Government of Canada
Canadian Forestry Service

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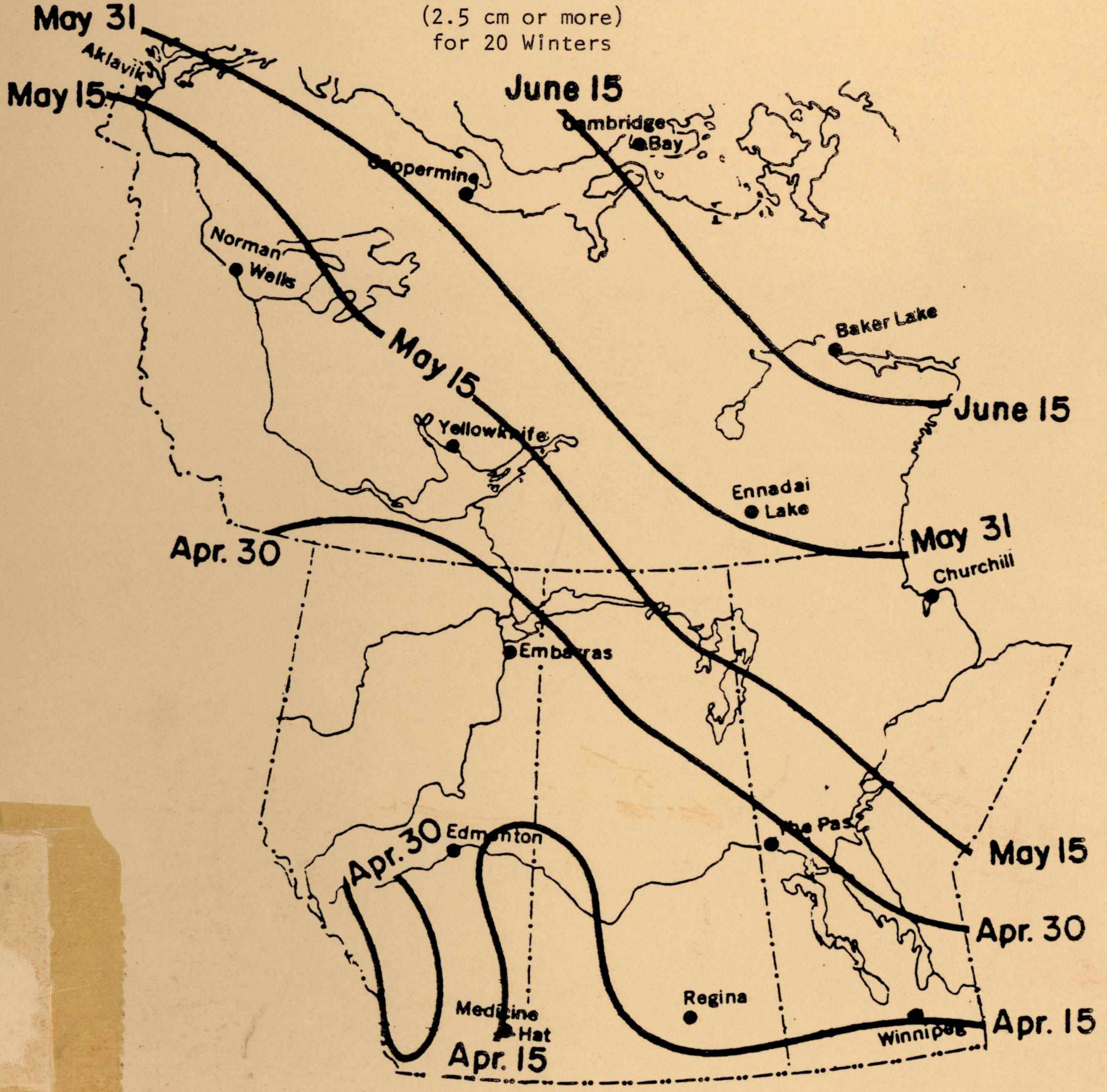
PROCEEDINGS OF THE THIRD CENTRAL REGION FIRE WEATHER COMMITTEE SCIENTIFIC AND TECHNICAL SEMINAR - April 3, 1986, Winnipeg, Manitoba

