THE ASSOCIATION BETWEEN THE OCCURRENCE OF MAJOR FIRES
AND A SYNTHETIC SOIL MOISTURE INDEX

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Abstract: An attempt has been made to assess the quantity of grass-fuels and their time of curing from records of monthly rainfall and evaporation, and from the occurrence of major fires in the Wagga-Riverina districts during 1948 to 1955.

In simulating a soil-moisture conservation approach the results seem promising but, for lack of certain data, any conclusions are still very subjective. Further development and modification of the procedures used will be necessary to produce a satisfactory forecasting aid.

A brief review of some of the published methods for assessing soil-moisture conservation is included. From these it may be possible to devise a more satisfactory means for assessing the state of grass-fuels from meteorological data.

1. INTRODUCTION

The abundance of growth and degree of curing of fuels comprise the seasonal (long-term) factors contributing to fire danger. Superimposed on these are the relatively short-term factors, consisting of a combination of meteorological elements conducive to the outbreak of serious fires when the fuel has reached a certain state.

At present (1957) fuel-state reports are planned to be received from only the more densely settled regions of the Commonwealth. This leaves large areas where the quantity and degree of curing of fuels are relatively unknown. Monthly stock and crop notes may give some
indication, but these generally arrive too late to be used in fire weather forecasting.

The association between rainfall in the months preceding the fire season and the state of the fuel has been mentioned in several technical papers. Foley (1947) has shown graphs of progressive totals of departure from normal of district rainfall - the significant feature of these being the occurrence of serious fires after distinct downward trends (representing periods of below average rainfall) in the graphs.

It was felt that the amount of growth and the degree of curing could be related to rainfall and effective rainfall. Preliminary investigations showed that fires in the Wagga-Riverina district occurred only after the rainfall had fallen well below the effective rainfall at Griffith. This result suggested that a soil-moisture conservation approach to the problem might be appropriate. Accordingly a method similar to that described by Hounam (1955) was tried.

2. SOME METHODS FOR COMPUTING RESIDUAL SOIL MOISTURE

Many authors have written quite extensively on the subject of residual soil moisture and its effects on plant growth, and some of them have outlined procedures for assessing this residual soil moisture. A few of these procedures have been selected with the view that they might be applicable to the problem of relating grass-fuel state with meteorological elements.

2.1 Thornthwaite and Mather (1955) have given comprehensive instructions for the calculation of storage, deficit, surplus, and detention of soil moisture using the parameters rainfall and mean temperature. For various localities in the U.S.A. the agreement between computed and measured soil moisture is quite good.

The calculations are made on a book-keeping basis, and the method may be applied to those stations where no tank evaporation readings are taken. Although tables for a soil moisture capacity of only 300 mm are given in their publication, more detailed instructions which are being prepared will include tables for use with values other than 300 mm for the water holding capacity.
2.2 From experiments on cylinders of soil, Staple and Lehane (1944) have given a series of curves relating removable soil moisture to tank evaporation for various incremental rainfalls. The progressive removable soil moisture between rain days can be assessed very quickly. On rain days adjustment is made by transferring the last computed value (of removable soil moisture) to the next appropriate set of curves.

The authors have compared their estimated soil moisture conservation with that computed from the change in soil weight of fallow tanks in the field. Agreement between the computed and measured values seems to be satisfactory, but it is to be expected that soils of different textures will have correspondingly different evaporation curves. A further criticism of this method appears in the paper by Bath and Fox (unpublished).

2.3 In Queensland, Bath and Fox (unpublished) have approached the problem of residual soil moisture and its effect on plants by considering firstly the rainfall required to initiate plant growth and secondly, the rainfall needed to maintain growth throughout plant life cycles. The authors give a method for calculating a running daily total of soil moisture (in the top few inches of soil).

2.4 Before the procedures briefly outlined in 2.1, 2.2 and 2.3 can be applied to the problem of computing grass fuel state, some knowledge of the water-holding capacity of the soil, and the characteristics of the predominant plant species is required. In particular, the depth of the root system is the major factor in assessing the soil moisture available to plants.

