in terms of a *climatic index,* such as that developed by Prescott.

The combination of meteorological data into various indices, which will approximately describe known geographical conditions, has received considerable attention in Australia and more particularly in the United States[9]. Climatic indices aim to secure some correlation between conditions of land-form, plants, animals and/or soils, and a single-valued function of weather data, which is considered to be most effective for the purpose at hand. Essentially, all of the methods involving a climatic index have tried to make allowance for the decrease in the effectiveness of rainfall under conditions of rising temperature. This has been done in some instances by devising a function involving both rainfall and temperature. In other cases, rainfall has been related to evaporation, either measured directly or indirectly by means of a function of the water-vapour pressure of the atmosphere. The latter has been calculated from observations on relative humidity and temperature.

An index which has received attention in Australia in recent years is the modified Transeau Ratio developed by Prescott, which relates rainfall (P) to some power (m) of evaporation (E) of the form P/E^m [10]. Such an index can be applied to monthly rainfall and temperature figures, for example, in order to determine the "length of the growing season" and the "period of influential rain," with respect to plant growth[11]. Prescott's formula makes allowance for the differential impact of rainfall occurring in different seasons, *e.g.,* summer as compared with winter.

Climatic indices have been used mainly for the compilation of diagrams showing the average position of climatic types. The movement of climatic boundaries or the shift in incidence of climatic types, which is more significant to the problem of climatic risk, has not received much attention in these studies. There does not appear to be any reason, however, why climatic indices measuring the character of influential rainfall cannot be applied to variability studies by mapping the frequency of occurrence of climatic years. This would mean that climatic indices would be placed upon a dynamic basis, demonstrating the yearly fluctuations of climatic conditions in an area of the Western Division, rather than merely representing the summation of average long-term conditions.

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[9] Elizabeth F. Lawrence, "Australian Climatology—a Review of Some Recent Work," *The Australian Geographer,* Vol. III, No. 7 (March, 1940), p. 29.

See also G. W. Leeper, "Thornthwaite's Climatic Formula," *The Journal of the Australian Institute of Agricultural Science,* Vol. XVI, No. 1 (March, 1950), p. 2.

[10] J. A. Prescott, "A Climatic Index," *Nature,* Vol. CLVII, No. 3991 (April 27, 1946), p. 555.

[11] Research along these lines has been undertaken by Trumble and others at the Waite Institute in South Australia employing the index P/E.

Using an index such as Prescott's P/E^m, it should be possible to devise an index value for a particular area which represents a critical climatic condition for the maintenance of desired levels of plant growth, over a specified period of time. By determining the number of months during a year, for example, which have experienced index values of a particular order, it would be possible to classify yearly climates as capable or incapable of supporting continuous growth of certain plants. On this basis, the sequence of climatic types could be determined.

Most work on climatic indices has been based upon monthly figures for rainfall and other data. To some extent monthly figures are unsatisfactory. First, important aspects of rainfall occurrence may not be revealed by the monthly data, although monthly figures are more satisfactory than yearly figures for this purpose. Second, the length of the month varies, so that errors may result from the use of monthly figures. At the present time, a daily or a weekly basis for analysing climatic data seems most suitable. Such analysis will obviously require a considerable amount of time.

Climatic indices, which employ figures for evaporation based upon readings from evaporimeters and the alternative measure involving saturation deficit, can give results, which, at best, will only approximate the factors controlling soil moisture conditions. Variations in infiltration capacities of the soil and rainfall intensities are the chief determinants of the proportion of the total rainfall which becomes available for plant growth, and should be the basis of any calculation of rainfall effectiveness in agro-climatic analysis. It is essential, therefore, that research be undertaken into the relationships between free-water surface evaporation and evaporation from the soil throughout the varied environments of the Western Division. This could follow the lines of research undertaken at the Waite Institute in South Australia[12]. There is some evidence to suggest that comparisons of evaporimeter records throughout the Western Division are misleading, due to the instruments being in non-comparable sites[13]. This requires investigation. Since research along the above lines is lacking throughout much of the more closely-settled parts of the state, it is probable that it will be some time before it will be undertaken, on any scale, in more remote and comparatively sparsely-settled areas such as the west.

