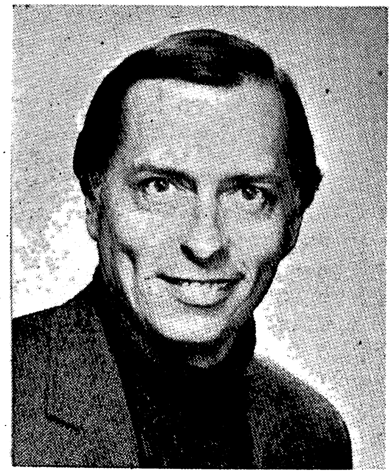

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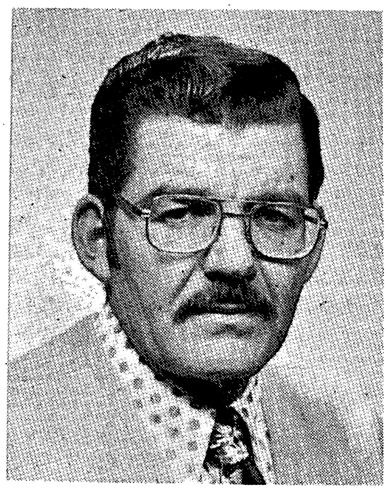

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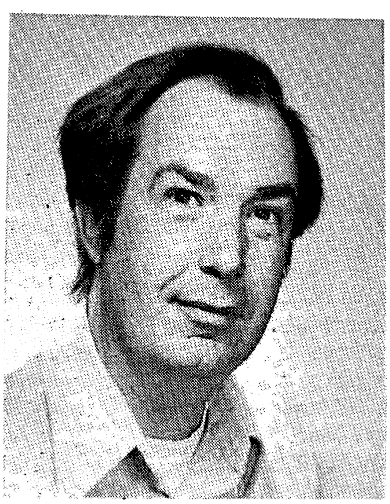

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CONTENTS

AN ASSESSMENT OF THREE MEASURES OF LONG-TERM MOISTURE DEFICIENCY BEFORE CRITICAL FIRE PERIODS

Donald A. Haines, Von J. Johnson, and William A. Main

Accounting for long-term drying has always been a major problem in the development of forest fire danger rating systems. It is a necessary component of any fire danger rating system because it provides guidance to the fire manager during critical conditions, i.e., periods when moisture contents of soil and fuel become so low that fire control difficulties are greatly intensified. Keetch and Byram (1968) pointed out:

> "The moisture content of the upper soil, as well as that of the covering layer of duff, has an important effect on the fire suppression effort in forest and wildland areas. In certain forested areas of the United States, fires in deep duff fuels are of particular concern to the fire control managers...(but)... in fire control, the critical effects of drought are not confined to deep organic soils. Dried out organic materials are frequently embedded in the shallow upper layers of mineral soils. These fuel pockets can become a deciding factor in whether or not fire lines will hold and be a further problem in mopup operations."

This does not imply that difficult forest fires cannot occur without prior, long-term moisture deficiency. For example, during early spring in the north-central and northeastern States, snowmelt is often followed by a period of dry, windy days. Greening of the low, finer vegetation has not yet occurred and conditions are ideal for fast-spreading surface fires. These types of fires may display crowning in conifer stands but rarely burn the deeper duff fuels. Consequently, low moisture amounts in the large fuels, deep duff, and soil mantle are usually not a contributing factor in this type of forest fire.

Early danger meters differed widely in their approach toward measurement of long-term drying. During the 1950's and 1960's, Buildup Indexes (BUI) were integrated into fire danger rating systems in the United States. They reflected the dryness or wetness of fuels that have a pronounced effect on fire behavior, except the fine, flashy fuels (Nelson 1964). Fire control organizations felt that containment and mopup became progressively more difficult when BUI values increased, which gave the Index meaning operationally.

However, many believed that the BUI did not indicate extreme drying conditions. In 1968, therefore, Keetch and Byram developed a drought index, which they stressed was not a substitute for the moisture parameters used in the spread phase of the National Fire Danger Rating System. They explained:

> "A drought condition is not a prerequisite for the occurrence and spread of fire in any area. The drought index does not replace the buildup index, because it represents an entirely different moisture regime in which the response to weather changes is much slower than with the buildup index. The purpose of the drought index is to provide fire control conditions in areas where such information may be useful in planning fire control operations."

Identification of the proper zone of progressive drying is a problem that also plagued other researchers, including Wayne Palmer of the National Oceanic and Atmospheric Administration. After developing a meteorological drought index (Palmer 1965), he was forced to later construct a crop moisture index (Palmer 1968). He explained:

> "The Meteorological Drought Index was designed to evaluate the scope, severity, and frequency of prolonged periods of abnormally dry weather. For this purpose it works reasonably well. However, since some people have been trying to interpret it strictly as a measure of the current status of agricultural drought; i.e., as a measure of the effects of abnormally dry weather on crops, a separate procedure has been developed that responds rapidly to changes in the soil moisture situation and takes

into account only those moisture aspects which affect vegetation and field operations."

Palmer accomplished this by combining an "evapotranspiration anomally index" and a "wetness index" (Palmer 1968). Therefore, both Palmer and Keetch-Byram independently came to the conclusion that the upper and the deeper soil layers represented such divergent moisture regimes that different bookkeeping methods were required in their description. They are not the only ones that finally arrived at a duel-entry system to identify long-term moisture deficiency because the Canadians developed a Forest Fire Weather Index that contains a Drought Code and a Duff Moisture Code (Van Wagner 1974).

ASSESSMENT PROCEDURES

In fire danger rating, is the long-term moisture deficiency best represented by:

1. large, surface fuels?
2. litter and duff layers (L, F, and H)?
3. soil profiles? or
4. living foliage?

We attempted to partially answer these questions by assessing the values for the following indexes before the 26 critical fire situations shown in figure 1:

1. The Buildup Index that was designed to represent drying in the top 2 to 3 inches of litter type fuel (see Appendix I).
2. The Keetch-Byram (K-B) Drought Index that is a moderately fast response system applicable to conditions in a layer from surface to deeper soils (see Appendix II).
3. The Palmer Drought Index that is a slow response system applicable to conditions in a layer from surface to deeper soils (see Appendix III).