Median Date of Last Snow Cover
(2.5 cm or more)
for 20 Winters



SNOW COVER STATISTICS FOR SELECTED STATIONS IN THE PRAIRIE PROVINCES & NORTHWEST TERRITORIES
(adapted from Potter 1965)

Station Location/ Name	Elev. (m ASL)	Date of Last Snow Cover				Date of First Snow Cover				Snow-free days[1]
		Mean	Median	Earliest	Latest	Mean	Median	Earliest	Latest	
ALBERTA										
Banff	1397	May 8	Apr 30	Apr 16	Jun 7	Oct 21	Oct 27	Sep 21	Nov 28	211
Beaverlodge CDA	762	Apr 17	Apr 14	Mar 27	May 1	Oct 31	Nov 2	Sep 21	Dec 24	224
Calgary A	1079	May 4	May 5	Mar 22	Jun 7	Oct 18	Oct 19	Sep 10	Dec 4	266
Coronation	798	Apr 24	Apr 28	Mar 24	May 24	Nov 5	Nov 10	Sep 21	Jan 2	233
Cowley A	1182	May 1	May 5	Mar 17	May 22	Oct 20	Oct 22	Sep 11	Jan 14	273
Edmonton Ind. A	676	Apr 16	Apr 20	Mar 23	May 11	Nov 5	Oct 31	Sep 26	Jan 6	244
Embarras	236	Apr 28	Apr 30	Apr 3	May 27	Oct 17	Oct 23	Sep 11	Dec 1	194
Fairview	658	Apr 22	Apr 22	Apr 3	May 6	Oct 20	Oct 29	Aug 15	Dec 7	210
Grand Prairie A	668	Apr 21	Apr 21	Mar 14	May 6	Oct 17	Oct 13	Aug 15	Feb 22	214
Jasper	1061	Apr 13	Apr 16	Mar 14	Jun 6	Oct 27	Nov 1	Sep 22	Dec 7	233
Keg River	428	Apr 18	Apr 15	Apr 5	May 3	Oct 26	Oct 27	Sep 27	Nov 28	212
Lac La Biche	559	Apr 18	Apr 17	Mar 29	May 15	Oct 25	Oct 30	Sep 26	Nov 26	222
Lethbridge A	920	Apr 21	Apr 22	Mar 22	May 18	Oct 21	Oct 19	Sep 17	Dec 2	284
Fort McMurray A	371	Apr 17	Apr 22	Mar 27	May 12	Oct 31	Oct 31	Oct 5	Dec 2	211
Medicine Hat A	721	Apr 9	Apr 10	Feb 28	May 15	Nov 7	Oct 30	Sep 23	Jan 3	281
Penhold A	904	Apr 22	Apr 26	Mar 16	May 29	Oct 26	Oct 23	Sep 21	Dec 21	237
Rocky Mtn. House	1006	Apr 28	May 2	Mar 6	May 30	Oct 24	Oct 26	Sep 10	Jan 2	222
Vermillon A	621	Apr 16	Apr 13	Mar 31	May 30	Oct 29	Oct 30	Sep 26	Nov 24	227
Wagner	584	Apr 21	Apr 14	Apr 2	May 29	Oct 28	Oct 27	Sep 25	Dec 7	219
Whitecourt	741	Apr 20	Apr 20	Apr 2	May 7	Oct 27	Oct 21	Sep 17	Dec 25	213
SASKATCHEWAN										
Broadview A	620	Apr 16	Apr 19	Mar 29	May 11	Nov 5	Nov 7	Sep 23	Dec 8	226
Dafoe A	540	Apr 23	Apr 23	Mar 31	May 11	Oct 31	Oct 28	Oct 7	Nov 26	216
Estevan A	574	Apr 10	Apr 8	Mar 14	May 9	Nov 5	Nov 6	Oct 6	Dec 16	239
Hudson Bay	372	Apr 21	Apr 24	Mar 28	May 31	Nov 1	Nov 4	Oct 6	Dec 1	211
Island Falls	299	Apr 30	May 2	Apr 10	May 17	Oct 23	Oct 24	Sep 23	Nov 11	188
Moose Jaw A	566	Apr 19	Apr 26	Mar 28	May 12	Nov 11	Nov 9	Sep 25	Jan 5	259
