CONTRIBUTIONS ON THE DEVELOPMENT OF A NATIONAL FIRE DANGER RATING SYSTEM

by
Forest Fire Research Group

PACIFIC FOREST RESEARCH CENTRE
CANADIAN FORESTRY SERVICE
VICTORIA, BRITISH COLUMBIA
INFORMATION REPORT BC-X-37

DEPARTMENT OF THE ENVIRONMENT
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Preface

In May 1969 a provisional new system of forest fire danger rating was completed and soon afterwards was issued to interested forest fire control people across Canada. It resulted from the joint efforts of Forestry Branch staff, in several locations across Canada, who turned out informal papers on many aspects of the new system during its development period. To preserve the record of this development, the Program Coordinator for Forest Fire Research has recommended that these papers be issued as Information Reports.

The three papers incorporated in this single Information Report were produced separately by personnel associated at that time with the British Columbia Regional Office.

Not all of the proposals outlined in these papers could be incorporated into the current version of the danger rating system; they are presented here only as a matter of record.

A DROUGHT INDEX TO SIMULATE MOISTURE CONTENT OF THE FULL ORGANIC LAYER

J. A. Turner, S. J. Muraro,
Gy. Péch, R. N. Russell

Paper presented at the
Joint S.A.F. - A. Met. S. Conference
on Fire and Forest Meteorology

Salt Lake City
March 12 - 14, 1968

A DROUGHT INDEX TO SIMULATE MOISTURE CONTENT OF THE FULL ORGANIC LAYER

The Drought Index Paradox

Any index of drought or of build-up is a mathematical model representing the moisture content of some specific slow-drying fuel. The fuel may be a large log or a moderately deep organic layer. This paper deals specifically with a deep organic layer.

Drying in such a fuel is generally well represented by an exponential relationship associated with a particular time constant or lag coefficient, referred to a standard day having specified drying conditions.

Wetting of the fuel is assumed to take place only as a result of precipitation. Any excess over that required to produce saturation of the layer is assumed to be lost as runoff, but any amount less than this is taken to be fully effective in wetting the fuel.

This is essentially the moisture budget approach used so successfully by Thornthwaite and subsequent investigators. The U. S. National Drought Index also uses this approach.

This simple model results in a paradox which is particularly disturbing when the index is expressed in time units rather than in terms of moisture content. The paradox is simply the reduction in drought index for a given rainfall at high values of the index is much greater than it would be for the same rainfall at a lower index. In other words, it takes longer to return to the pre-rain value of the index when the organic layer is dry than when the fuel is more moist.

Figure 1 (P. 12) shows the reduction in the Drought or Build-up Index for given values of rainfall and initial index. To make the results completely general, the rainfall has been expressed as a fraction of the rainfall equivalent of the range from equilibrium to saturation of the layer. The index has been plotted in units of Time Constant or Lag Coefficient.

Dissatisfaction with the relatively exaggerated effect of small rains at high Index values led to the development of the model discussed in this paper. This dissatisfaction was presented in a paper at the 1966 Fire Weather Conference.*

The Basic Drought Index

The Drought Index is similar in concept to the U. S. National Drought Index. As in the U. S. National Build-up Index, each drying day contributes a specific number of drying factor units to the cumulative index. A standard drying day with a temperature of 70°, a relative humidity of 20% and a 3 mph wind contributes 3 drying factor units. The time constant is 48 drying factor units or 16 of these "standard" days.

The Accelerated Drying Rate

Examination of fire histories, and discussion with experienced fire control personnel, failed to disclose evidence in support of the concept that the effective period of a small rain should be any longer

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* "Correlation of Build-up Index and Fire Season Severity", Jas. K. Tyrrel and Geo. R. Miller, Mineo. Paper. presented at Western Fire Weather Conference, Portland, Ore. 1966.

under severe drought conditions that it would be for the same rain under less severe conditions. It was therefore assumed that a given amount of rain should have the same effective period, regardless of the level of Drought or Build-up Index. This may be an over-simplification, but it appears to be essentially true.

The last assumption can be made compatable with the two previous ones, provided that the drying rate following the rain is appropriate to the saturated state rather than the moisture content of the whole layer. Figure 2 (P. 12) illustrates this effect.

Such a drying regime would be about the same as that of a layer saturated from the top down as the rainfall progresses. This is not true in all duff layers but appears to be the case in some deep organic layers.

It is also consistent with the fact that root systems in a layer of pronounced moisture stratification will extract moisture where it is most readily available.

Such stratification is often observed. Figure 3 (P. 13) presents two examples of such stratification observed during the past summer .

The drying rate, during the time the moisture is assumed to be strongly stratified, is called the <u>Accelerated Drying Rate</u>* as opposed to the <u>Standard Drying Rate</u>.

The Standard Drying Rate appropriate to a given value of the index is based on the profile which results from the uniform upward diffusion of moisture through the layer.

The ratio of the accelerated rate to the standard rate is called the Acceleration Quotient or Acceleration Coefficient.

* The term "Accelerated" in this connection has some erroneous connotations and could more accurately be replaced by "Enhanced" or simply "stratified".

Figure 4 (P. 13) shows the relationship between the quotient and the two factors on which it depends. The acceleration quotient is just sufficient to bring the index back to its pre-rain level after the appropriate number of drying units have been accumulated.

Figure 5 (P. 14) shows how a section of the rainfall tables might be set up.

The accelerated drying rate is used only until the pre-rain value of the index is reached again. Once that level has been attained, the Acceleration Quotient goes to 1 and the drying factor units are accumulated without further acceleration.

Figure 6 (P. 14) shows the results of calculation for two fire seasons based on readings from the Prince George airport in central British Columbia. During the last three weeks in August, 1961, two fires burning within 20 miles of the airport covered a total of 90,000 acres, consuming almost all of the available organic material. It is significant that trails 3-4 inches deep in ash on August 25 were impassable on September 5th because of mud.

During the 1967 fire season, one of the authors (S. J. Muraro) conducted a series of test burns on 46 plots in spruce-balsam slash, averaging two acres per plot in the McLeod Lake area, about 80 miles north of Prince George.

Figure 7 (P. 15) shows the relationship between the percentage depletion of the organic layer as a result of these burns and the Drought Index calculated according to our system. The resulting correlation co-efficient was 0.89, confirming that the index is a useful predictor of the fuel available for combustion in the moderately deep organic layer.

Figure 8 (P. 15) shows the equivalent moisture content based on the proposed index plotted against the measured values for the full organic layer, taken in a seed block adjacent to the test area. This sampling technique was not started until mid-August; still, the 14 points suggest a strong correlation ($r = 0.98$).

Figure 9 (P. 16) shows the same relationship as Figure 8, except that the index was calculated without any acceleration in the drying rate. The correlation is still good, but the absolute values of moisture are no longer represented ($r = 0.93$).

The accelerated drying tends to shift the peak value of the index later in the season. For example, at McLeod Lake in 1967, the peak value indicated with the unmodified index was 127 on July 18, with a secondary peak of 87 on August 31.

By contrast, the modified system indicated a maximum index value of 204 on August 31 as opposed to 144 on July 18. The behavior of slash fires and moisture content measurements indicates that the latter picture was much more representative of the true situation than the one given by the unmodified index.

Conclusions

A modification to the accepted form of Drought Index is presented. This modification is designed to eliminate the apparent paradox that results when light rains occur during a period of severe drought. Preliminary results suggest that this model simulates actual conditions better than the conventional model.

APPENDIX

DROUGHT INDEX CALCULATIONS

(Victoria Mark II)

General: The Drought Index is calculated at 1600 hours each day unless rain is falling at that time. Calculations are based on the previous value of the Index, current relative humidity, temperature and wind speed. If rain is falling at 1600 hours the Drought Index is not calculated for that day; instead the index is calculated for the following day using the accumulated rainfall since the last observations was made.

To Start Calculations: Index calculations will normally be started on the third day that the snow has been gone from the area or on the first day after a rainy period totalling 1.5 inches or more. On that day assume the previous index to have been zero.

Then go to instructions in Column A.

A.

STANDARD DRYING PROCEDURE

1) Look up the Drying Factor (DF) for the day in Table 1.*

2) Add this value of the DF to Yesterday's Drought Index (DIo) to give the Drought Index for today (DI).

↓

3) For each successive day that no rain falls or rainfall is less that .06 inches repear 1) and 2) above.

↓

Until a daily rainfall of .06 inches or more is recorded

↓

4) Then circle the last value of DI before the rain.

5) Look up the values for the Acceleration Coefficient (Q)+ and the Drought Index at Cessation of Rainfall (DIr) in Table II

6) Go to instructions in Column B.

* Remember to subtract 1 from the Drying Factor for rain of .02 inches or more.

\+ After September 1st a seasonal effect may be introduced by using $(Q+1)/2$ instead of Q.

B.

ACCELERATED DRYING PROCEDURE

1) Look up the Drying Factor for the day in Table 1.*

2) Multiply this by the value of Q. Round this result off to nearest whole number and add this to DIr to get the value of the Drought Index for that day.

3) For each successive day that less than .06 inches is recorded, repeat 1) and 2) above using the same value of Q. - but adding the product to the previous value (DIo) of the Drought Index instead of to DIr.

UNTIL

The Drought Index for today would have exceeded the last circled value of the Drought Index

THEN

4') Take the latest circled value of the index as the Drought Index for today.

5') Return to Column A and continue as in A 1).

UNLESS

a daily rainfall of .06 inches or more is recorded.

THEN

4) look up new values of Q and DIr in Table II.

5) If this new value of Q is greater than the previous one - continue to use the smaller value. Otherwise use the new value.**

6) Go back to 1) in this column (B).

* Remember to subtract 1 from the Drying Factor for rain of .02 inches or more.

** Always use this new DIr value.

TABLE I. Drying Factor

Relative Humidity (%)	Temperature (°F) Less than 70			70 or higher		
	Wind Speed (m.p.h.) 0 - 4	5 - 9	10+	0 - 4	5 - 9	10+
	Drying Factor					
76 or more	2	2	2	2	2	2
66 - 75	2	2	3	2	3	3
46 - 65	2	3	3	2	3	3
36 - 45	2	3	3	3	3	4
16 - 35	3	3	4	3	4	4
15 or less	3	4	4	4	4	4

For any day on which the rainfall is .02 inches or more, the Drying Factor obtained above will be reduced by 1 unit.