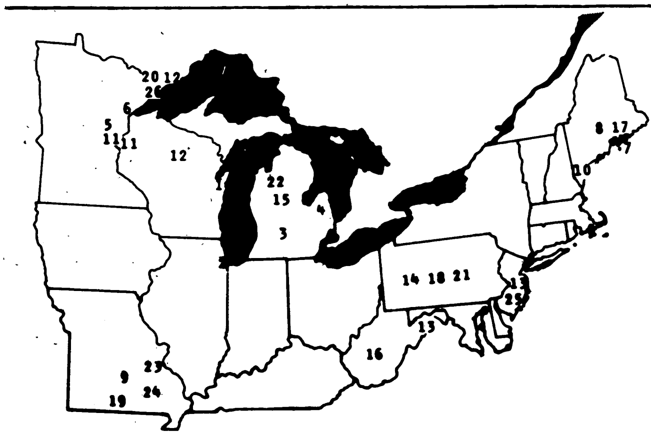

Figure 1.--*General location of critical fire situations. The numbers correspond to the following:*

October 8-10, 1871

1 *Peshtigo (Wisconsin), 1,280,000 acres burned; 1,300 lives lost. Extensive areas of logging and land clearing slash interspersed with millions of acres of standing timber; mostly conifer.*

2 *Chicago (Illinois), 17,450 buildings burned; 200 lives lost.*

3 *Lower Michigan, 2.5 million acres burned; 200 lives lost. Extensive areas of logging and land clearing slash interspersed with millions of acres of standing timber; mostly conifer.*

September 1-5, 1881

4 *Thumb Fires (Michigan), 1 million acres burned; 169 lives lost. Principally large acreages of dead timber from 1871 fires, and large areas of windfalls and conifer slashings.*

September 1, 1894

5 *Hinckley (Minnesota), 160,000 forested acres burned; 418 lives lost. Fire started in large, logged-over pine areas and then moved into standing timber.*

October 12, 1918

6 *Cloquet (Minnesota), 1,280,000 acres burned; 538 lives lost. Fire started in brush, slash, and peat bogs and then moved into standing conifer timber.*

October 23, 1947

7 *Bar Harbor & York County Fires (Maine), 150 miles of fire line; 220,000 acres burned. Dense growth of spruce and other softwoods, dry stubble of cut hayfield, large volumes of slash.*

May 23, 1950

8 *Greenfield (Maine), 6,355 acres burned. High hazard area with large amounts of slash.*

November 1, 1952

9 *Missouri Fires, a 33,000 acre fire, partly on the Clark National Forest. State had*

625 fires during October; Govenor closed all forests. Grass, brush, and standing hardwood timber with freshly fallen leaves.

May 8-9, 1957

10 Sanford-Kennebonk (Maine), 13,000 acres burned, one of several large fires in the northeast and Canada. Fuel moisture 3.3 on afternoon of the 8th; severe crowning. Pine cover with old pine slash areas.

May 1, 1959

11 Grantsburg (Wisconsin), Moose Lake and Badoura (Minnesota), crown fires burned 26,000 combined acres at Grantsburg and Badoura. Moose Lake reported large grass fires. Natural jack pine cover with interspersed red pine plantations.

May 30, 1961

12 Bear Trail (Minnesota) and Boundary (Wisconsin), 600-acre crown fire on Superior National Forest; two crown fires burned 600 acres on Nicolet National Forest. Bracken fern at origin; fire burned over swamps and into standing conifer timber.

April 20-21, 1963

13 Paw Paw (West Virginia) and New Jersey fires, 6,626 acre fire in West Virginia; over 200,000 acres burned during spring season in New Jersey. Mostly shrub oak and pitch pine areas in New Jersey with fire carried in wind-driven oak leaves. In West Virginia cover was mixed hardwood with some Virginia pine and scrub oak.

October 14, 1963

14 St. Lawrence (Pennsylvania), 3 fires joined; 3,000 acres burned. Began in low vegetation along a railroad track.

April 12-17, 1964

15 Lower Michigan, 9 large fires burned between 306 and 3,000 acres each; crowning with high winds. Some burned in large grass areas, and also in hardwood and jack pine stands.

November 5-11, 1964

16 District 5 (West Virginia), 413 fires in this district during November. Five large fires burned between 1,200 and 3,370 acres.

August 4, 1965

17 Centerville (Maine), 12,062 acres burned with much crowning and spotting. Fire started in a peat bog; it continued into cutover areas and then spread into spruce-fir stands.

November 4, 1965

18 Tuscorora Mt. (Pennsylvania), 550 acres burned; difficult mopup, fire broke out again on November 6.

April 5-6, 1967

19 White Ranch (Missouri), 2,050 acres burned with low vegetation in cured stage. Previously burned hardwood area with a large number of snags.

June 3, 1967

20 Clearwater (Minnesota), 800 acres burned with crowning and spotting. Fire started in cured low vegetation (grass, moss, and dry duff). It then burned through heavily stocked, pole size, spruce and fir stands.

April 19, 1968

21 Broad Mt. (Pennsylavania), 819-acre fire; "Governor issued a proclamation cautioning extreme fire danger." Unbroken scrub oak.

May 8, 1968

22 (Michigan), two fires of 1,570 and 4,692 acres, much crowning and spotting. Oak and jack pine.

March 19-22, 1969

23 (Missouri), eight large fires burned a total of 5,700 acres. Low vegetation in cured stage; mostly grass and second growth hardwoods burned.

March 31, 1971

24 (Missouri), eight large fires burned a total of 6,400 acres; 15,000 acres were burned across the State. Serious fires also reported in south Illinois. Mostly second growth hardwoods in late dormancy.

April 18, 1971

25 Manahawkin (New Jersey), 21,000 acres burned in 7 hours. Critical fires also reported in eastern Pennsylvania. Fire began in a grass field near the Pine Barrens region. It displayed extensive crowning as it moved into pitch pine.

May 14, 1971

26 Little Sioux (Minnesota), 15,000 acres burned with much crowning and long distance spotting. Sixty-five percent of area had been recently logged. The fuels included tall, dead, marsh grass and aspen and conifer stands.

These 26 fire situations include most of the well known fires that have occurred in the northeastern and north-central States since 1871 as well as situations judged especially difficult by State fire-control organizations. They do not represent all the critical fire situations that have occurred in these States, only those for which weather and fire behavior data were well documented. The selection emphasizes fires since 1960 because personnel currently employed in fire-fighting organizations had first-hand experience in their containment.