N. Battleford A	547	Apr 11	Apr 11	Mar 20	Apr 28	Oct 27	Oct 26	Sep 23	Nov 27	231
Prince Albert A	431	Apr 22	Apr 24	Apr 4	May 11	Oct 30	Nov 3	Sep 30	Nov 28	211
Regina A	574	Apr 17	Apr 21	Mar 21	May 12	Nov 5	Nov 2	Sep 25	Feb 5	235
Saskatoon A	501	Apr 22	Apr 26	Mar 30	May 12	Nov 11	Oct 31	Oct 9	Dec 1	235
Swift Current A	816	Apr 11	Apr 14	Mar 11	May 15	Oct 21	Oct 24	Sep 23	Jan 4	245
Yorkton A	504	Apr 21	Apr 23	Apr 2	May 6	Nov 4	Nov 6	Sep 23	Dec 1	213
MANITOBA										
Brochet	351	May 13	May 5	Apr 17	Jun 3	Oct 17	Oct 10	Oct 1	Nov 13	170
Churchill A	35	May 28	May 27	Apr 24	Jun 9	Oct 15	Oct 14	Sep 18	Nov 9	156
Dauphin A	305	Apr 22	Apr 26	Apr 2	May 15	Nov 2	Nov 5	Oct 8	Dec 6	213
Gillam	138	May 22	May 19	Apr 13	Jun 7	Oct 14	Oct 15	Aug 16	Nov 5	171
Gimli A	221	Apr 20	Apr 16	Mar 31	May 12	Nov 5	Nov 7	Oct 2	Dec 5	226
Neepawa A	388	Apr 22	Apr 27	Mar 29	May 15	Nov 8	Nov 8	Oct 6	Dec 15	230
Rivers A	473	Apr 17	Apr 18	Mar 31	May 8	Nov 5	Nov 3	Oct 7	Dec 7	224
The Pas A	272	Apr 28	Apr 27	Apr 12	May 27	Nov 2	Nov 5	Oct 6	Nov 16	201
Wabowden	233	May 7	May 4	Apr 11	Jun 1	Oct 24	Oct 26	Sep 23	Nov 11	188
Winnipeg Int. A	240	Apr 11	Apr 9	Mar 29	May 15	Nov 3	Nov 4	Oct 3	Dec 1	239
NORTHWEST TERRITORIES										
Aklavik	9	May 21	May 21	May 13	Jun 23	Oct 1	Sep 29	Sep 2	Nov 1	136
Baker Lake	9	Jun 20	Jun 17	Jun 6	Jul 9	Oct 6	Oct 4	Sep 13	Oct 28	116
Chesterfield	4	Jun 19	Jun 19	Jun 8	Jul 1	Oct 7	Oct 6	Sep 10	Oct 31	116
Coppermine	9	Jun 9	Jun 12	Apr 30	Jun 29	Oct 4	Oct 3	Sep 21	Oct 31	107
Ennadai Lake	325	Jun 7	Jun 7	May 25	Jun 22	Sep 27	Sep 28	Sep 15	Nov 2	117
Fort Good Hope	77	May 8	May 10	Apr 27	May 20	Oct 14	Oct 12	Sep 23	Nov 13	159
Fort Norman	91	May 9	May 9	Apr 27	May 19	Oct 21	Oct 23	Sep 23	Nov 13	164
Fort Providence	159	May 3	May 5	Apr 11	May 23	Oct 21	Oct 16	Sep 28	Nov 20	182
Fort Reliance	164	May 18	May 20	May 1	May 28	Oct 7	Oct 6	Sep 17	Oct 25	150
Fort Resolution	167	May 1	May 1	Apr 18	May 27	Oct 16	Oct 14	Sep 27	Nov 14	176
Fort Simpson	129	May 7	May 6	Apr 25	May 22	Oct 22	Oct 24	Sep 27	Nov 13	172
Fort Smith A	203	May 2	May 2	Apr 13	May 27	Oct 15	Oct 15	Sep 27	Nov 18	178
Hay River	161	Apr 30	Apr 30	Apr 13	May 18	Oct 21	Oct 23	Sep 25	Nov 19	180
Norman Wells A	64	May 11	May 14	Apr 22	Jun 1	Oct 7	Oct 3	Sep 23	Nov 3	159
Port Radium	191	May 26	May 21	May 4	Jun 15	Oct 19	Oct 21	Sep 29	Nov 7	149
Yellowknife A	208	May 5	May 6	Apr 18	May 21	Oct 24	Oct 25	Sep 26	Nov 19	174