TABLE II Acceleration Quotient and Drought Index at Cessation of Rain

Rainfall in Inches		Drought Index before Rain (DIo): 0 to 2	3 to 9	10 to 16	17 to 23	24 to 30	31 to 37	38 to 44	45 to 51	52 to 58	59 to 65	66 to 72	73 to 81	82 to 90	91 to 99	100 to 108	109 to 117	118 to 126	127 to 137	138 to 148	149 to 161	162 to 174	175 to 187	188 to 200	201 to 213	214 to 226	227 or more
		Acceleration Quotient (Q) and Drought Index at Cessation of Rain (DI_r)																									
.06 - .10	Q	1.0	1.1	1.2	1.4	1.6	1.9	2.2	2.5	2.9	3.3	3.8	4.4	5.2	6.2	7.2	8.5	9.9	11.7	13.9	16.7	20.1	23.1	28.1	32.6	37.5	42.5
	DI_r	0	3	10	17	23	30	36	43	49	55	61	68	75	82	89	95	101	107	113	119	125	130	135	138	141	143
.11 - .15	Q	1.0	1.1	1.2	1.4	1.6	1.8	2.1	2.4	2.7	3.1	3.5	4.1	4.8	5.6	6.6	7.6	8.7	10.2	11.9	14.0	16.5	19.2	22.1	25.1	28.3	31.7
	DI_r	0	2	9	15	21	28	34	40	45	51	57	63	69	75	81	86	91	97	100	106	110	114	117	119	121	123
.16 - .20	Q	1.0	1.0	1.2	1.3	1.5	1.7	2.0	2.3	2.6	3.0	3.3	3.9	4.5	5.2	6.0	6.9	7.9	9.0	10.4	12.1	14.1	16.1	18.3	20.6	23.1	25.4
	DI_r	0	1	7	13	20	25	31	37	42	47	53	58	64	69	74	79	83	88	91	95	99	102	104	106	107	108
.21 - .30	Q	1.0	1.0	1.1	1.3	1.5	1.7	1.9	2.1	2.4	2.7	3.1	3.5	4.1	4.7	5.4	6.1	6.9	7.8	8.6	10.2	11.7	13.3	14.9	16.5	18.3	20.0
	DI_r	0	0	5	11	17	22	28	33	38	43	47	52	57	62	67	71	74	78	81	84	86	89	90	91	93	93
.31 - .40	Q	1.0	1.0	1.1	1.2	1.4	1.5	1.7	2.0	2.2	2.5	2.8	3.2	3.6	4.1	4.7	5.2	5.8	6.6	7.4	8.4	9.5	10.6	11.7	13.0	14.2	15.4
	DI_r	0	0	2	8	13	18	23	28	33	37	41	45	50	54	57	60	63	66	68	71	73	75	76	77	78	78
.41 - .50	Q	1.0	1.0	1.0	1.2	1.3	1.4	1.6	1.8	2.0	2.3	2.5	2.8	3.2	3.6	4.1	4.5	5.1	5.6	6.3	6.5	7.9	8.8	9.7	10.6	11.5	12.5
	DI_r	0	0	0	5	10	15	19	24	28	32	35	39	43	46	49	52	54	57	59	61	62	64	65	65	66	66
.51 - .60	Q	1.0	1.0	1.0	1.1	1.2	1.3	1.5	1.7	1.9	2.1	2.3	2.6	2.9	3.3	3.6	4.0	4.4	4.9	5.5	5.8	6.8	7.5	8.2	8.9	9.5	10.2
	DI_r	0	0	0	2	7	11	16	19	23	27	30	33	37	40	42	45	47	48	51	52	54	55	55	56	57	57
.61 - .80	Q	1.0	1.0	1.0	1.0	1.1	1.2	1.3	1.5	1.6	1.8	2.0	2.2	2.5	2.8	3.1	3.4	3.7	4.1	4.5	5.0	5.5	6.0	6.5	7.1	7.7	8.2
	DI_r	0	0	0	0	3	9	11	14	17	20	23	26	29	32	34	36	37	39	41	42	43	44	45	45	46	46
.81 - 1.00	Q	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.3	1.4	1.5	1.7	1.8	2.1	2.3	2.5	2.7	3.0	3.2	3.5	3.9	4.3	4.7	5.1	5.4	5.8	6.2
	DI_r	0	0	0	0	0	1	4	7	10	13	15	18	21	23	24	26	27	29	30	31	32	32	33	33	34	34
1.01 - 1.20	Q	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.2	1.3	1.4	1.5	1.7	1.8	2.0	2.2	2.4	2.6	2.8	3.1	3.3	3.6	3.9	4.2	4.5	4.8
	DI_r	0	0	0	0	0	0	0	2	4	7	9	11	13	15	16	18	19	20	21	22	23	23	24	24	24	24
1.21 - 1.50	Q	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.2	1.3	1.4	1.5	1.7	1.8	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5
	DI_r	0	0	0	0	0	0	0	0	0	0	2	3	5	7	8	9	10	11	12	13	13	14	14	14	15	15
1.51 +	Q	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.2	1.3	1.4	1.5	1.5	1.7
	DI_r	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	2	2

Examples illustrating the calculation of DROUGHT INDEX, VICTORIA MARK II

M = missing record, R = raining

Date	Temperature (°F)	Wind (m.p.h.)	Relative Humidity (%)	Rain (in.)	Drying Factor (DF)	Acceleration Quotient (Q)	(DF x Q)	Previous Drought Index (DI_o)	Drought Index After rain (DI_r)	Today's Drought Index (DI)	Case Illustrated
					Snow disappeared from operational areas on April 29						
MAY											
1										0	
2	58	3	48		2			0		2	A1+2
3	60	2	30		3			2		5	A1+2
4	63	4	28		3			5		8	A1+2
5	65	10	22	.01	4			8		12	A1+2
6	M	M	M	R	M			12	raining		
7	60	11	34	Trace	4			12		16	A1+2
8	M	M	M	R	M			16	raining		
9	58	5	64	.03	3-1=2			16		18	A3
10	60	2	50	.04	2-1=1			18		19	A3
11	M	M	M	R	M			19	raining		
12	63	2	76	.25	2-1=1	1.3	1.3x1=1.3	19	11	12	A4,5,+6
13	66	6	37		3	1.3	1.3x3=3.9	12		16	B1+2
14	68	Calm	26		3	1.3	1.3x3=3.9	16		19	B2,4',5'
15	70	7	24		4			19		23	A1+2
16	62	5	64	.05	3-1=2			23		25	A3
17	70	6	33		4			25		29	A1+2
18	71	5	24		4			29		33	A1+2
JULY											
20	76	6	21		4			76		80	A1+2
21	69	1	72	.40	2-1=1	3.2	3.2x1=3.2	80	45	48	A4,5,+6
22	72	2	37		3	3.2	3.2x3=9.6	48		58	B2
23	68	Calm	58		2	3.2	3.2x2=6.4	58		64	B2
24	69	5	48		3	3.2	3.2x3=9.6	64		74	B2
25	70	7	60	.12	3-1=2	3.2	3.2x2=6.4	74	63	69	B4,5,+6
26	72	1	38		3	3.2	3.2x3=9.6	69		79	B1+2
27	76	5	22		4	3.2	3.2x4=12.8	79		80	B4'+5
28	78	6	21		4			80		84	A1+2
29	72	5	49		3			84		87	A1+2
30	70	9	34	.05	4-1=2			87		90	A3

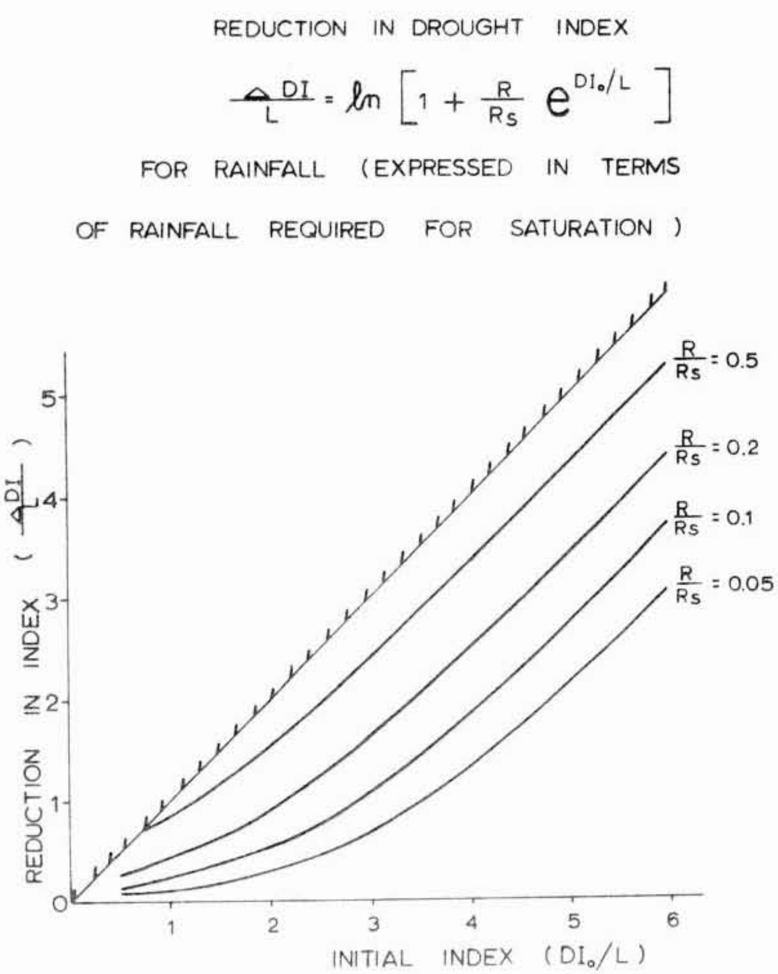

REDUCTION IN DROUGHT INDEX
$\frac{\Delta DI}{L} = \ln\left[1 + \frac{R}{R_S} e^{DI_o/L}\right]$
FOR RAINFALL (EXPRESSED IN TERMS
OF RAINFALL REQUIRED FOR SATURATION)
REDUCTION IN INDEX ($\frac{\Delta DI}{L}$)
INITIAL INDEX (DI_o/L)
$\frac{R}{Rs} = 0.5$
$\frac{R}{Rs} = 0.2$
$\frac{R}{Rs} = 0.1$
$\frac{R}{Rs} = 0.05$

FIG. 1

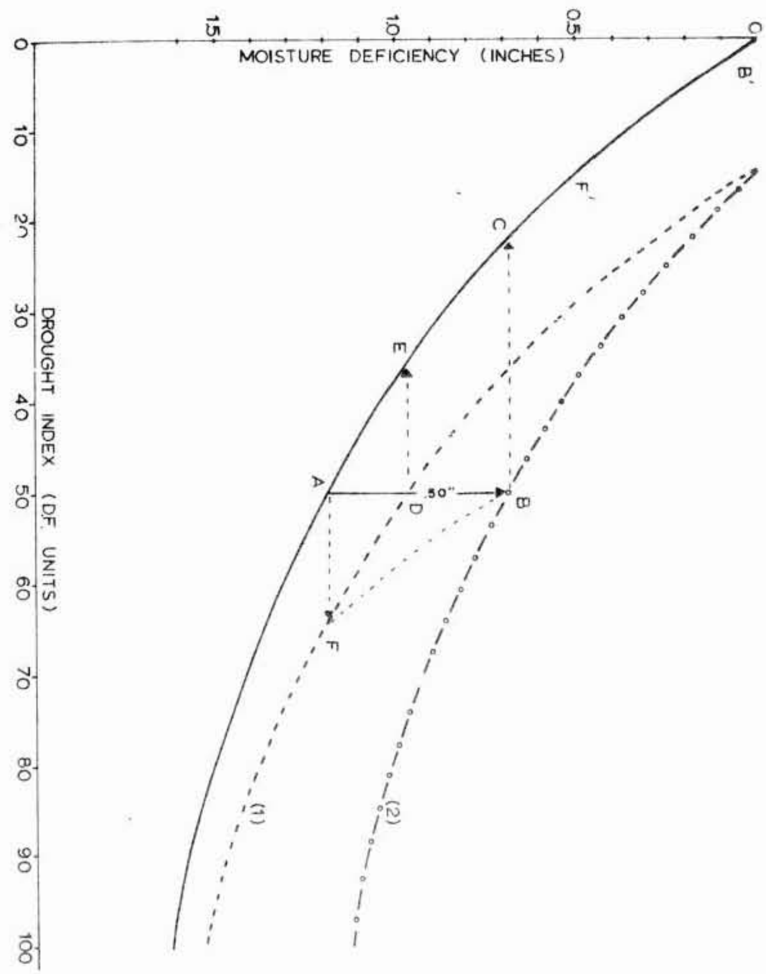

MOISTURE DEFICIENCY (INCHES)
DROUGHT INDEX (DF. UNITS)
.50"
(1)
(2)