INTERPRETATION OF RESULTS

The values of the three indexes before the 26 critical fire periods are tabulated in table 1. Almost all the median and mean

Table 1.--*Immediate weather conditions and index values at the time of fire start*

Map No.	Observation station(s) or climatic division(s)	Weather conditions: Temperature	Relative humidity	Wind speed	Indexes: Palmer	K-B	BUI
		°*F*	*Percent*	*M.p.h.*			
1.	Madison, Wisconsin		24		[1]-3.79	300	101
	Sturgeon Bay, Wisconsin	63		12			
2.	Chicago, Illinois	85	24	22		394	80
3.	Lansing, Michigan	78	37	12	[1]-3.04	381	60
4.	Thornville, Michigan	99	40	34	[1]-4.93	435	80
5.	Sandy Lake, Minnesota	90	28		[1]-9.15	438	198
	St. Paul, Minnesota			20			
6.	Cloquet, Minnesota				[1]-2.46	246	66
	Duluth, Minnesota	76	31	[2]65			
7.	Coastal Maine				-3.00		
	Portland, Maine	82	36	[3]27		580	100
	Bar Harbor, Maine					510	82
8.	Coastal Maine				-2.50		
	Portland, Maine	72	47	16		98	46
9.	Eastern Ozarks, Missouri				-2.20		
	Salem, Missouri	75	44	8		622	104
10.	Coastal Maine				-2.43		
	Portland, Maine					160	68
	At fire	86	20	12			
11.	East-central Minnesota				-2.15		
	Duluth, Minnesota	80	27	20		21	32
	North-central, Minnesota				-2.34		
	Moose Lake, Minnesota	89				32	
	Park Rapids, Minnesota	93		50		38	
12.	Northeast Minnesota				-1.38		
	Duluth, Minnesota	77	22	14		48	38
	Winton, Minnesota					62	
	Green Bay, Wisconsin	74	26	10			54
13.	Southern New Jersey				-1.50		
	Atlantic City, New Jersey	79	15	25		150	78
	Pemberton, New Jersey					155	
	Northeast West Virginia				-1.00		
	Romney, West Virginia					218	
14.	South-central Mountains Pennsylvania				-4.57		
	Pittsburg, Pennsylvania	70	16	4		567	35
	Altoona, Pennsylvania					532	
15.	Northwest Lower Michigan				-1.54		
	Traverse City, Michigan	72	31	[4]50		7	10
	Central Lower Michigan				-1.86		
	Northeast Lower Michigan				-2.74		
16.	Southwest West Virginia				-2.75		
	Charleston, West Virginia	70	20	20		550	75
17.	Coastal Maine				-4.69		
	Mitten, Maine	78	30	18			88
	Jonesboro, Maine					530	
	Ellsworth, Maine					580	
18.	Mid-Susquehanna, Pennsylvania				-2.68		
	Harrisburg, Pennsylvania	66	26	16		177	41
19.	Eastern Ozarks, Missouri				-1.34		
	West Plains, Missouri	86	24	18		258	63
	Rolla, Missouri					155	
20.	Northeast Minnesota				-0.52		
	Isabella, Minnesota	79	26	16		60	56

Table 1 continued on next page

Table 1 continued

Map No.	Observation station(s) or climatic division(s)	Weather conditions: Temperature	Weather conditions: Relative humidity	Weather conditions: Wind speed	Indexes: Palmer	Indexes: K-B	Indexes: BUI
		°F	Percent	M.p.h.			
21.	East-central Mountains, Pennsylvania				-1.63		
	Cressona, Pennsylvania	73	29	10+			67
	Allentown, Pennsylvania					101	
22.	Northwest Lower, Michigan				+1.05		
	Houghton Lake, Michigan	65	52(1 p.m.) 24(4 p.m.)			50	40
	At fire			15+			
23.	Eastern Ozarks, Missouri				-0.32		
	Summerville, Missouri					30	
	Fremont Tower, Missouri						49
	Eminence, Missouri	79	17	13			
24.	South-central Missouri				-1.00		
	Salem, Missouri	73	14	21		28	[5]55
25.	Southern New Nersey				-0.67		
	Tuckerton, New Jersey	70	23	[6]19		50	
	Coastal New Jersey				-0.73		
	Cedar Bridge, New Jersey						52
26.	Northeast Minnesota				+2.77		
	Ely, Minnesota	76	15	16			45
	Cook, Minnesota				[1]-1.23		
	Winton, Minnesota					55	

[1]Values computed for a single station and not a climatic division.
[2]Winds were fire induced.
[3]Wind was the highest of the day.
[4]Highest wind observations at fire.
[5]Ranged from 42 to 63 across the fire area.
[6]Wind gusts to 60 at fire.

values of the individual spring and autumn sets in figures 2, 3, and 4 are very close (table 2). Correlation (N=26) between the indexes are significant at the 1 percent level as follows:

	Palmer	*K-B*	*BUI*
Palmer	--	--	--
K-B	-0.62	--	--
BUI	-0.67	0.56	--

However, an appreciable portion of the variability is not accounted for; this emphasizes that all three indexes respond somewhat differently to various phases of the water exchange process. We did not attempt to compare variability by computing the coefficient of variation because of the nature of the number scales in the three systems.

Our data re-emphasizes that long-term moisture deficiency in itself cannot be used to forecast critical fire situations. If the smaller fuels are wet or green and winds are calm, serious fires usually will not occur at any time of year. Most critical fires are caused from a combination of factors that occur in conjunction with drought conditions. Consequently, it is not possible to establish precise "threshold values" at which critical fire situations may develop although most of the 26 fire situations we examined began with BUI values above 30 in the spring and well above 40 in the fall (fig. 2). None of them developed when the Palmer Index was less than -2.2 in autumn (fig. 4). The other three seasonal data groupings are more ambiguous (figs. 3 and 4).

Table 2.--*Median, mean, standard deviation, and 90th percentile levels of 3 indexes in the spring and fall before 26 critical fire periods*

Index	Median	Mean	Standard deviation	90th Percentile levels
SPRING (N=14)				
BUI	51	50	17	14 to 86
Keetch-Byram	52	82	68	0 to 227
Palmer	-1.49	-1.0	1.4	1.98 to -3.98
FALL (N=12)				
BUI	80	86	42	0 to 178
Keetch-Byram	438	439	145	123 to 755
Palmer	-3.1	-3.7	2.0	0.66 to -8.1

Response times are often quite different when we compare the three systems (fig. 5). For example, in the late fall of 1952 (figure 1, No. 9) a proclamation by the governor of Missouri, followed by similar Forest Service action, closed all woods and forests in that State to the public, the only time this action has ever been taken there. The people of the eastern Ozarks