3. PHYSIOGRAPHY OF THE SELECTED REGION

The selected region comprises all of the area bounded by the Rivers Lachlan and Murray, and (in the east) approximately by the 800 ft contour. This area, with an average height of about 500 feet above MSL, has a general fall to the west of roughly 400 feet in 200 miles. Since the region is virtually flat, it may be presumed that meteorological readings at various stations would be representative for considerable distances.
The average annual rainfall increases fairly uniformly from about 12 in. for the far west to about 22 in. for the east of region. The average annual evaporation (computed from saturation deficits) decreases fairly uniformly from about 65 in. in the northwest to 50 in. in the southeast of the region.

4. PRELIMINARY INVESTIGATIONS

The monthly effective rainfalls for Griffith were calculated from Prescott's formula:

\[ \frac{P}{E^{0.7}} = 0.54 \]

where \( P \) (the effective rainfall in inches) is that rainfall necessary to start and maintain growth after break of drought and \( E \) is the monthly tank evaporation in inches. Fig. 1 shows the plot of monthly effective rainfalls (dotted line), together with corresponding values of actual rainfall (vertical lines). The graph infers that where the actual monthly rainfall greatly exceeded the effective rainfall in the winter, followed by a spring and summer where the effective rainfall greatly exceeded the actual rainfall, serious fires generally occurred in the area during the summer. This was considered to represent a good winter grass growth, which had dried out in the spring and summer, thus presenting a considerable fire hazard.

Where the difference between actual and effective rainfall was generally small during the winter, it was considered that the grass growth would have been poor. Consequently, even if it was dried out thoroughly during the following summer, it would not then present a very serious fire hazard. Also, when the actual rainfall exceeded the effective rainfall during or just before the summer, it was considered that the fire hazard would be correspondingly low.

These considerations seem to be borne out by the occurrence of serious fires as shown in Fig. 1. However, the results presented in this way are somewhat subjective, and only give a qualitative indication of the extent of grass growth and subsequent drying.
Fig. 1. Griffith. Actual and effective monthly rainfall from January 1920 to December 1955 (see text for details). Abscissa alignment marks indicate the month of January. Arrows below abscissa indicate the months of fire occurrence in the Riverina. The letters above the peaks in the effective rainfall line indicate summer conditions according to the inset table.

A - Good growth and dry summer.
B - Fair growth and dry summer.
C - Fair to poor growth and dry summer.
D - Poor growth and dry summer.
E - Fair to poor growth and wet summer.
F - Poor growth and wet summer.
√√ = Effective rainfall.

Actual rainfall (Monthly)
Fig. 2. Difference between actual and effective rainfall for Wagga—Jan 1948-Jan 1956
Fig. 2 shows the plot of the difference between actual and effective rainfall for Wagga (which has only eight years of evaporation records). If the area under the curve on the negative side of Fig. 2 is considered as an index of cumulative drying, then one could expect some kind of relationship between the occurrence of fires and some minimum area below the zero difference level. The variability in these areas up to the time of fire outbreaks infers that:

(i) In some fire seasons, weather conditions are not conducive to the outbreak of fires at the time when this minimum area is reached, and/or

(ii) The fire risk (associated with safety precautions, etc.) is greater in some years than in others, and/or

(iii) The retention of moisture in soils plays some part in accelerating or retarding the rate of curing of fuels.

The first of these inferences forms part of a separate study, now in progress, and the second is beyond the scope of meteorological research. The subject of soil moisture retention forms the basis of Section 5.

5. SIMULATED SOIL MOISTURE INDEX

5.1 Trial method

Hounam (1955) has described a procedure for assessing the daily balance of residual soil moisture available for the growth of shallow-rooted plants. At present no detailed data regarding the characteristics of the soil, and the root-depth of the predominant grass species are available for this district. However, it was proposed that a similar method should be tried. For this it was assumed that the predominant plant species could draw on a moisture supply amounting at saturation to 4 in. (Thornthwaite, 1948). Also, it was assumed that evapo-transpiration (on a monthly basis) was equal to the effective rainfall. These are extremely broad assumptions but, even if the soil moisture index calculated this way is erroneous, it was considered that the results might show some connection with the occurrence of serious fires.
5.2 Calculations involved

A succession of relatively large negative differences between actual and effective monthly rainfall indicates a prolonged dry spell. Commencing from the first positive difference after a prolonged dry spell, monthly cumulative totals of these differences were tabulated. Negative differences were subtracted from the value of 4 in. if the progressive value was greater than 4 in. Similarly, positive differences were added to zero if the progressive value was less than zero. Thus the cumulative total was confined between the limits 0 in. and 4 in.