FIG. 2

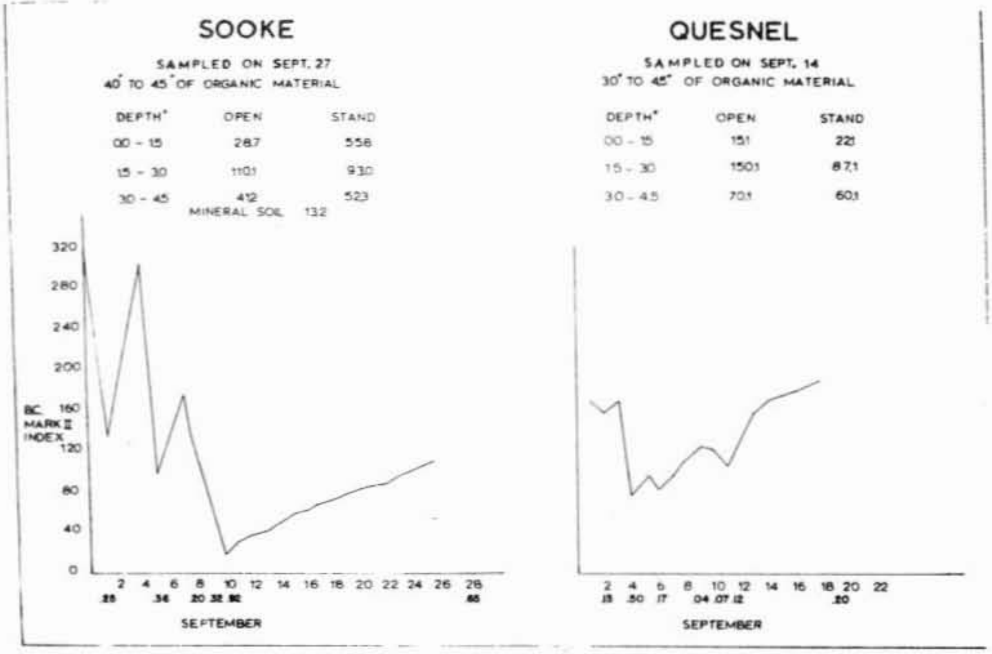
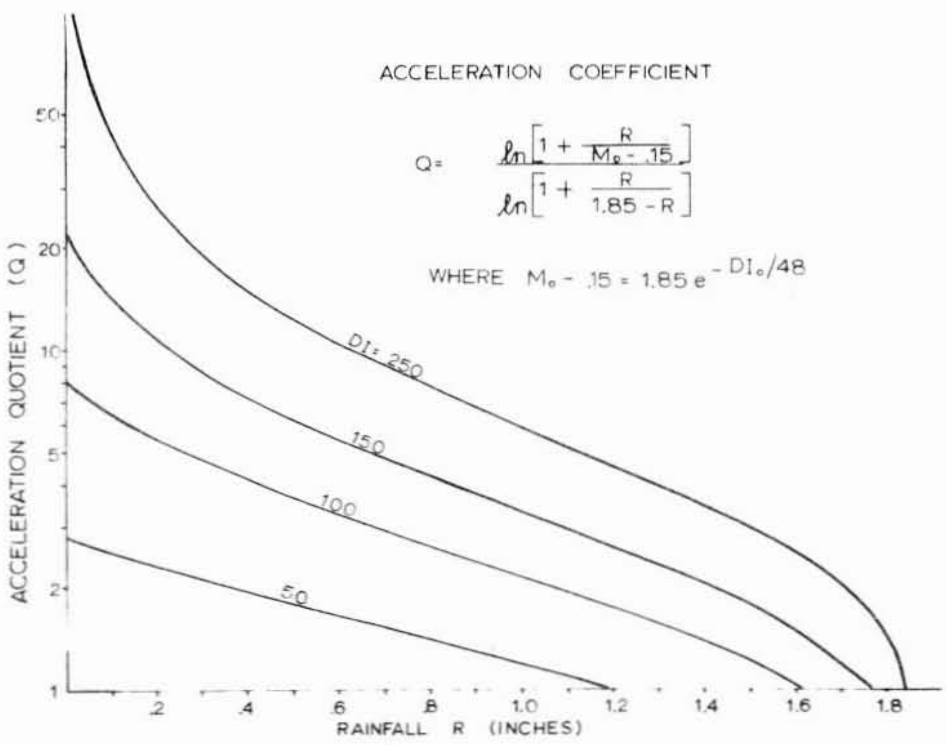

SOOKE
SAMPLED ON SEPT. 27
40" TO 45" OF ORGANIC MATERIAL
DEPTH" OPEN STAND
00 - 15 28.7 55.8
15 - 30 110.1 93.0
30 - 45 41.2 52.3
MINERAL SOIL 13.2
BC MARK II INDEX
SEPTEMBER
QUESNEL
SAMPLED ON SEPT. 14
30" TO 45" OF ORGANIC MATERIAL
DEPTH" OPEN STAND
00 - 15 15.1 22.1
15 - 30 150.1 87.1
30 - 45 70.1 60.1
SEPTEMBER

FIG. 3

FIG. 4


ACCELERATION COEFFICIENT
$$Q = \frac{\ln\left[1 + \frac{R}{M_o - .15}\right]}{\ln\left[1 + \frac{R}{1.85 - R}\right]}$$
WHERE $M_o - .15 = 1.85\, e^{-DI_o/48}$
DI = 250
150
100
50
ACCELERATION QUOTIENT (Q)
RAINFALL R (INCHES)

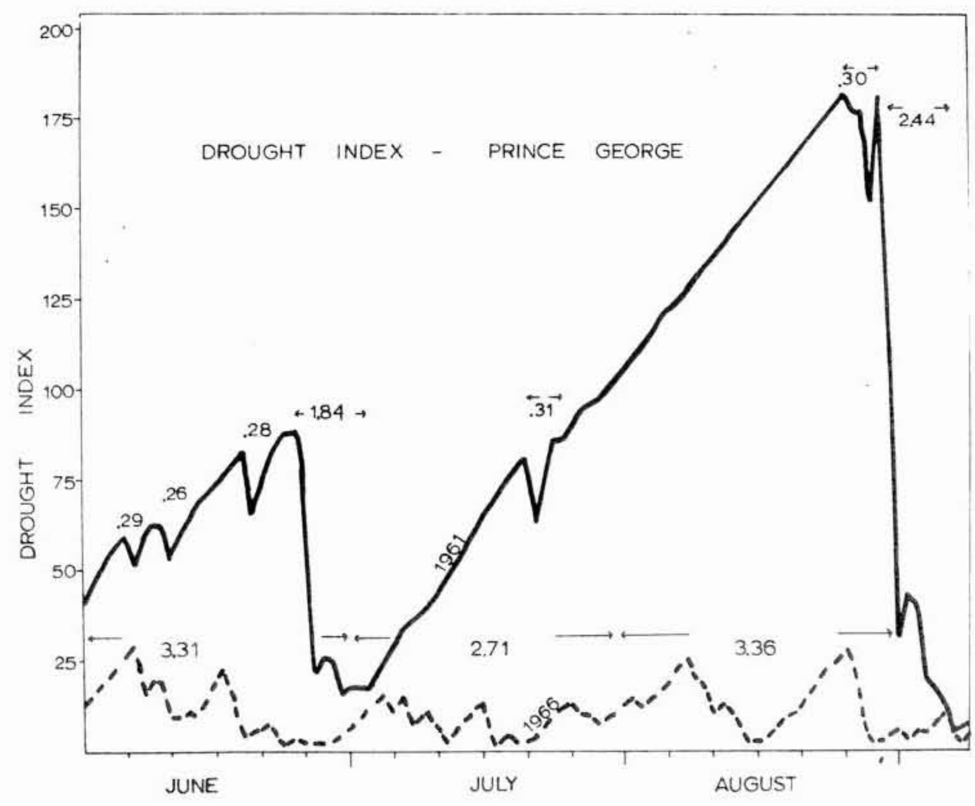
RAINFALL IN INCHES		DROUGHT INDEX BEFORE RAIN (DI_o) 66 to 72	73 to 81	82 to 90	91 to 99	100 to 108
.21 - .30	Q	3.1	3.5	4.1	4.7	5.4
	DI_r	47	52	57	62	67
.31 - .40	Q	2.8	3.2	3.6	4.1	4.7
	DI_r	41	45	50	54	57
.41 - .50	Q	2.5	2.8	3.2	3.6	4.1
	DI_r	35	39	43	46	49
.51 - .60	Q	2.3	2.6	2.9	3.3	3.6
	DI_r	30	33	37	40	42
.61 - .80	O	2.0	2.2	2.5	2.8	3.1
	DI_r	23	26	29	32	34

EXERPT FROM TABLE II

ACCELERATION QUOTIENT AND DROUGHT INDEX AT CESSATION OF RAIN

FIG. 5

FIG. 6



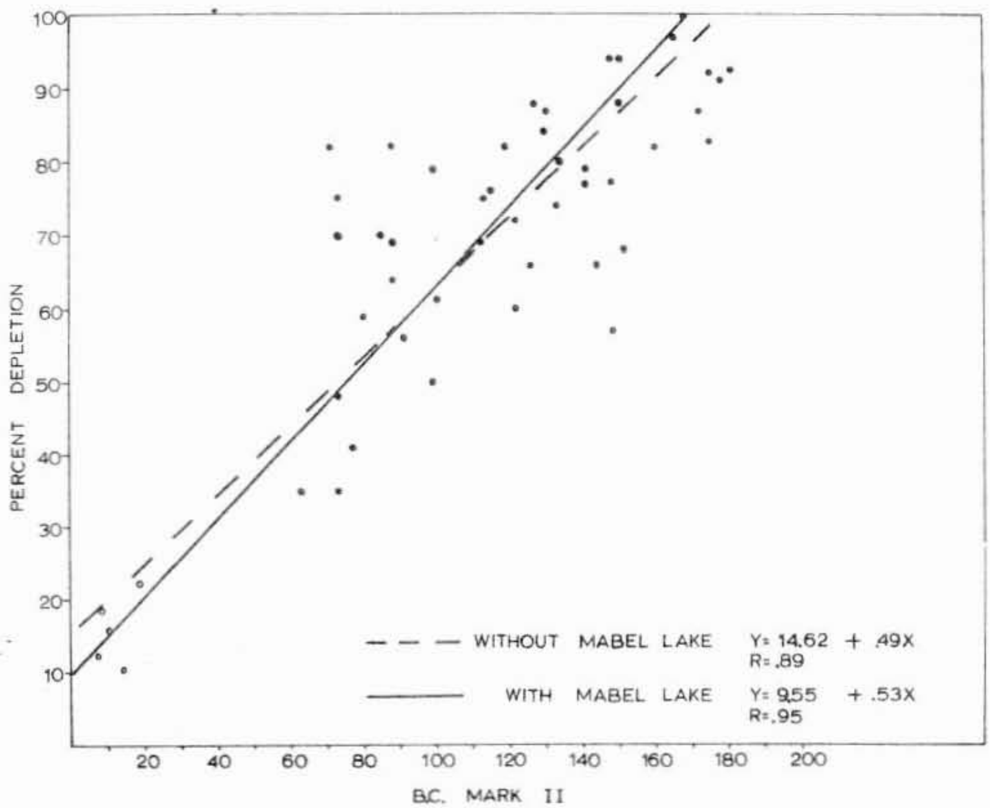
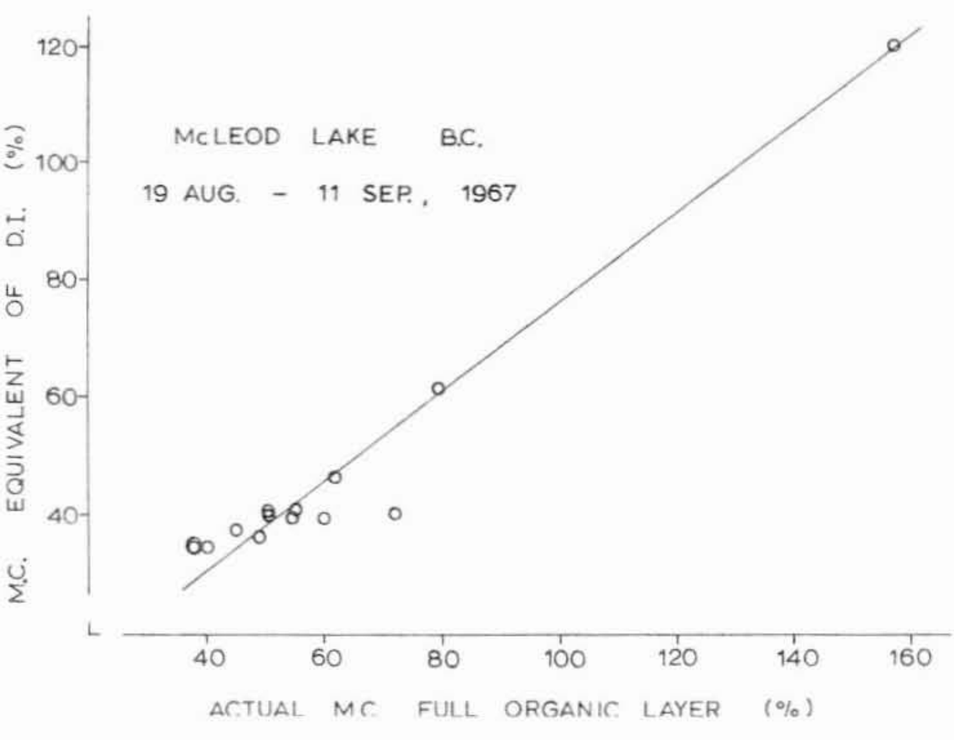