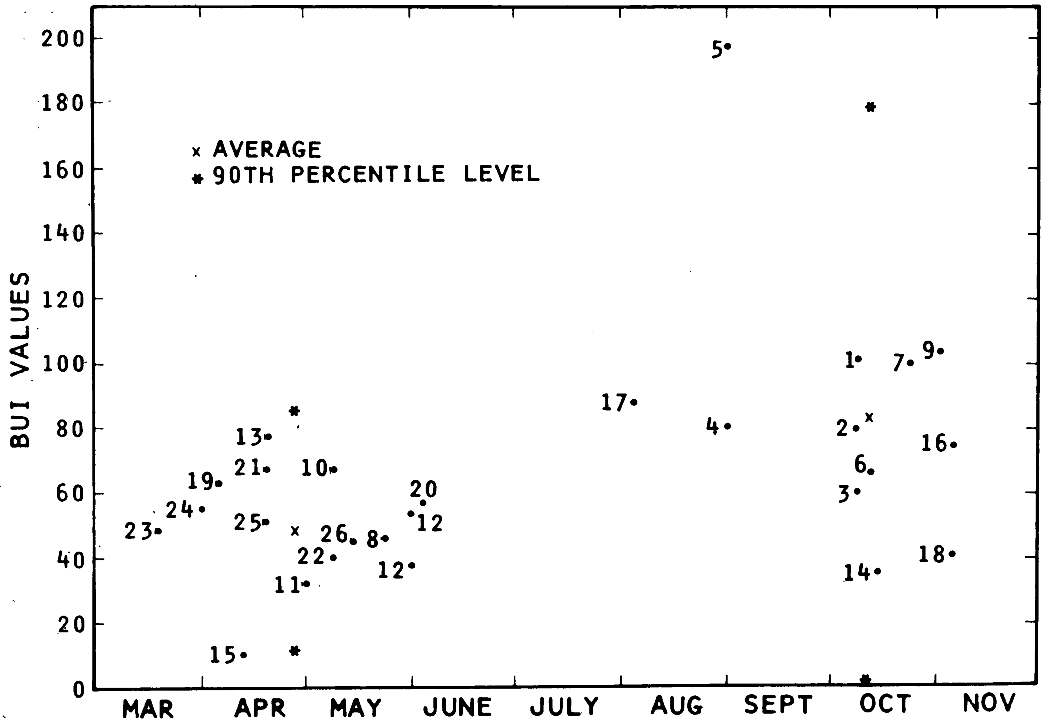

Figure 2.--*BUI values before the critical fire periods shown in figure 1.*

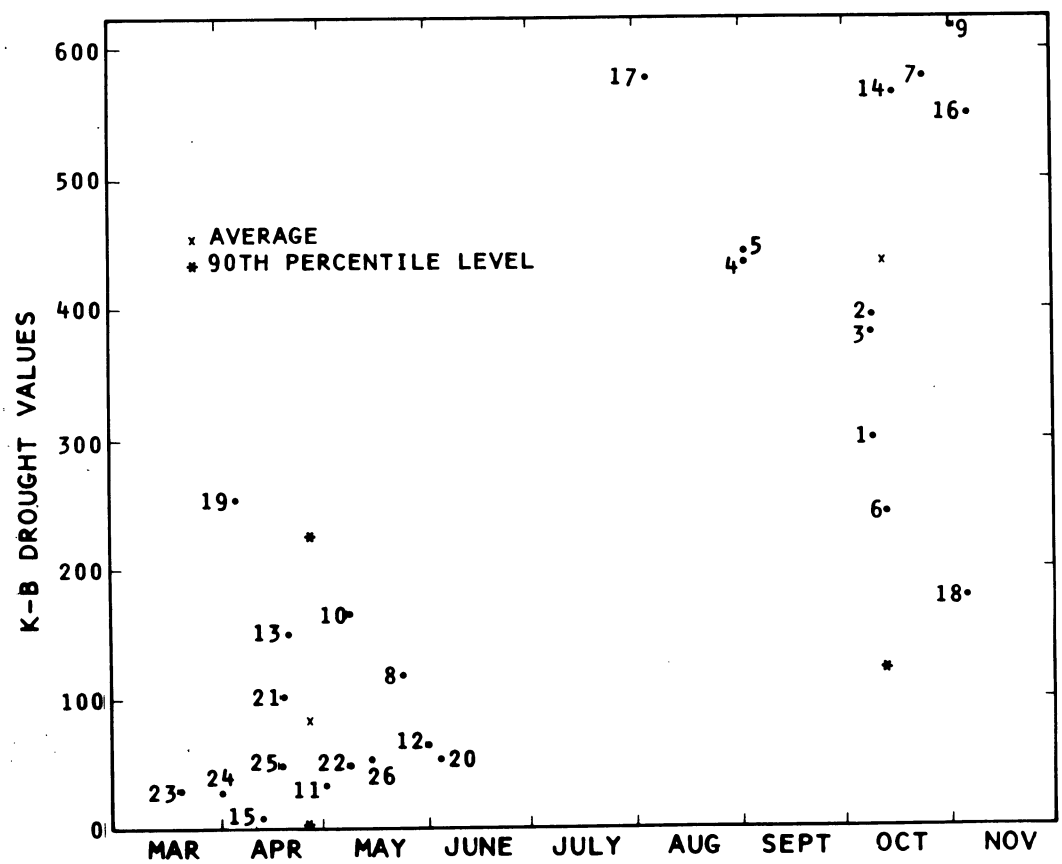

Figure 3.--*K-B Drought values before the critical fire periods shown in figure 1.*