For the purposes of this trial method, the water-holding capacity of the soil was also assumed to be 4 in., and the amount by which the cumulative total would have exceeded 4 in. was regarded as run-off and artesian seepage. When the cumulative total reached zero, the soil was regarded as dry, and the plants were then beginning to wilt.

An example of the calculations is given in Table 1.

<table>
<thead>
<tr>
<th>Month</th>
<th>Difference</th>
<th>Cumulative Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>-2.10</td>
<td></td>
</tr>
<tr>
<td>February</td>
<td>-0.91</td>
<td></td>
</tr>
<tr>
<td>March</td>
<td>-2.10</td>
<td>Prolonged dry</td>
</tr>
<tr>
<td>April</td>
<td>-0.33</td>
<td>spell</td>
</tr>
<tr>
<td>May</td>
<td>-0.62</td>
<td>0</td>
</tr>
<tr>
<td>June</td>
<td>+2.57</td>
<td>Table commenced</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.57 New Growth</td>
</tr>
<tr>
<td>July</td>
<td>-0.14</td>
<td>2.43</td>
</tr>
<tr>
<td>August</td>
<td>-0.46</td>
<td>1.97</td>
</tr>
<tr>
<td>September</td>
<td>-1.48</td>
<td>0.49</td>
</tr>
<tr>
<td>October</td>
<td>-0.75</td>
<td>0</td>
</tr>
<tr>
<td>November</td>
<td>-1.11</td>
<td>...Plants wilting</td>
</tr>
<tr>
<td>December</td>
<td>-0.19</td>
<td>0</td>
</tr>
<tr>
<td>January</td>
<td>-1.56</td>
<td>0</td>
</tr>
<tr>
<td>February</td>
<td>+3.76</td>
<td>3.57 New Growth</td>
</tr>
<tr>
<td>March</td>
<td>+1.94</td>
<td>4.00 Maximum</td>
</tr>
</tbody>
</table>

Note: Moisture...
Figs 3&4. Synthetic soil moisture index for Wagga and Griffith respectively (cumulative difference between actual and effective rainfall in inches for a maximum cumulative total of 4 inches)
Figs. 5 & 6. Synthetic soil moisture index for Griffith and Wagga respectively (cumulative difference between actual and effective rainfall in inches for a maximum cumulative total of 2 inches.)
(Due to the manner in which this cumulative total has been compounded it has been called a "synthetic" soil-moisture index)

These cumulative totals have been prepared for Wagga and Griffith and are shown graphically in Figs. 3 and 4. For comparison, Figs. 5 and 6 show the synthetic soil moisture indices assuming that the plant species can draw on a moisture supply of 2 in. at saturation, also assuming that the water holding capacity of the soil is 2 in.

5.3 Discussion of results

Fig. 4 shows that, with the exclusion of the 1953-54 season, all the major fires in the Wagga-Riverina districts during the period 1948-1955 occurred after the soil moisture index had fallen to zero. Fig. 3 shows that fires occurred only after the synthetic soil moisture index for Wagga had fallen to around 2 in.

Mangoplah (18 miles SSW of Wagga) suffered an extremely large, serious fire during the period 22 January to 1 February, 1952. This fire occurred after the synthetic moisture index for Wagga (Fig. 3) had fallen to zero. The remainder of the major fires during the period 1948 to 1955 occurred generally well to the west of Wagga, and the indications for their occurrence seem to be displayed more clearly in the graph for Griffith (Fig. 4).

Figs. 5 and 6 (using an upper limit of 2 in.) seem to give the best results. Again, the occurrence of fires in the west of the Riverina seems to be more adequately indicated by Fig. 5 (Griffith).

During the 1954-55 fire season no major fires occurred in the area. Fig. 5 suggests that, in the vicinity of Griffith, the conserved soil moisture during the winter of 1954 was insufficient to promote a good grass growth, resulting in a low fire hazard during the summer. However, in the Wagga area, Fig. 6 indicates a fair to moderate grass growth during the winter of 1954. It remains to examine the 1954-55 and also the 1948-49 and 1955-56 fire seasons to determine whether this was due to the non-occurrence of short-term factors conducive to the outbreak of serious fires.
5.4 Comparison of results with Monthly Stock and Crop Notes

No record has been kept of fuel state observations in the Wagga-Riverina during the period 1948 to 1955. It appears that the only method of assessing the synthetic soil moisture index at present is by recourse to monthly stock and crop notes on the returns from meteorological observers. Over the period (1948-1955) very little information on the conditions of grasses and pastures is available from Griffith. However, both the Research Station and the Agricultural College at Wagga have reported the state of pastures, grasses and crops fairly regularly. A qualitative comparison of the synthetic soil moisture index with the Wagga reports is shown in Table 2.