PERCENT DEPLETION
B.C. MARK II
WITHOUT MABEL LAKE Y= 14.62 + .49X R=.89
WITH MABEL LAKE Y= 9.55 + .53X R=.95

FIG. 7

FIG. 8


McLEOD LAKE B.C.
19 AUG. - 11 SEP., 1967
M.C. EQUIVALENT OF D.I. (%)
ACTUAL M.C. FULL ORGANIC LAYER (%)

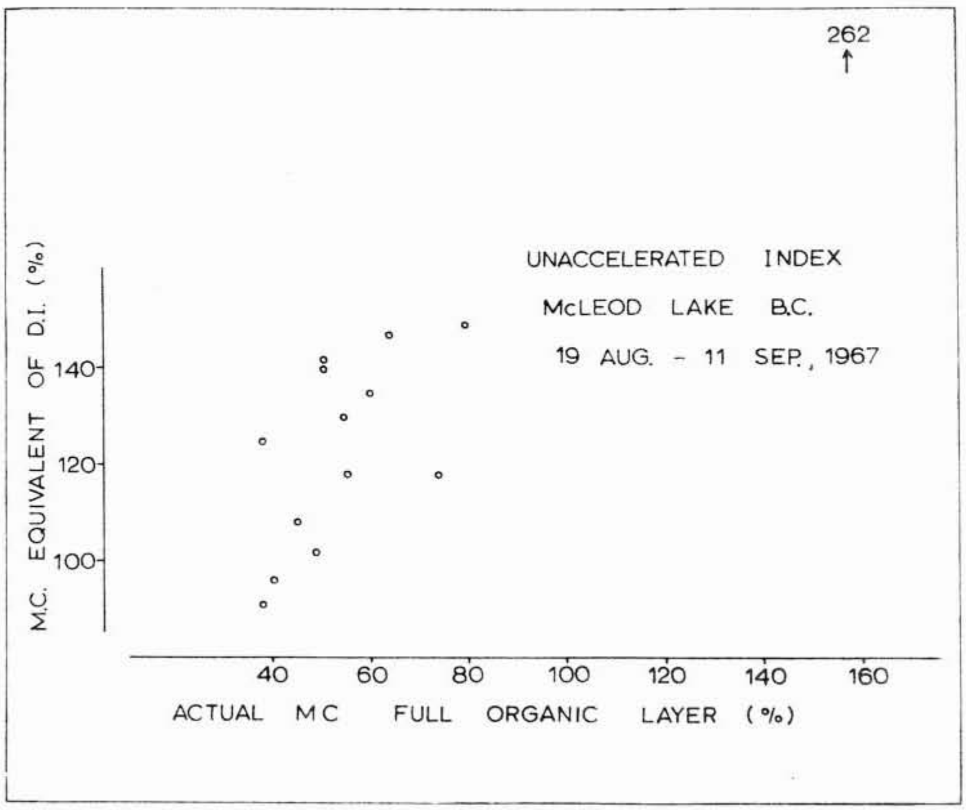

262
UNACCELERATED INDEX
McLEOD LAKE B.C.
19 AUG. - 11 SEP., 1967
M.C. EQUIVALENT OF D.I. (%)
100
120
140
40
60
80
100
120
140
160
ACTUAL M C FULL ORGANIC LAYER (%)

FIG. 9

COMPARISON OF PETAWAWA MARK IV AND B. C. MARK II

DROUGHT INDEXES

S. J. Muraro & J. A. Turner

for

Presentation to Meeting of Fire Research Personnel - Ottawa

Feb. 25-28, 1968

The periodicity and amount of precipitation during the summer months dictates the severity of a fire season. In forests of the north temperate region the proportion of fuel available for combustion is largely dependent on the cumulative drying of the large, slow-drying fuel components. A parameter of the moisture content of these fuels is an integral component of all Fire Danger Ratings Systems designed for this zone.

The decision to revise the Canadian Fire Danger Rating System resulted in the proposal of a number of parameters of the moisture content of the slow-drying fuel components. The Petawawa Mark III, developed by Van Wagner at Petawawa and the B. C. Mark II, developed by Turner, in co-operation with members of the B. C. Regional Fire Research Section, were two such indexes discussed at the Calgary meeting in May, 1967. Pursuant to field testing and further work, both indexes have been changed; the B. C. Mark II only in computation techniques, but the Petawawa enough to justify the new nomer of Petawawa Mark IV.

The B. C. Mark II index was designed to simulate the moisture regime in organic layers having moisture-holding properties similar to the samples displayed. These organic layers are common to all areas of the Coast, Subalpine, Columbia and Boreal Forest regions of British Columbia. In the Montane Forest Region they occur on all but the extremely dry lodgepole pine and ponderosa pine sites.

These organic layers are usually composed of integrated moss litter overlying a dense fermentation and humus layers often consisting largely of rotten wood containing a fair proportion of living roots. These organic layers are generally deeper on wet or poorly drained sites and more shallow on drier sites. Characteristics of the samples are included in Table I.

Table I. Characteristics of organic samples.

Sample	wt* lbs	depth inches	area ft^2	vol. ft^3	lbs/ft^2
1	.35	2.5	.17	.036	2.06
2	.26	3.0	.17	.029	1.53
3	.25	2.2	.17	.032	1.47
4	.53	3.5	.15	.044	3.53

* Air dried only -- 9 months in laboratory where average conditions are 70° F and 30% R. H.

If we presuppose that the index is a satisfactory reflection of the general drying trend of the organic layers described, and if similarity of surface appearance is any criteria of the general moisture retention characteristics, then the B. C. Mark II Index would probably be applicable to the remainder of the Canadian Boreal Region and to the wetter areas of the Great Lakes and Acadian Regions. The B. C. Mark II is thought to be applicable to forests occurring in all but the shaded areas on Figure 1.

As a result of the discussions concerning the two indexes at the Calgary meeting in May, 1967 every opportunity was taken to compare the indexes during the 1967 fire season. All readily available data from field studies and wild fire action were analyzed and related to the two drought indexes in question. The data accumulated were from four main sources.

(1) Wild fire action in British Columbia during the 1967 fire season

(2) Destructive sampling for organic layer moisture content

(3) Fire impact studies for B. C. 608 and B. C. 606

(4) Observation and experience

The fourth source must be recognized because, regardless of the results of these discussions, this factor is most important from the user's point of view.

Wild Fire Action

If the drought index is accepted as being a good relative index of fire season severity, then the general fire load should be reflected in the drought index. The Petawawa Mark IV Index and the B. C. Mark II Index were calculated for four stations in the Nelson and Kamloops Forest District for general comparisons and collation with fire activity.

Figure 2 shows the Petawawa Mark IV Index and the B. C. Mark II Index with the date and amount of rain for the 1967 fire season. There are two areas of significance. The first is the striking similarity of the two indexes at the lower values and the similar drying rates when the B. C. Mark II Index is on the standard drying rate. The second is the pronounced difference in length of period affected by rainfall at the higher drought index numbers. Consider the three rains of July 7, 19 and August 4; the bracketed numbers following the effective period is the mean daily moisture loss in inches shown by the recovery rates of the two indexes.

		Effective Period (Days)	
Date of Rain	Amount (inches)	B. C. M. II	Pet. M IV
July 7	.27	3 (.09)	11 (.024)
July 19	.12	2 (.06)	7 (.017
Aug. 4	.37	4 (.09)	22 (.017)

The drought indexes for Cranbrook (Fig. 3) reveal the same characteristics as Figure 2. The essentially similar reaction at the lower levels and a similar rate of drying during the standard rate are apparent. Even more striking is the difference caused by the .13 inches of rain on August 7, because the seasonal peak is displaced by three weeks, the Petawawa Index never recovering from this rain even after the 23 days shown. The effect of the rainfall of .07 on July 19 is also different but does not have the psychological impact of displacing the period of relative severity.

Figure 4 shows the similarity of standard drying rates indicated in the previous two figures. From this figure, the effective periods for the rain occurring on the same day as those at Shuswap Falls are compared below; as in Figure 2, the bracketed figures are the daily moisture loss in inches.

		Effective Period (Days)	
Date of Rain	Amount (inches)	B. C. M. II	Pet. M IV
July 7	.15	2 (.075)	14 (if continued) .015
July 19	.53	10 (.053)	18 (if continued) .029
Aug. 4-6	.18 + .08	3 (.086)	14 .018

Kamloops Forest District fire action in terms of total manpower is shown on a logarithmic scale. Periods of varying degrees of activity which coincide with high periods of both indexes are obvious. The man power peaks coinciding with the rains mentioned previously are in part due to the lightning fires associated with the rains. The leveling off in the latter part of August indicates the fire load saturation point rather than a decreasing severity.

The comparison of drought indexes and fire action in the Nelson Forest District during 1967 reveals many of the same characteristics as that for Chase. Again, the similarities at the lower index levels and the similar drying rates are apparent. The inconsistencies in fire action are due to the same causes as those mentioned for Chase. Note the difference in the Petawawa index value calculated at Creston (Fig. 5) and Cranbrook (Fig. 3) caused by the .13 inches of rain on August 7.