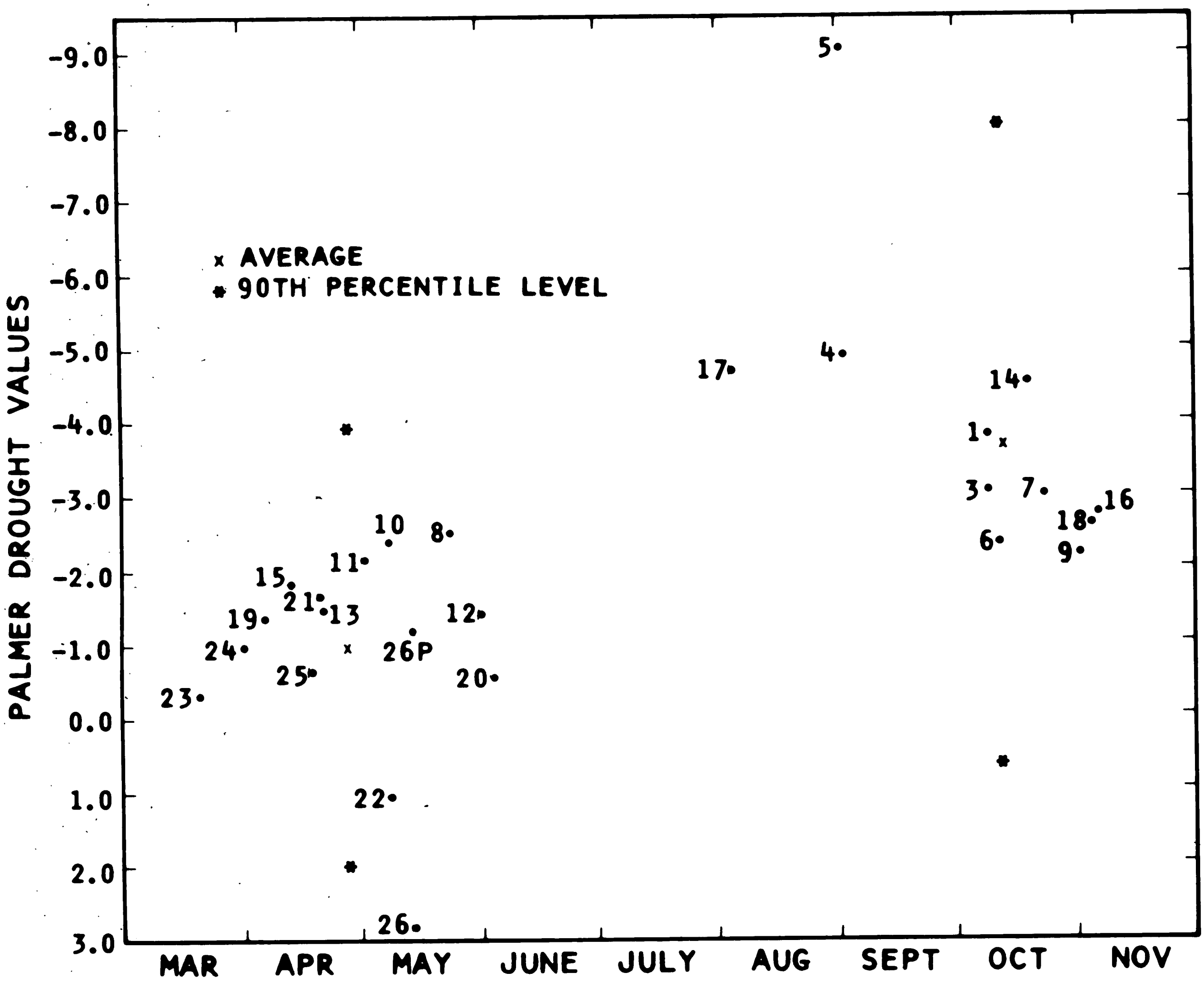

Figure 4.--*Palmer Drought values before the critical fire periods shown in figure 1. For May 14, 1971 (figure 1, No. 26), two values are given: the second (26 p.) was computed using point-source observations taken near the fire area.*

considered that drought and fire danger period to be the worst in memory. The Palmer Index classed the Missouri area as "very wet" through the spring of 1952. Consequently the Palmer system, because it reacts slowly, only rated this area as mild-to-moderate drought by autumn. On the other hand, the Keetch-Byram system assigned the most critical value of all 26 fire situations examined (622) and the BUI assigned the second most critical value (104). The Keetch-Byram and the BUI systems appear to give more realistic assessments of the true 1952 fire potential in Missouri because both were designed to respond more rapidly to fast changing situations than the Palmer Index.

All three indexes produce markedly different sets of spring vs. fall values. Spring-fall value differences are very pronounced in the Keetch-Byram system and obvious in the Palmer Drought Index. These differences are not as distinct in the BUI. Index values are not as high in spring as in autumn because causal factors assume varying degrees of importance from season to season. For example, critical fires almost always occur in the spring when ground vegetation is in the cured stage and this is often the decisive factor in that season, not the soil moisture deficit.

In spring, many large-fire situations develop without an appreciable increase in

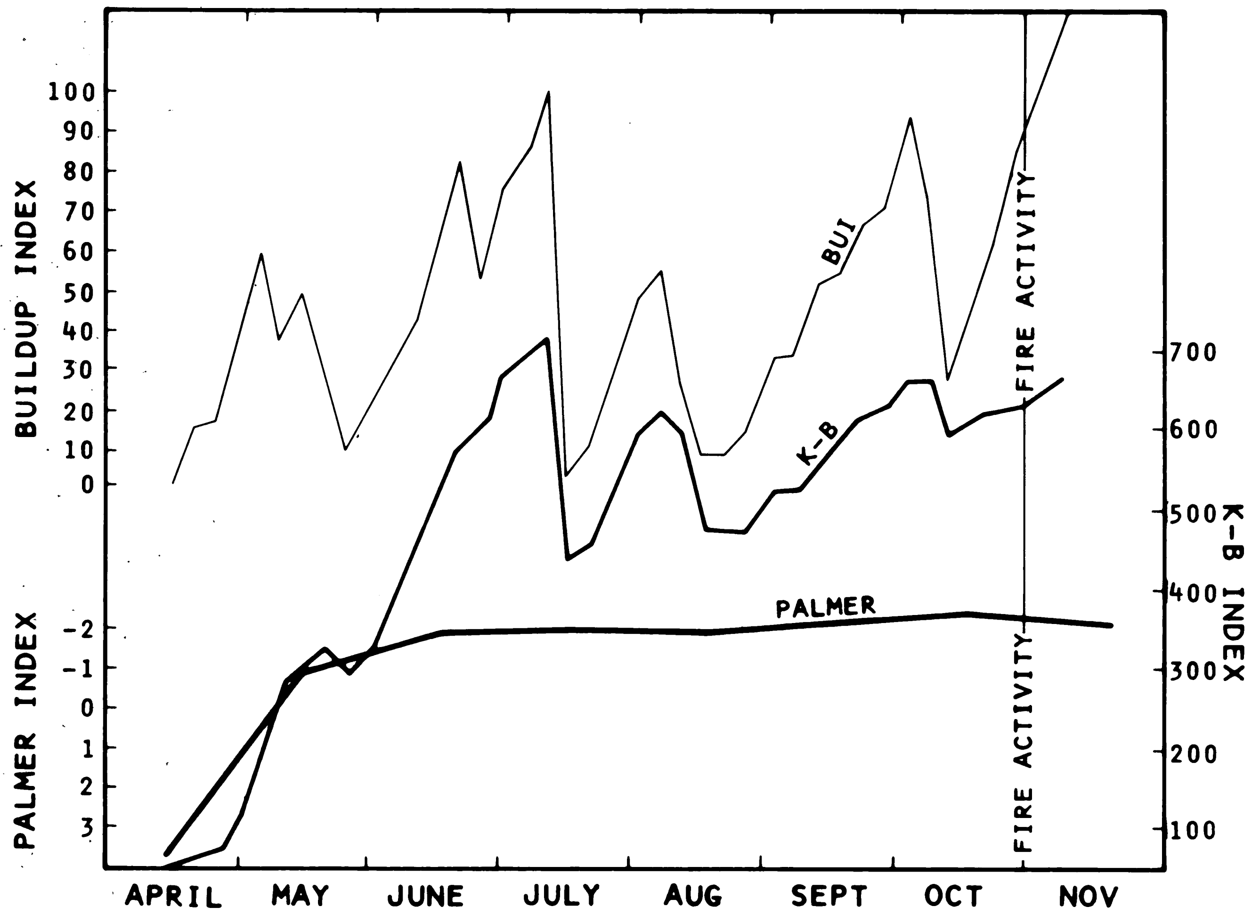

Figure 5.--*Values of BUI, K-B Drought, and the Palmer Drought Indexes during the 1952 fire season in Missouri, including the November 1 fires (figure 1, No. 9). Palmer Drought values are given for the East Ozark division. The BUI and K-B Drought values were computed using data from the Salem station.*

the Keetch-Byram Index. Apparently this is because the index does not increment unless afternoon temperatures are above 50°F. There is usually little or no carryover from year to year in K-B values, even in the southern sectors of the north-central and northeastern States (fig. 6). In Missouri, for example, K-B values are usually at their lowest during the early-spring, fire season. This type of index is obviously more appropriate for late summer and fall evaluations of danger situations.