Although a schematic idea of the distribution of climatic types and the variability of climate in the Western Division can be gained from the use of a single climatic index, such as Prescott's $\frac{P}{E^{0 \cdot 70}}$, it is doubtful whether the universal application of a single index to an area as large as this would adequately treat the local aspects of climate which appear to be most relevant to the problem of climatic risk. The writer considers that this problem can only be solved by a fairly detailed approach, although the principles embodied in the climatic index would be a desirable basis for such an anlysis. The effectiveness of rainfall is determined only by intensive experiments in type areas, and the results of such experiments will have only local application. The most suitable

[12] See H. C. Trumble, "The Climatic Control of Agriculture in South Australia," *Transactions of the Royal Society of South Australia,* Vol. LXI, (December, 1937), p. 41.

[13] See Beadle, *op. cit.,* p. 30.

approach, as pointed out by Prescott, will be to "examine each problem of bioclimatology and agroclimatology on its own merits, and to determine the most suitable index to meet each particular need as it arises"[14].

It has been suggested above that measurement of effective rainfall conditions can be best attained by use of the principles embodied in the modern climatic index. It has also been suggested that the use of this method for describing climatic conditions, when adapted to the method of demonstrating climatic variability by climatic years, will provide a worthwhile approach to the analysis of climatic risk. However, to be of real value to the latter analysis, any climatic index, which seeks to accurately describe climatic conditions in any one year, must give some expression to the effects upon soil moisture and plant conditions in that year, of conditions which prevailed in the period prior to that year. That is to say, the climatic index will need to give expression to the cumulative impact of climatic variations which the Coef*vs* attempts to demonstrate. Measurements of the "growing season" for certain plants using the P/E index usually have made some attempt to take account of this factor within the average year.

d. The Probability of Occurrence of Critical Levels of Climatic Experience.

For practical purposes, the analysis of climatic variability must be placed on an actuarial basis. Some expression must be given to the probability of occurrence of certain climatic conditions, expecially those which tend to force the farm firm below its particular survival limit. With a scientific expression of risks due to climatic factors available, it should be possible to organize the farm business in such a fashion as to minimise the chances of disposable income falling below the critical level for farm and personal maintenance.

A useful method of measuring rainfall probability, is to assess the probability of a locality receiving more or less that a specified critical amount over a particular period[15]. As yet, little is known, in quantitative terms, of critical rainfalls in the Western Division, with respect to the requirements of pastures and stock. When reliable data are available for a large number of recording stations, the concept of probability will be of value in an analysis of climatic risk in the pastoral and agricultural areas of western New South Wales. Thus it might be possible to express the probability of occurrence of any critical climatic condition, and also the probability of occurrence of significant sequences of such conditions.

3. VEGETATIONAL CHANGES AS POINTERS TO CLIMATIC CHANGE.

Where meteorological evidence is not available for a long period of time, Beadle has suggested that the study of climatic trends in the Western Division could be supplemented with data on vegetational

[14] J. A. Prescott, "Indices in Agricultural Climatology," *The Journal of the Australian Institute of Agricultural Science,* Vol. 4, No. 1 (March, 1938), p. 40.

[15] For a statistical analysis of drought frequency, employing the concept of probability, see G. Blumenstock, "Drought in the United States Analysed by Means of the Theory of Probability," *U.S.D.A. Technical Bulletin,* No. 819 (April, 1942).

See also Crowe, *op. cit.,* and C. E. Hounam, *Climate of the South-western Wheat Belt of N.S.W. with Special Reference to Rainfall Over Marginal Areas,* Commonwealth of Australia, Bureau of Meteorology, *Studies in Applied Climatology,* Pamphlet No. 2, (1947).

changes. "Vegetational trends will probably serve as a better guide to climatic trends than the rainfall records of so short a period as sixty or seventy years[16]." This applies particularly to studies of long-range climatic changes and drought occurrences. The geographical movement of vegetational types may provide a better indication of increasing or decreasing aridity than the limited meteorological evidence now available. As pointed out by Beadle, there is strong evidence of a westward movement of vegetation communities, which tends to discount the notion of an eastward movement of the arid areas as indicated merely by limited climatic data. The use of tree-ring analysis has been a feature of studies in the history of arid conditions in certain areas of the United States[17]. A detailed knowledge of vegetational conditions is essential for a true assessment of variations in effective rainfall conditions.