The regression of the weekly burned acreage in the Nelson District and the highest drought index for the week calculated at Creston is shown in Figure 6. The equations for the regression lines (not shown) are Y = 1.05 + .015 and Y = 1.11 + .02X for the B. C. Mark II and Petawawa Mark IV indexes, respectively. The respective correlation coefficients are .80 and .78. The similarity of these correlation coefficients are understandable when the similarity of the indexes from Figure 5 is recalled. In Figure 7, the regression of burned acreage in the Kamloops District and the drought indexes calculated at Chase, B. C. are shown.

In this figure there is a significant difference in the correlation coefficients of the two indexes; for the B. C. Mark II it it .77, and for the Petawawa Mark IV it is .61. This is meaningful when the difference in the drought indexes shown in Figure 4 is considered. The figures beside each point in both figures are the chronological order of the weeks commencing in June. The larger acreages burned in the last few weeks verify the reason of fire-load saturation for the leveling off of man power on Figures 4 and 5 for the latter part of August.

Destructive Samples of Organic Layers

Project B. C. 608, "Development of a Burning Index and Guidelines for Prescribed Burning in Spruce Balsam Logging Slash", offered an opportunity to test the ability of the two drought indexes to indicate the moisture content of the organic layer. On this area (2,800'a.s.l.), located near the south end of Macleod Lake, the organic layers are typical of those displayed, with the exception of having a less luxuriant growth of moss and being generally more shallow. Two samples are described below.

Sample	wt O. D. g	depth inches	area ft^2	lbs/ft^2
1	379.8	1.8	.73	1.14
2	575.4	2.4	.79	1.59

Samples 1 and 2 included 27 and 144 grams of roots, respectively. These roots were large and easily removed; an unknown proportion of smaller roots remained.

From each of the 46 plots shown in Figure 8, three composite samples of the upper and three of the lower organic layers were taken prior to each burn.

The Macleod Lake plots were burned from June 19 to August 24. The B. C. Mark II drought indexes and the Petawawa Mark IV for the season, including this period, are shown in Figure 9.

The regression of the destructive samples of the upper and full organic layer moisture contents and the two drought indexes are shown in Figure 10.

The inconsistencies in moisture content due to location are more striking when Figure 11 is examined. The relation shown in this figure is from the mean of four samples of the full organic layer under a seed block adjacent to the study area. Shortage of help prevented this type of sampling for the major part of the summer and those shown commenced on August 19 and continued on a daily basis to September 2. The sample at the lower right of 157 per cent was taken on September 11 after a total of 1.28 inches of rain had fallen since September 1. The point on September 2 at 79 per cent M. C. had sustained a rainfall of .26 inches since the previous day's M. C. of 37.7 per cent. The equations for these lines are Y + 188.4 - .75x and Y = 124.0 - 2.46X for the B. C. and Petawawa indexes, respectively; their correlation coefficients are -.95 and -.63, respectively. The moisture content of the upper mineral soil on September 11 was 13 per cent, relatively dry for these fine textured soils, indicating that the 1.28 inches of rainfall that occurred from September 1 had not penetrated the entire organic layer. This again illustrates the strong stratification of moisture in organic layers similar to those displayed.

Fire Impact Studies

The last means of comparing the two drought indexes is perhaps the most meaningful; this is the comparison through analysis of the amount of organic material removed by prescribed fires. An index that can be confidently applied to this purpose becomes an invaluable tool for selecting necessary weather regimes to accomplish a predetermined treatment. Such an index can also be applied to determine damage potential of wild fires to wildland values other than timber. A meaningful index that can be related to fire impact is a necessary priority before relating the fire characteristic of intensity to the fire danger rating system. Figure 12 shows the regression of organic layer depletion in per cent and the B. C. Mark II drought index. Note the strong correlation coefficient of .80

using the Macleod Lake data. To test this prediction capability, depletion data from the six burns on Mabel Lake were plotted; with this data the correlation coefficient is increased to .95. Only the B. C. Mark I index and Turner's soil moisture index showed regressions that even approached the Mark II. In this regression, per cent depletion rather than absolute depletion was used to avoid the complications of a transition in organic layer depths.

Various other indexes, including the Petawawa Mark II and Mark IV U. S. national buildup, and the Canadian 25 day system, are on the subsidiary scattergrams. Regressions for these systems were not calculated because of the bimodal distribution of the sample population.

To conclude this comparison some personal observations during the Macleod Lake project are added. There is no doubt that conditions were much drier at the end of August than on July 19 where the Petawawa index shows the most extreme condition. Surface water was still present on July 19 and continued to decrease up to the time of the September rains. A small creek which had to be forded during the early part of the season ceased showing surface water on about July 10. Surface water showed for one day on July 20, never to reappear in 1967, not even after the early September rains. Traversing the area with vehicles was still extremely difficult in mid-July and it was not until mid-August that this condition was alleviated. The rate of drying of surface drainage from puddles coincided roughly with recuperation of the Mark II. The increasing severity of the situation was verified by the increasing fire intensity on the test plots.

These observations are supported, in principle, by the feelings of the Prince George Protection Personnel, who had no doubt of the greater severity during the late-August period over that which existed in July.

The evidence offered in this paper shows the B. C. Mark II index to be a more realistic parameter of moisture content in organic layers similar to those displayed than the Petawawa Mark IV. The Petawawa Mark IV index is probably more applicable to the relatively uncompacted organic layers in the drier areas of the Great Lakes Forest region; however, the relative scarcity of these organic layers precludes the use of the Petawawa Mark IV index as a component of the revised fire danger rating system.

A MODULAR APPROACH TO A REVISED NATIONAL FIRE DANGER RATING SYSTEM

By

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for

Presentation to Meeting of Fire Research Personnel

February 25-28, 1968

A MODULAR APPROACH TO A REVISED NATIONAL

FIRE DANGER RATING SYSTEM

We live in an era of change; obsolescence precedes perfection. Industry meets the challenge of changing demand with the modular concept of design. This modular concept, pioneered by the electronics industry, maximizes product versatility by confining each function to a specific but interchangeable block or module. A change in function requires only a change of module rather than a change of the entire product.

Fire researchers concerned with modifying the fire danger rating system face the same challenge as the innovators of the modular concept. New and increasingly more expensive suppression techniques; increasing wild land values; variations in regional application and climates and the increasingly important role as a decision making aid are factors that contribute to the varied requirements of a fire danger rating system. As researchers, we have the responsibility of providing operations with a rating system that accurately defines the characteristics of fire behavior while retaining flexibility to meet a variety of applications. For the researcher, a rating system is equally important; in addition to its use as a research tool, it is the yardstick by which operations implement research.

This proposal for the revised Canadian National Fire Danger Rating System suggests a modular concept to facilitate development and application. The advantage of this approach is that further sophistication is easily accomplished by refinement or addition of tables without having to alter the basic framework. This would allow an easy program of updating instead of the crash program with which we are presently involved. The modular concept would be extended to the expression of the index, each table yielding a defined value related to some characteristic of fire behavior which has a definite meaning to the user.

Fine Fuel Moisture Content

The two basic building blocks are the moisture contents of two standardized fuels. The first is the moisture content of a standard fine surface fuel and is derived through the use of a number of modules dependent on the particular application. For the standard operational procedure of daily index calculation, two modules are used: one to obtain the daily maximum moisture content of the fine fuels at 0600 hr; the other to obtain the daily minimum moisture content at 1600 hr. (Tables I and II in Appendix I)[1/] To determine the fine fuel moisture at other times of day, additional modules, Tables Ia to Id, are applied for the times of 0800, 1000, 1200 and 1400 hr. To determine the fine fuel moisture content after 1600 hr, Tables IIa to IIc are applied at the times of 1800, 2000 and 2400 hr. The moisture content of the standardized fine fuels are determined from a mathematical transformation of the pine mat data or from composite samples of needles on the surface of the forest floor on the drier pine sites. A large segment of this work has been completed. Lawson has compiled a series of tables from the work in the Prince George area by Russell, Lawson and Péch.

The tables developed by Lawson predict the moisture content of a composite sample of surface needles on a dry pine site, using current relative humidity or precipitation and initial moisture content. (The original

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1/ Subsequent decisions to incorporate moisture regimes of three fuels resulted in changing the flow chart shown by Appendix I.

tables by Lawson are appended to a later publication dealing with their revision (Muraro and Russell, 1969)[1/]). The initial moisture content is the moisture content from either the 0600 table or the 1600-hr tables, depending upon which of these calculations were most recent.

This combination of modules replaces the Drying Code Table in the previous rating system. The twice-a-day calculation reduces the need for a rainfall table if rains between the operational periods are corrected according to the tables.

The previous drying code was entirely satisfactory to determine moisture contents of these fine surface fuels in mid-afternoon when noon relative humidity was used as the independent variable. Field work to gather data for the new tables was initiated primarily to increase the flexibility of the rating system to allow application at other times of day and to restrict the effect of the nighttime humidity to the fine fuel moisture index rather than to the final index. This approach of using the approximate maximum and minimum weather to determine fuel moisture increases accuracy because extremes are defined and intermediate calculations are confined to one phase of the diurnal moisture cycle. Insofar as British Columbia is concerned, the addition of a second table to determine the fine fuel moisture code is of little consequence since it replaces the overnight R.H. correction table.

[1/] Muraro, S. J. and R. N. Russell with appendix by B. D. Lawson. 1969. Development of Diurnal Adjustments Table for the Fine Fuel Moisture Code. Info. Report BC-X-35. Forestry Branch, Dept. of Fisheries and Forestry Victoria, B. C.

Values in this table are expressed in percent moisture content, rather than the coded values previously used, and the tables are called the Fine Fuel Moisture Index. In the National Fire Danger Rating System, the fine fuel moisture index is dependent only on weather and is completely independent of regional differences. Adherence to the modular concept precludes correction for the drying effect of wind in this module because the magnitude of this effect is at least partially dependent on the particular fuel complex.

Large Fuel Moisture Index

The moisture content of the slower drying fuels is the second basic building block of the revised Danger Rating System. This parameter will be called the Build-up Index because of the common usage and understanding of this term. The Build-up Index consists of two modules or tables: one table to define the rate of drying; the other to define the wetting effect due to precipitation. The most important requirement of this table is that it can be an accurate relative parameter of the moisture regime of the slow drying fuels. Because of the preceding discussions concerning the choice of this particular index, no further discussion is warranted[1/]. The Build-up Index, like the Fine Fuel Moisture Index, is dependent only on weather. (The proposed set of tables for the Build-up

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1/ Muraro, S. J. and J. A. Turner, 1968. A Comparison of Petawawa Mark IV and B. C. Mark II Drought Indexes. Working paper for meeting of Fire Research personnel, Ottawa, Feb. 25-28, 1968.

Index is appended to a paper by Turner et al. 1968[1].) The relevance of these modules to the rating system is shown in Appendix I by Tables III and IV.

The Fire Weather Index Media

The Fine Fuel Moisture Index and the Build-up Index are the foundation of this proposal to the revised Danger Rating System. In principle, they offer nothing new, as all Fire Danger Rating Systems for the north temperate regions include parameters of at least two fuel moisture regimes. To review the previous discussion, the proposal consists of two indexes that express the moisture regimes in standardized fuels having unique drying rates dependent only on weather. Integrating these moisture indexes to obtain a strictly weather dependent model of fire growth to use as a national rating system requires the selection of a fuel complex for use as a growth media. The fuel complex selected, for the fire growth model should have two important qualifications.

(a) It must be common to most areas in which the index is to apply.

(b) It should be as normal as practical to obtain, offering a minimum of unique characteristics such as loading, distribution or size.