Because the Palmer system is normalized, its average values are near zero for any given month of the year (fig. 7). A zero value indicates that soil conditions are near the normal for that geographic area. For Missouri's three spring fire situations (figure 1, Nos. 19, 23, and 24), the Palmer values show near normal to mild drought (Appendix III), not an indication of potentially serious conditions (fig. 7). The Keetch-Byram system produced near seasonal normal values for two of these same critical fires (fig. 6). Only the BUI showed a consistent danger value in all three situations (fig. 8); it gave extreme values that might be expected 1 year in 20.

The Keetch-Byram Index may do an adequate job of representing moisture conditions at lower levels throughout the year, but the importance of moisture to fire potential at this level changes with season. On spring days when temperatures are below 50°F, moisture loss from lower layers will probably be negligible, but evaporation

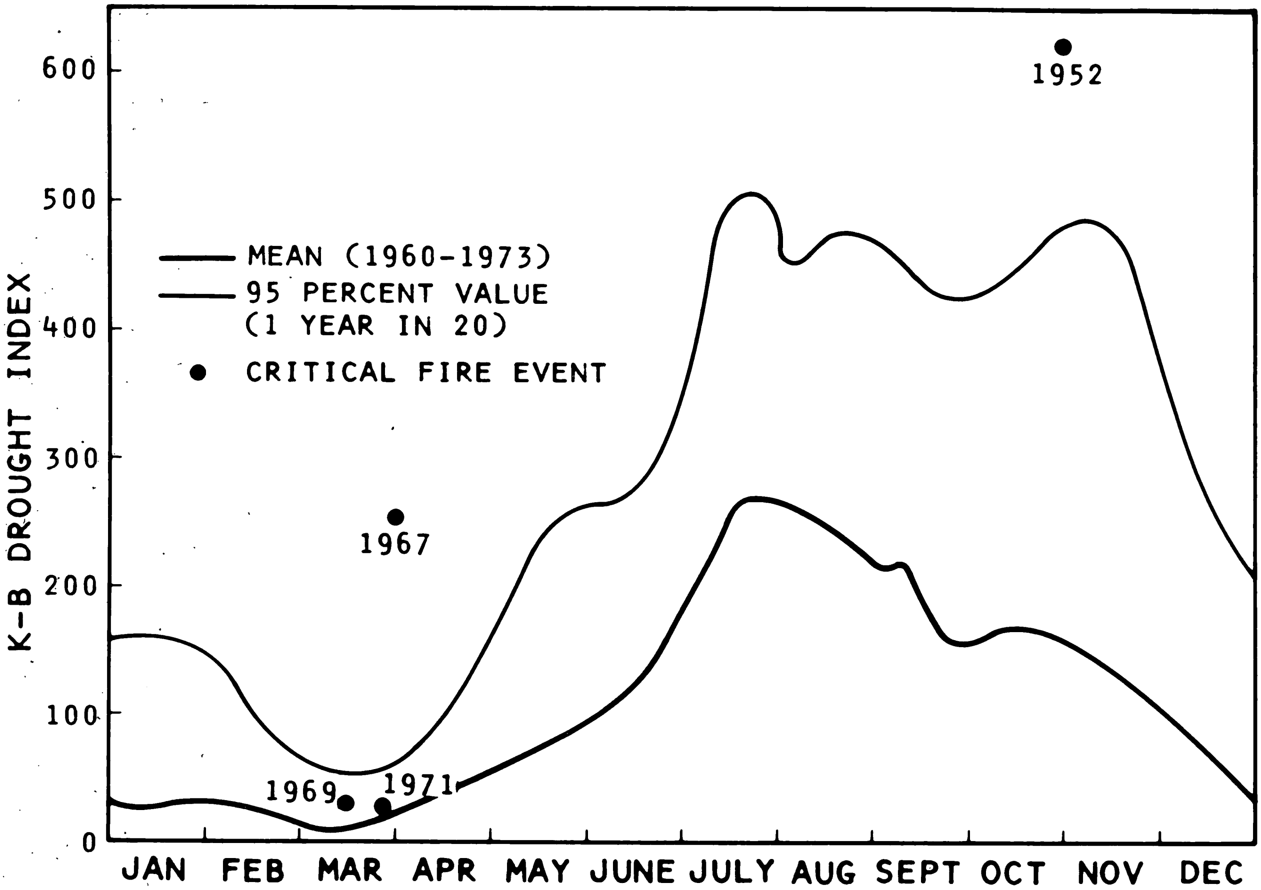

Figure 6.--*K-B Drought Index for Salem, Missouri, showing the 1960-1973 mean values and the extreme values to be expected 1 year in 20. Values are also shown for the critical Missouri fire periods during 1952, 1967, 1969, and 1971 (figure 1, Nos. 9, 19, 23, 24).*

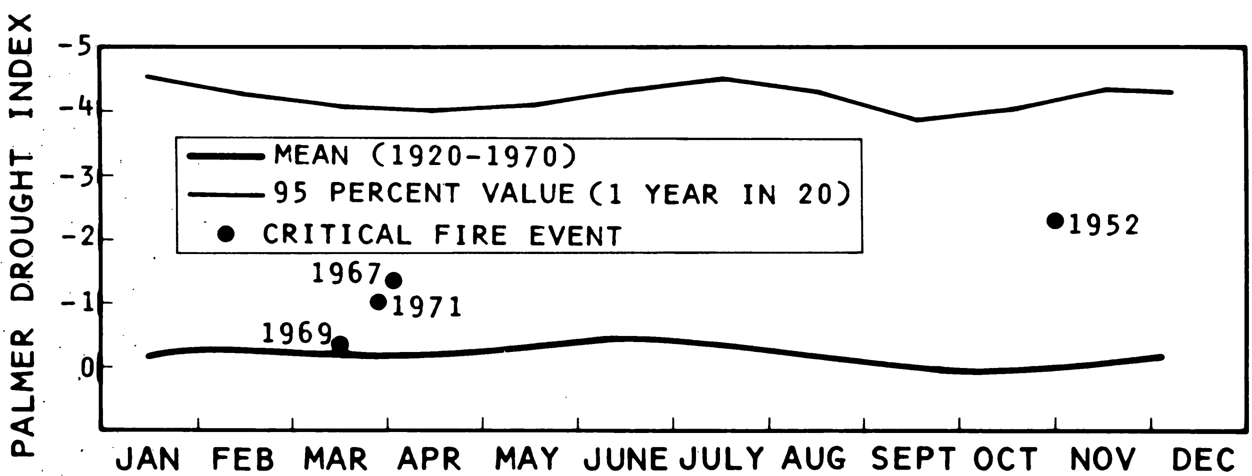

Figure 7.--*Palmer Drought Index in the Eastern Ozarks (Missouri) showing the 1920-1970 mean values and the extreme values to be expected 1 year in 20. Values are also shown for the critical Missouri fire periods during 1952, 1967, 1969, and 1971 (figure 1, Nos. 9, 19, 23, 24).*