4. THE LOCAL IMPACT OF CLIMATIC RISK PROBLEMS.

Because of the variety of geographical conditions throughout the Western Division, considered both in their natural state and in the light of the differential impact of man's occupancy, it would seem that the problem of climatic risk will only be adequately treated by a special study of each problem area. Hence the analysis of the socio-economic implications of climatic variability and income instability in these areas must take as its basic frame of reference the individual farm firm considered as a going concern. Assuming the continuation of present-day land settlement patterns in the Western Division, climatic variability is a problem which could have a differential effect on each holding. It may even have a varied impact within one holding if the holding is very large or consists of several non-contiguous parcels of land.

5. THE DIFFERENTIAL IMPACT OF CLIMATIC RISK IN A VARYING HUMAN SITUATION.

In approaching the problem of farm management and permanency of settlement in high risk areas, it is important to remember that the risk problem is a complex of physical, human and economic factors[18]. That is to say, the managerial decisions of each pastoralist in the Western Division will be influenced by a complex set of elements such as (*a*) certain geographic factors, including the rainfall regime, soil, and plant conditions, etc.; (*b*) the expected and desirable financial returns from various levels of production; (*c*) the farm capital structure, credit resources and the farmer's liquidity preferences; and (*d*) certain psychological propensities, such as the farmer's attitude to the alternatives offered by the risk situation.

Farm survival in areas of high climatic risk will, therefore, be influenced, not only by the natural and economic factors affecting the individual firm; it will also be affected by the attitudes of the farmer to such a situation, as well as his resourcefulness in achieving desirable adaptations to the situation. The latter will involve factors of subjective judgment probably beyond the scope of empirical measurement.

[16] Beadle, *op. cit.*, p. 259.

[17] Isiah Bowman, "Our Expanding and Contracting Desert," *The Geographical Review*, Vol. XXV (1935), p. 43.

[18] For studies of the administrative, economic and psychological aspects of the climatic risk problem, see Rainer Schickele, "Farm Business Survival Under Extreme Weather Risks," *Journal of Farm Economics*, Vol. XXXI, No. 4, Part 2 (November, 1949), pp. 931-943; also "Farm Adaptations to Income Uncertainty," same Journal, Vol. XXXII, No. 3 (August, 1950), pp. 356-374.

6. CONCLUSIONS.

As pointed out by Clawson:

> A major factor in the adjustment of a people to any physical environment is their understanding of that environment . . . . If there is a common misconception as to the character of that environment, then adjustment to it must necessarily be imperfect. If the climate is one which easily leads to misconceptions, the problem of adjustment is clearly more difficult[19].

The climate of Western New South Wales, in so far as it is characterized by runs of good and bad seasons, is one which tends to create false ideas as to the long-range character of the climate in the area. The future success of land settlement throughout the west will depend greatly upon the degree to which a scientific appraisal of climatic variability replaces existing unscientific concepts of long-range normal conditions.

It is considered that the problem of climatic risk in the Western Division can be best approached by employing a number of devices. These are as follows:

(*a*) An analysis of climatic conditions on a localised scale taking into account the complex of geographic factors determining the effectiveness of rainfall in maintaining certain levels of fodder supplies.

(*b*) On this basis, the determination of a critical level, and mode of occurrence, of effective rainfalls throughout the year, and from year to year, which constitute the basic limit to "satisfactory" pastoral operations in a particular area. It is considered that both (*a*) and (*b*) can best be treated by an approach akin to that of the modern climatic index, but incorporated in the type of variability study employed by Lawrence. This will involve the mapping of climatic years, each of which will be defined in terms of a suitable index.

(*c*) Using the climatic year analysis, the determination of the probability of occurrence of years characterized by designated climatic conditions and also the probability of occurrence of varying lengths of sequences of such conditions.

It should be remembered that any formula, which seeks to portray realistically climatic conditions as they impinge upon the success of pastoral operation, should be sufficiently flexible to take account, not only of the variety of conditions from area to area throughout the Western Division, but also to measure climatic experience in terms of the cumulative effect of variations throughout time for any locality.

Since the problem of climatic risk, as it affects the individual farm firm, is one involving a complex consideration of geographic and socio-economic factors, it cannot be treated by some simple equation. It must be approached in a detailed manner so that each factor affecting the situation can receive emphasis according to the particular situation at hand.

To be of any value to future farm management problems in the west, the analysis of climatic variability on the basis of the complex of considerations mentioned above, must be based upon accurate observations of conditions over a long period of time. Since accurate records of most of the geographic components of the problem have not been kept in the past, it is imperative that the task of collecting the necessary data for a large and widespread number of observation stations be commenced as soon as is practicable.

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[19] Clawson, *op. cit.*, p. 281.