The various pine fuel complexes, lodgepole pine in the west and Jack pine in the east, have previously been selected as media for the weather dependent fire growth model. These stands fulfill the above qualifications

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1/ Turner, J. A., S. J. Muraro, Gy Péch and R. N. Russell, 1968. A Drought Index to Simulate the Moisture Content of the Full Organic Layer. Presented to Conference on Fire and Forest Meteorology of the A. M. S. and S. A. F. March 12-14, 1968, Salt Lake City, Utah.

and are further recommended because of the potentially large quantity of applicable test fire data. It is appropriate that a weather dependent model of fire growth be termed the Fire Weather Index.

Derivation of the Fire Spread Index

Integration of the moisture content of the two sizes of fuels parametered by the Fine Fuel Moisture Index and the Build-up Index to obtain a fire behavior model is based upon established principles. In a particular fuel complex in the absence of wind, fire spread is well correlated with the moisture content of the fine fuel components. This relation is different for each fuel complex dependent on the proportion of fuel in the smaller size classes. Wind has a far stronger effect on rate of spread than does fuel moisture. Again, this effect is partially dependent on the distribution of size classes. In general, the effect of wind on frontal fire spread is most pronounced at the moderate velocities and lesser at the low and high velocities.

The obvious course of action is to develop a module using the Fine Fuel Moisture Index and wind velocity as independent variables to predict the dependent fire spread. The spread module should be expressed in relative terms on a scale of 0 to 100. This table constitutes the fifth module shown as Table V in Appendix I.

The values for this table would be derived directly from test fire data for the less critical periods. Modeling techniques would be applied to test fire data for the more critical periods because, until crowning occurs, fires under stands are not fully influenced by ambient winds. Wild fires could be used as another source of data of fire spread. If these methods fail, a program of large-scale test fires should be instituted. If the proper conditions are selected, good rate of spread values should be obtainable from a maximum of 20 well-instrumented areas. This spread index is used primarily to maintain continuity toward derivation of the Fire Weather Index; however, it does have limited operational applications. In the modular concept, it isolates a specific characteristic of fire behavior and thus allows internal modifications as better information becomes available.

Effect of Moisture Content of Large Fuels

The proportion of the large, slow-drying fuels available for combustion is dependent on the moisture content of these fuels. In Byram's equation of fire intensity

$$I = HWR,$$

H is the heat combustion in BTU's per pound of fuel. For forest fuels, this averages about 8600 BTU's per pound and is considered nearly constant. The two strongest variables are W, the weight of available fuel in pounds per square foot and R, the rate of spread in feet per second.

In pine fuel complexes, the potential available fuel, not considering stem volume, attains fuel loadings up to three pounds per square foot. The proportion of this fuel available for combustion is highly dependent on the Build-up Index. For other fuel complexes, the influence of the Build-up Index on the available fuel varies. In grass, for example, the Build-up Index would have relatively little effect on available fuel.

Because the moisture content of the large fuels is dependent upon the Build-up Index, a value of fire intensity for a specific fuel complex is obtained by the product of available fuel and rate of spread determined by the spread index. The result of this step is the sixth and final module for the Fire Weather Index and is shown on Appendix I as Table VI.

The Fire Weather Index

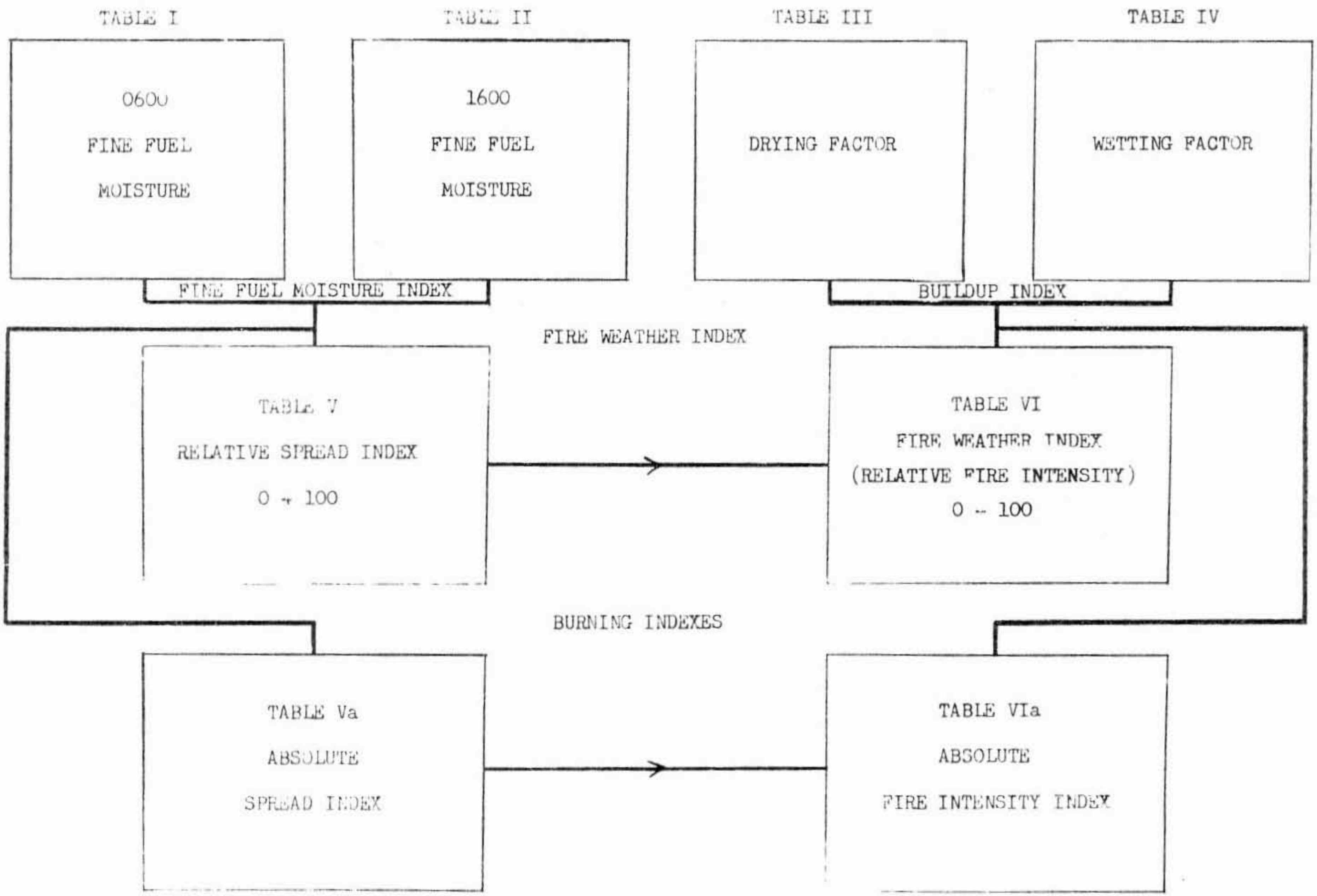
The fire weather is defined as: A weather dependent relative index of fire intensity in a standardized fuel complex. This index is proposed to express the National Fire Danger Rating System for use as a basis of comparing and disseminating a measure of fire weather on a national scale. Because this is a standard index, this index is expressed in relative terms on a scale of 0 to 100 units. In principle, only two values from the computation form would be reported to Central Control, the Fire Weather Index and the Build-up Index. The Build-up Index is submitted because it is the most realistic measure of presuppression activities handled usually by Central Control. Activities of this nature would include tanker dispersement and allocation of initial attack crews. Establishment of fire action classes would be on a zonal system dependent on the usual range of drying regimes, although identical index numbers would be obtained.

If weather data were submitted to a central point for machine computation, three values would be returned to the user: Fire Weather Index for local public relation purposes; Build-up Index, and Fine Fuel Moisture Index for local computation of the appropriate Burning Indexes.

Burning Indexes - Their Development and Use

The relation of Burning Indexes to the Fire Weather Index is shown in Appendix I by Tables V and VIa. A Burning Index is defined as: An index expressing the influence of the total fire environment on fire behavior in absolute units of spread and intensity.

APPENDIX I. FLOW CHART OF PROPOSED FIRE DANGER RATING SYSTEM



Each Burning Index applies to a specific and recognizable fuel complex defined at this stage according to cover type, and contains two modules; the first expresses the relation of the standard Fine Fuel Moisture Index and wind velocity to obtain a Fire Spread Index in the particular fuel type, and a second integrates the weight of available fuel as dictated by the Build-up Index with rate of spread to obtain the Fire Intensity Index. These modules result in absolute values of lineal spread and intensity. The values so obtained for a number of fuel complexes provide the land manager with a criteria by which he may make attack priorities on wild fire, or a tool to determine fire impact and control difficulty of prescribed fires.

The distinction between the Burning Indexes and the Fire Weather Index is best illustrated by their respective index units; the Burning Indexes are expressed in absolute units, while the Fire Weather Index is expressed on a relative scale of one hundred units.

The modular concept offers most advantage to the Burning Indexes. Because these indexes offer a variety of applications, they must be capable of accepting adjustments for unique fire environments at the proper phase of index calculation. Topographic effects and atmospheric stability are examples of such unique environments. To illustrate, aspect affects fuel moisture; therefore, only the Fine Fuel Moisture Index from Table I or II is modified. Slope affects spread in somewhat the same manner as wind, so only the Fire Spread Table of the particular Burning Index is adjusted. Stability affects intensity, so this adjustment is made to the Fire Intensity Index. The definitive nature of this system eliminates the accumlative effect that could result from similar adjustments to other rating systems.

Advantages of This Proposal

(1) Values are meaningful in terms of fire behavior and to the user.

(2) Adjustments for unique situations can be applied to affect only the appropriate module and the extent of such adjustments are incorporated by subsequent modules.

(3) Each Burning Index calculated offers new information; therefore, the use of each additional table has the incentive of need.

(4) General up-dating and improvement of the tables can be accomplished on a modular basis without affecting subsequent modules.

(5) The system offers complete flexibility to arrive at an index value at any time of day using either current weather parameters or forecasted parameters.