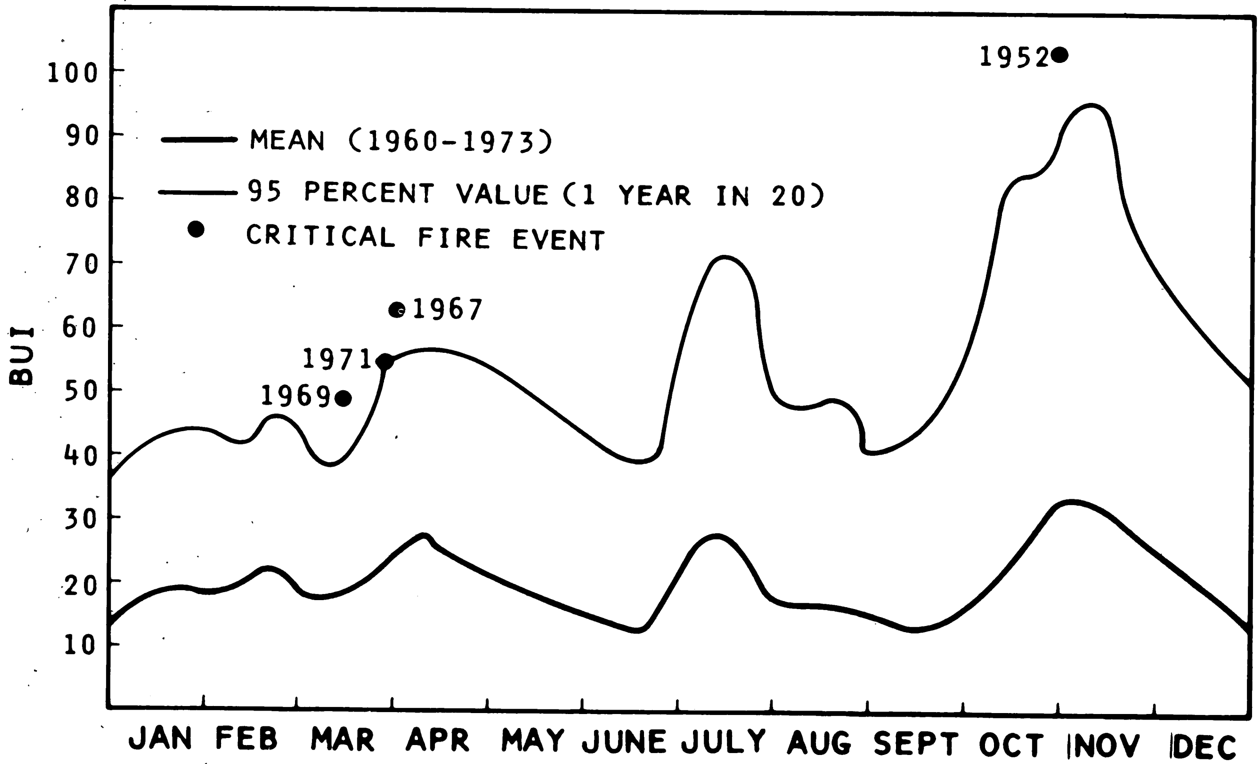

Figure 8.--*BUI at Salem, Missouri, giving the 1960-1973 mean values and the extreme values to be expected 1 year in 20. Values are also shown for the critical Missouri fire periods during 1952, 1967, 1969, and 1971 (figure 1, Nos. 9, 19, 23, 24).*

from the upper levels may be important. Inasmuch as vegetation is usually dormant in spring, the effects of transpiration are nil and moisture at lower levels is usually of no concern. During spring, moisture at surface and in the extreme upper layer largely determines the condition of the available fuels.

Later in the year, living vegetation draws moisture from the upper and lower levels and other physical phenomena cause water loss from all layers. Therefore, it appears that a measure of long-term progressive drying for the late growing season should focus on both the upper and lower layers as a source of moisture.

CONCLUSIONS

Any system that is dependent upon one fixed depth of soil horizon to indicate fire danger is not usable throughout the fire season in the north-central and northeastern States. Therefore, a danger system employing a multilayer soil model having varying response features would be optimum but highly complex.

Given a choice of realistic alternatives, it appears that a litter-duff index having rapid response features gives best results in the spring. An index having slower response features that considers a greater depth of soil horizon appears to be satisfactory during the late summer-fall fire season, especially if it is used in combination with a litter-duff model. Therefore, these data reinforce the decision of those modelers who have opted for a duel-entry system in accounting for long-term moisture deficiency.

Such a system does not include the direct contribution of large surface fuels and living vegetation. Indirectly, however, the relative moisture status of these materials may be reflected by the soil moisture trends. The moisture content of living vegetation is partially determined by the availability of moisture to root systems, while the water content of large surface fuels responds to the same environmental stimuli as does soil water. Although extensive investigation is needed to represent the actual integrated response of the total fuel complex to drought, immediate needs appear best met by a two-layer system.

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APPENDIX I.--THE BUILDUP INDEX

The Buildup Index in the 1964 National Fire Danger Rating System is defined as "a number expressing the cumulative effects of a daily drying factors and precipitation in fuels having a 10-day timelag constant."[1] It appears, however, that it might be more representative of fuels having a 5-day timelag constant. The designers of the BUI used a 10-day timelag because they hoped it would equal the drying rate for the average forest floor; thus it would have significance nationally. They felt the index represented conditions in the upper 2 to 3 inches of litter-type fuels.

The BUI is a numerical expression of the accumulated rate of moisture absorption-desorption. A numerical factor of 5 (a drying factor) is assigned for a standard drying day (80°F, 20 percent relative humidity). A colder or more humid day is assigned a lesser number. A hotter or dryer day is assigned a greater number.

Precipitation reduces the value of the BUI as follows:

$$BUI=-50(LOG_e(1.0-(1.0-EXP(\frac{-BUO}{50}))EXP(-1.175(P-0.1))))$$

where BUO = yesterday's BUI and P = past 24-hour precipitation. The BUI is then adjusted by adding the drying factor.

This index is similar to the Timber Buildup used in the California Wildland Fire Danger Rating,[2] but a dry-wet bulb temperature measurement is used to arrive at a daily drying factor. In the Wildland System a timber buildup factor is derived from daily fuel-stick moisture. These factors were accumulated to provide the drying portion of Timber Buildup.