<table>
<thead>
<tr>
<th>SEASON</th>
<th>Indicated end of growing season</th>
<th>Condensed remarks from Monthly Stock and Crop Notes for Wagga</th>
<th>Area under curve of Fig.6 as an index of amount of growth during growing season</th>
</tr>
</thead>
</table>

TABLE 2 Comparison of Results with Stock and Crop Notes
<table>
<thead>
<tr>
<th>SEASON</th>
<th>Indicated end of growing season</th>
<th>Condensed remarks from Monthly Stock and Crop Notes for Wagga</th>
<th>Area under curve of Fig. 6 as an index of amount of growth during growing season</th>
</tr>
</thead>
<tbody>
<tr>
<td>1952-53</td>
<td>March (1953) March? (1953)</td>
<td>FEB. Fair amount of green matter. Winter species dried off. MARCH. Owing to continued dry conditions there is only limited dry feed in paddocks. Surface soil very dry.</td>
<td>193</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>1953-54</td>
<td>Dec. (1953) Oct-Nov (1953)</td>
<td>NOV. Green feed almost completely dried off. DEC. Extensive drying up of pastures.</td>
<td>135</td>
</tr>
</tbody>
</table>

It is apparent from Table 2 that the synthetic soil moisture index indicates the end of the growing season approximately one month later than that indicated by the stock and crop notes. This is probably due to the calculated value of evapo-transpiration \(0.54E^{0.7}\) being lower than the actual value when the plants were near maturity. (The relation \(P/E^{0.7} = 0.54\) is an estimate of the rainfall necessary to start and maintain growth after break of drought.) So the value of the constant (0.54) would be higher for mature plants than for young shoots just commencing their growth.

However, with the exception of the 1951-52 season, Fig. 6 seems to indicate the month during which the grasses and pastures in the vicinity of Wagga were fully cured.

Compared with fuel state reports, the stock and crop notes do not give precise information regarding the amount of growth, and the progressive degree of curing of the grass fuels. Thus, for lack of data, any conclusions drawn from Stock and Crop Notes are still somewhat subjective.
5.5 Assumptions involved in the trial method

In the trial method it is assumed that:

(1) There is no subterranean seepage and no run-off until the calculated soil moisture reaches a certain fixed limit which is also assumed to be the water-holding capacity of the soil.

(2) The predominant plant species (at all stages of growth) can draw on a moisture supply amounting, at saturation, to the same fixed limit.

(3) Evapo-transpiration (on a monthly basis) is equal to the effective rainfall.

(4) The amount of plant growth can be qualitatively expressed by the area under curve of synthetic soil moisture index.

(5) The degree of curing of grass-fuels can be qualitatively determined by the length of time that the synthetic soil moisture index had remained at zero.

(6) The cumulative effects of temperature, radiation and humidity on plant growth and subsequent curing were constant over all periods of the year, i.e., that soil moisture is the major factor in determining the amount of growth and time of curing.

5.6 Summary and conclusions

Using a synthetic soil moisture index, the calculated end of the growing season gives a rough indication of the time of curing of fuels. For lack of more precise confirmatory data, no conclusions can be drawn at present regarding the amount of fuel.

The trial method only gives qualitative results, and it is presented here solely with the object of indicating an avenue for future research. It is suggested that if methods similar to those mentioned in Section 2 were applied to the problem of relating fuel state to meteorological elements, it is probable that more realistic results would be obtained.
6. RECOMMENDATIONS

It is recommended that an investigation of this nature be deferred until sufficient data are available. The data required will probably include:

(1) Fuel state returns in order to compare calculated results with actual conditions.

(2) A knowledge of the water-holding capacity and field capacity of the soil.

(3) A knowledge of the predominant grass species for the region to be considered. In particular, it is desired to know the average depth of the plant root-system at maturity and, if possible, at various stages of growth.

(4) A reliable means for estimating evapotranspiration.

7. ACKNOWLEDGEMENTS

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