EXPECTED APPLICABLE AREA FOR
BC MARK II DROUGHT INDEX.
Predominantly Forest
Great Lakes-St. Lawrence
Grassland

FIG. 1

FIG. 2


COMPARISON DROUGHT INDICES
SHUSWAP FALLS 1967
PETAWAWA MARK IV
VICTORIA MARK II
PETAWAWA MARK IV
MAY
JUNE
JULY
AUGUST

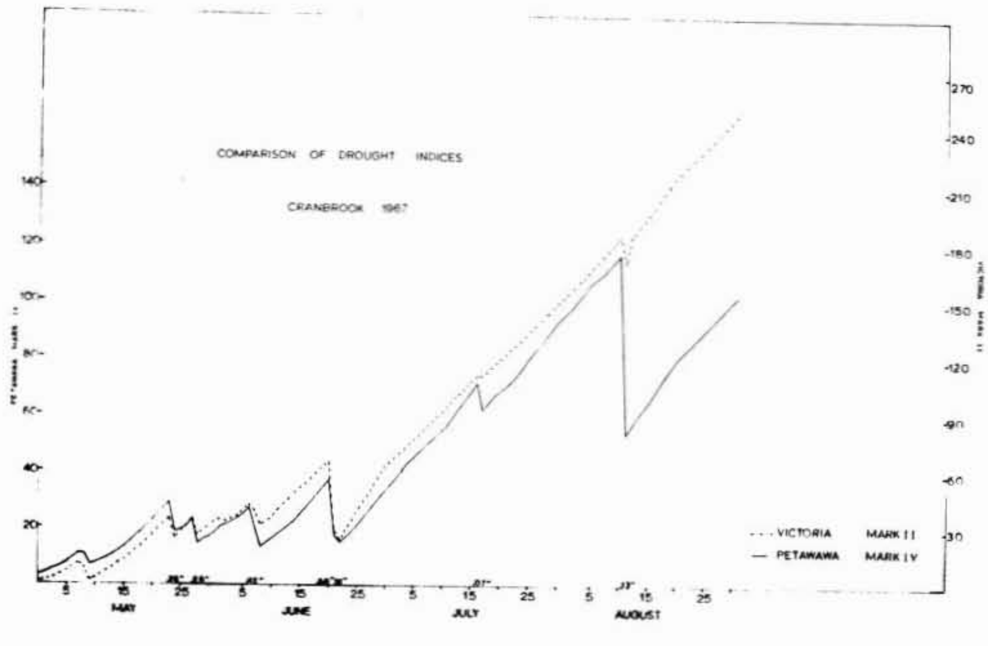
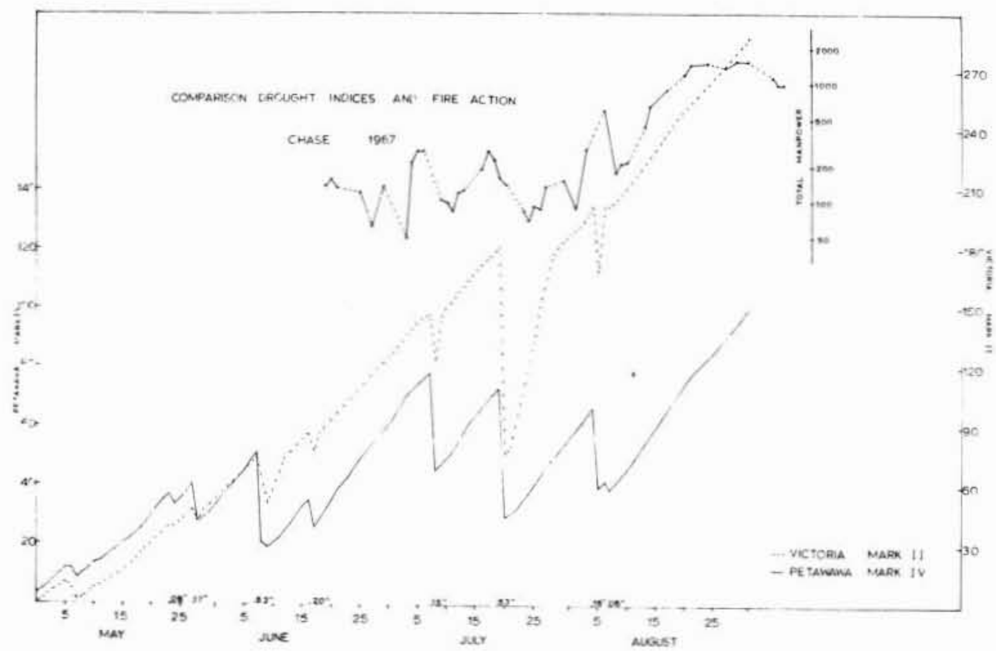

COMPARISON OF DROUGHT INDICES
CRANBROOK 1967
VICTORIA MARK II
PETAWAWA MARK IV
MAY
JUNE
JULY
AUGUST

FIG. 3

FIG. 4


COMPARISON DROUGHT INDICES AND FIRE ACTION
CHASE 1967
TOTAL MANPOWER
VICTORIA MARK II
PETAWAWA MARK IV
MAY
JUNE
JULY
AUGUST

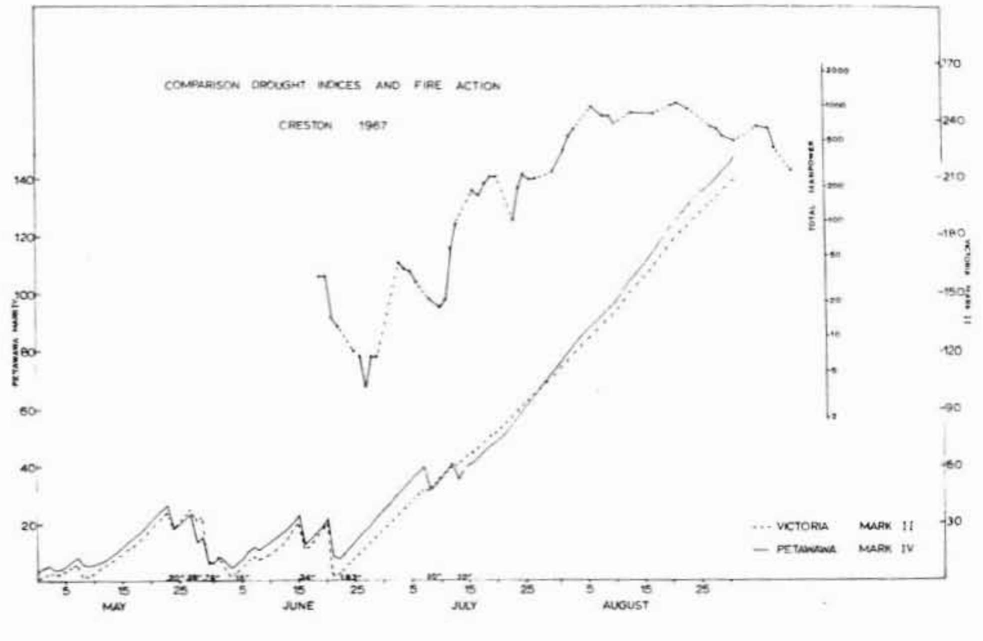
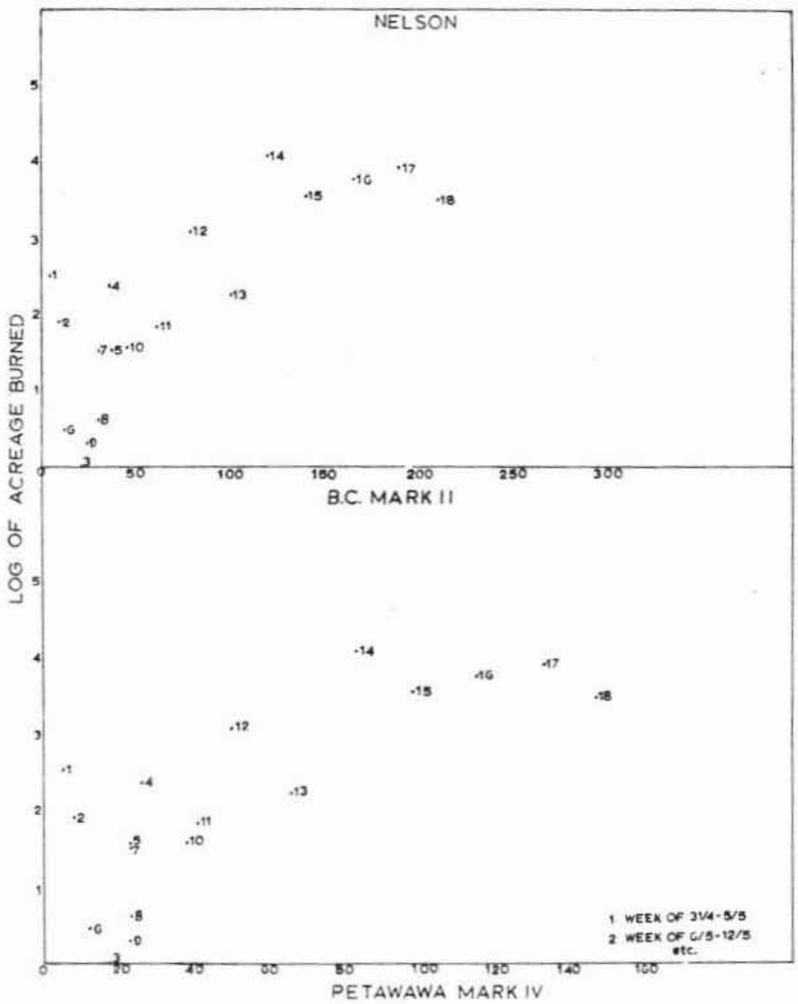

COMPARISON DROUGHT INDICES AND FIRE ACTION
CRESTON 1967
PETAWAWA MARK IV
TOTAL MANPOWER
VICTORIA MARK II
--- VICTORIA MARK II
— PETAWAWA MARK IV
MAY
JUNE
JULY
AUGUST

FIG. 5

FIG. 6


NELSON
LOG OF ACREAGE BURNED
B.C. MARK II
PETAWAWA MARK IV
1 WEEK OF 31/4-5/5
2 WEEK OF 6/5-12/5
etc.

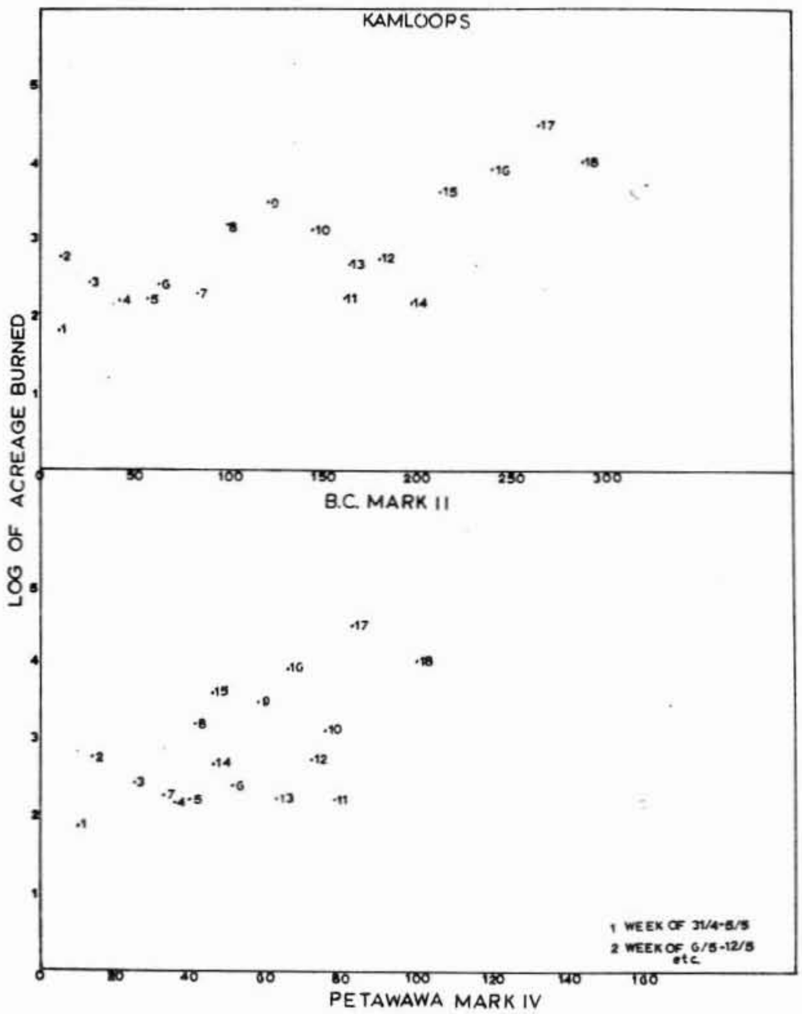
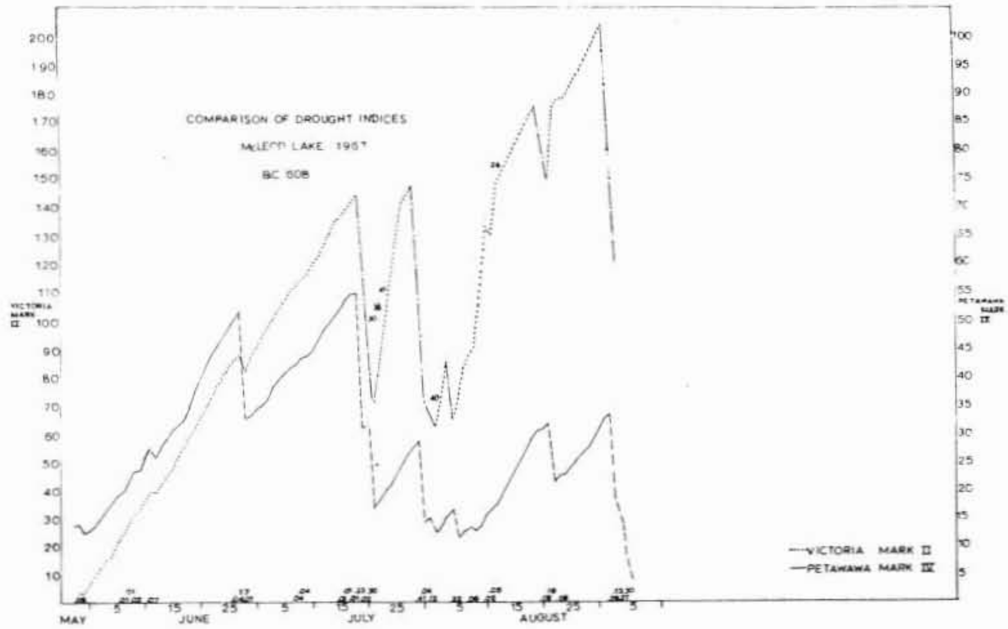