"As the Buildup Index increases, there should be more fuel burning and greater fire persistence. These changes should be reflected in the difficulty of handling fires, and thus call for stepped up preparedness beyond what would be necessary for a change in spread index alone," according to Keetch.[3]

Where snow often covers the ground all winter, the BUI usually starts anew each spring. In southern areas values can carry through the winter. In some States, Missouri, for example, users reported that the numbers did not seem to have the same meaning in spring as they did in autumn.

Calculation requires: (1) book tables (Nelson 1964), (2) wet-dry bulb temperatures, and (3) 24-hour precipitation amounts. Some fire control units in southeastern States use the following rule of thumb: the herbaceous stage changes from green to transition when BUI values reach 50 and changes to

[1] *Timelag is defined as the time necessary for a fuel particle to lose approximately 63 percent of the difference between its initial moisture content and its equilibrium moisture content.*

[2] *Unpublished report by the USDA For. Serv., Pac. Southwest For. and Range Exp. Stn. 1962.*

[3] *Development of the national fire danger rating system: basic structure and spread phase. 82 p. Unpublished manuscript on file at the Southeast. For. Exp. Stn., Asheville, North Carolina.*

cured when they reach 100. This appears to have been based upon administrative judgment, not empirical evidence.

Advantages of the BUI

1. The system is easy to compute and provides a continuous record because it is updated daily.
2. Point source computation permits the estimation of values for small areas. It is not restricted to a bounded land area.

Disadvantages of the BUI

1. A point source computation will not always be representative of a larger area, although Gerrie (1969) found that single stations are representative of the Canadian areal drought index about 90 percent of the time.
2. The index requires relative humidity observations, which are more difficult to obtain than temperatures or precipitation amounts. Relative humidity does not have conservative meteorological properties, and its measurement is more subject to observational error.

APPENDIX II.--KEETCH-BYRAM DROUGHT INDEX

The Keetch-Byram Drought Index attempts to measure the amount of precipitation necessary to return the soil to full field capacity. It is a closed system ranging from 0 to 800 units and represents a moisture regime from 0 to 8 inches of water through the soil layer. At 8 inches of water, the Keetch-Byram Index (K-B) assumes saturation.

The expression for the drought equation takes the general form:

$$dQ = \frac{[800-Q][0.968 EXP(0.0486T)-0.83]d\tau}{1 + 10.88\ EXP\ (-0.0441R)} X10^{-3}$$

where dQ = the drought factor, Q = the moisture deficiency, T = the maximum temperature °F, R = the mean annual precipitation in inches, and τ = the time in days during which soil-duff has been losing moisture. The time increment is usually set equal to 1 day.

Routine calculation requires: (1) the above equation or book tables (Keetch and Byram 1968), (2) daily maximum temperature or the 2:00 p.m. temperature, and (3) the 24-hour precipitation amount.

Advantages of the Keetch-Byram Index

1. The system is easy to compute and provides a continuous record because it is updated daily.
2. Point source computation allows one to estimate values for small areas. It is not restricted to a bounded land area.
3. It does not require a routine schedule of meteorological observations that are difficult to obtain.

Disadvantages of the Keetch-Byram Index

1. Point source computation will not always be representative of a larger area, although Gerrie (1969) found that single stations are representative of the Canadian areal drought index about 90 percent of the time.
2. Computation often produces values reflecting soil field capacity during the spring fire season, but these do not necessarily indicate whether fire conditions are critical.

APPENDIX III.--THE PALMER DROUGHT INDEX

This index measures a departure from normal and is the only one of the three that has been normalized. Classes for dry periods follow:

Monthly index value	*Class*
4.00 and above to 0.50	Extremely wet to incipient wet spell
0.49 to -0.49	Near normal
- .50 to - .99	Incipient drought
-1.00 to -1.99	Mild drought
-2.00 to -2.99	Moderate drought
-3.00 to -3.99	Severe drought
-4.00 and below	Extreme drought

Monthly data were used to determine drought values by the standard Palmer methodology. Results seem realistic because the system responds rather slowly to change. Palmer (1965), after comparing output using weekly and monthly computations, reported, "the weekly data provide more detail and apparently get just a little closer to a realistic measure, but for climatological purposes the differences are slight." Weekly analysis makes it possible to keep current with the progress of drought on an operational basis.

The soil is divided into two arbitrary layers, and the moisture loss is calculated as follows:

$$L_s = S_s \text{ or } (PE-P),$$

(whichever is smaller), and

$$L_u = (PE-P-L_s)\frac{S_u}{AWC},\ L_u \leq S_u$$

where L_s = moisture loss from surface layer, S_s = available moisture stored in surface layer at start of month, PE = potential evapotranspiration for the month, P = precipitation for the month, L_u = loss from underlying levels, S_u = available moisture stored in underlying levels at start of month, AWC = combined available capacity of both levels.

Calculation requires: (1) a large number of constants (Palmer 1965), (2) maximum and minimum temperature (weekly or monthly means), and (3) weekly or monthly precipitation amounts. A computer program has been written that outputs these data for single station analysis.[4]

Advantages of the Palmer Index

1. It is a highly complex system that considers an impressive array of features such as the estimated run-off, the potential recharge, and three severity indexes.
2. It is presently computed weekly for all climatic divisions of the country by NOAA through most of the fire season and published periodically in a NOAA-USDA joint publication, *Weekly Weather & Crop Report.*
3. The values are normalized based on the 1930-1960 climatic period.
4. It does not require a routine schedule of meteorological observations that are difficult to obtain.

Disadvantages of the Palmer Index

1. Because this is an extremely complicated system, hand computation is difficult for those lacking an extensive background in drought analysis.
2. Climatic division values are not always representative of smaller inclusive areas. During the Little Sioux fire in 1971, for example, the index value for the Minnesota northeast climatic division was +2.77. A point source computation for the immediate fire area produced a value of -1.23 (table 1).
3. A final index value requires a probability computation. This probability term allows the user to select a drought value given three choices: (1) What is the severity index if a wet spell is becoming established? (2) What is the severity index if drought is becoming established? (3) What is the severity index for any wet spell or any drought that has become definitely established? The index of drought (or wet spell) severity is unassigned when the probability term is between 0 and 1.0. The proper choice is easily determined on a climatological basis (after the fact). Operationally, however, the choice is much more difficult to make, and the selected index value must be considered a best guess on a real time basis. Operationally this is not entirely a detriment because it also provides valuable options. It may make the system more difficult to use as a simple descriptive tool, yet it provides a wider range of autonomy and allows a predictive capability.

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[4]*Main, W. A., and D. A. Haines. Point source, computer program for the Palmer Drought Index. 12 p. Unpublished manuscript on file at the North Cent. For. Exp. Stn., East Lansing, Michigan.*

☆ U.S. Government Printing Office: 1976—669-587/159 Region No. 6