KAMLOOPS
LOG OF ACREAGE BURNED
B.C. MARK II
PETAWAWA MARK IV
1 WEEK OF 31/4-6/5
2 WEEK OF 6/5-12/5
etc.

FIG. 7


1967 Study Area - Project BC
wind direction
pump station
plot number
Aug 7 date of burn
plot 21 was burned on Aug 1 and reburned on Aug 2. This second burn was numbered plot 8

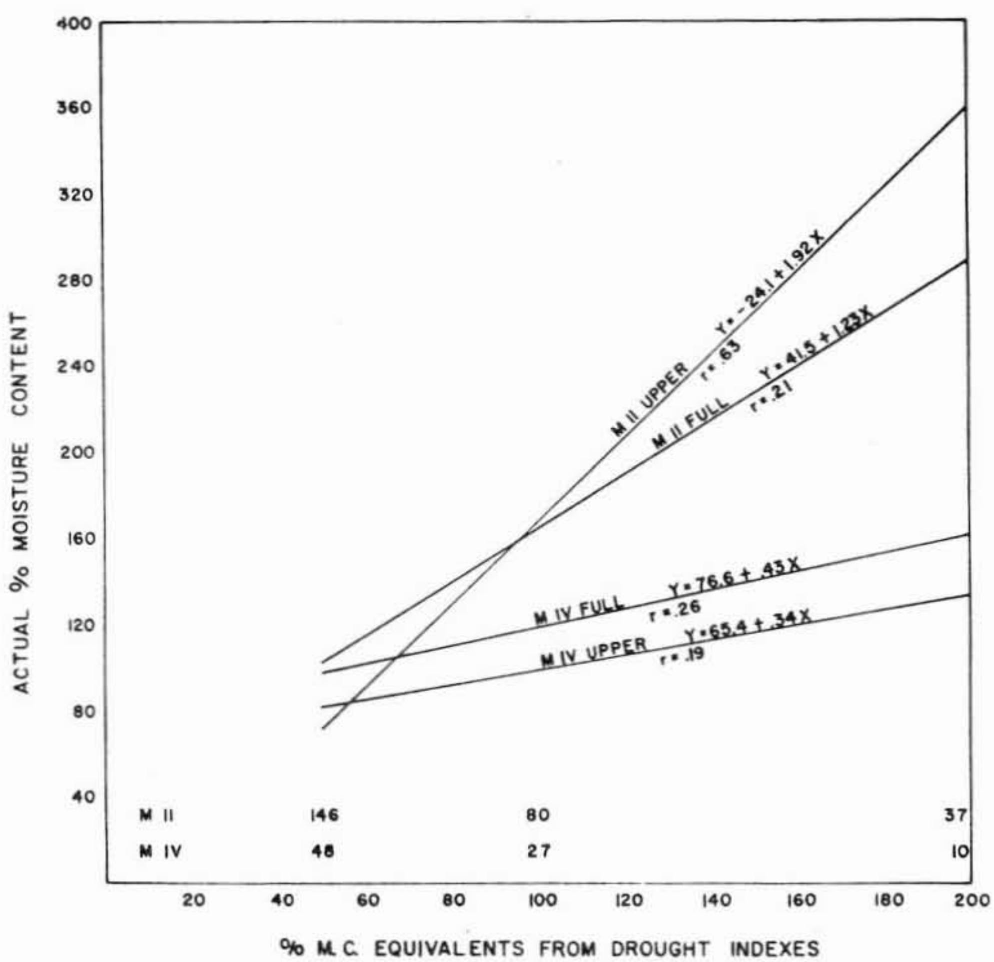
FIG. 8



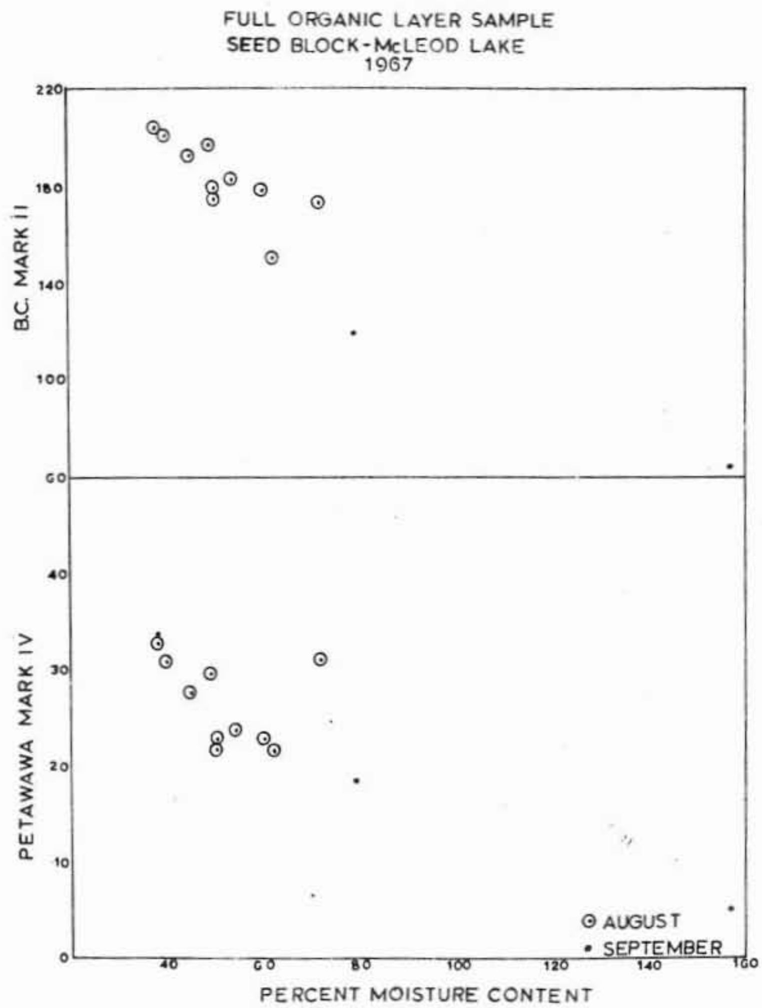
COMPARISON OF DROUGHT INDICES
McLEOD LAKE 1957
BC 608
VICTORIA MARK II
PETAWAWA MARK IV
MAY
JUNE
JULY
AUGUST

FIG. 9

FIG. 10



ACTUAL % MOISTURE CONTENT
% M.C. EQUIVALENTS FROM DROUGHT INDEXES
M II UPPER Y = -24.1 + 1.92X
r = .63
M II FULL Y = 41.5 + 1.23X
r = .21
M IV FULL Y = 76.6 + .43X
r = .26
M IV UPPER Y = 65.4 + .34X
r = .19
M II 146 80 37
M IV 48 27 10



FULL ORGANIC LAYER SAMPLE
SEED BLOCK-McLEOD LAKE
1967
B.C. MARK II
PETAWAWA MARK IV
AUGUST
SEPTEMBER
PERCENT MOISTURE CONTENT

FIG. 11

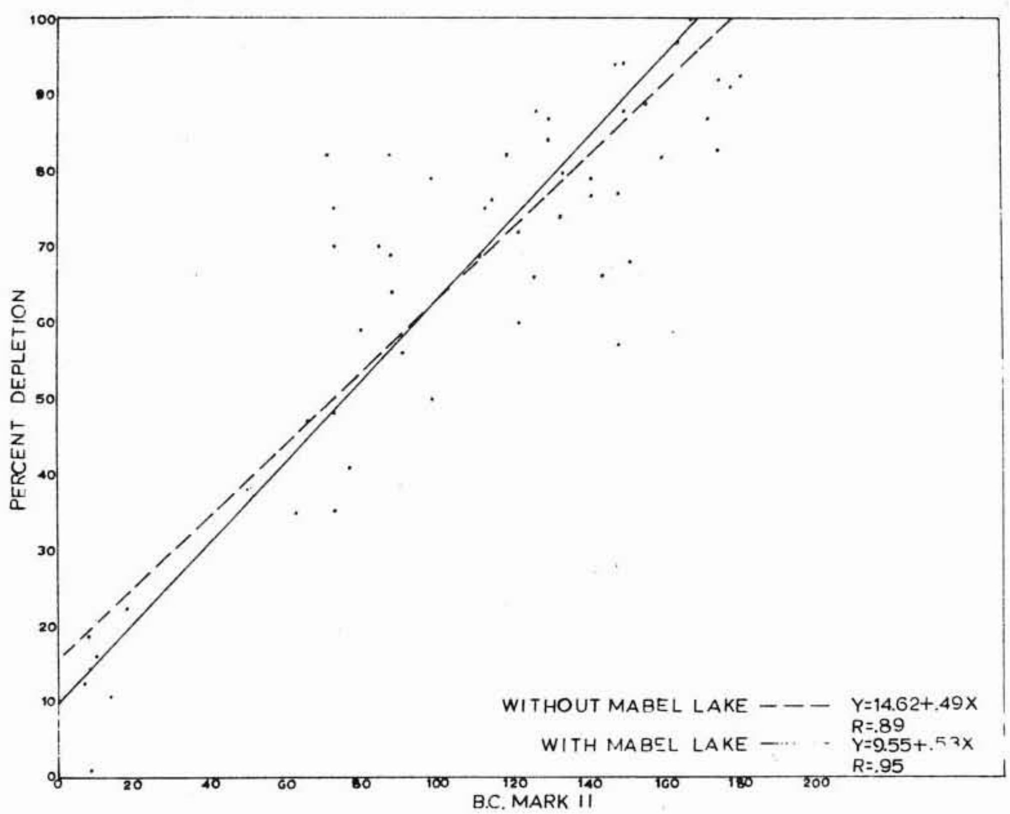

PERCENT DEPLETION
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
B.C. MARK II
WITHOUT MABEL LAKE
Y=14.62+.49X
R=.89
WITH MABEL LAKE
Y=9.55+.53X
R=.95

FIG. 12