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[1] Based on the 'mean' dates of first and last snow cover.

PROCEEDINGS
OF THE THIRD CENTRAL REGION FIRE WEATHER COMMITTEE
SCIENTIFIC AND TECHNICAL SEMINAR

April 3, 1986
Winnipeg, Manitoba

Compiled and Edited

by

Martin E. Alexander
Fire Research Officer

Study NOR-5-05 (NOR-5-191) File Report No. 16

Northern Forestry Centre
Canadian Forestry Service
Western and Northern Region
Government of Canada
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CONTENTS

ERRATUM

The cover of the proceedings for the Second Central Region Fire Weather Committee Scientific and Technical Seminar showed the status of the lightning location system in the western and northern of Canada as of April 1, 1985. The **CONTENTS** page indicated that the Direction Finder (DF) coverage was based on an effective range of 400 km from each DF site. The map displayed on the cover was mistakenly prepared using a radius of 250 km rather than 400 km.

COVERS: Charts illustrating the median date of last *(Front)* and first *(Back)* snow cover in the western and northern region of Canada (source: Potter, J.G. 1965. Snow cover. Canada Department of Transport, Meteorological Branch, Toronto, Ont. Climatological Studies Number 3. 69 p.). Refer to the inside front cover for snow cover statistics on selected stations.

FOREWORD

The 1975 Federal Department of the Environment (DOE) Policy on Meteorological Services for Forest Fire Control sets out the responsibilities of the Atmospheric Environment Service (AES) and Canadian Forestry Service (CFS) in provision of fire weather forecasts, fire danger forecasts, and other weather-related services to the various fire control agencies. Briefly, this policy gives AES the responsibility of providing current and forecast fire weather and Fire Weather Indices in accordance with the needs of fire control agencies. The CFS role is that of research and development of improved indices, research on fire behavior relationships with weather factors, and cooperation with AES in preparation of training aids and manuals. Both AES and CFS share the responsibility of improving meteorological services for forest fire control in Canada. Van Wagner (1984)[1] recently re-emphasized these specific obligations.

In 1976, six regional committees[2] were formed to facilitate the implementation of the DOE Policy on Meteorological Services for Forest Fire Control. The "charter" for these regional fire weather committees is as follows:

Membership: 1 or more AES representatives designated by AES Regional Director; 1 or more CFS representatives designated by CFS Regional Director; and 1 or more fire management agency representatives designated by the Provincial or territorial chief(s) of forest fire management.

Terms of Reference: Each Regional Committee will make recommendations to the Regional Directors of DOE Services (i.e., AES and CFS) for the development and implementation of a program of Meteorologial Services for Forest Fire Control which is suited to the needs of the Region and is within the DOE Policy and Guidelines.

Guidelines: Regional Committees will be responsible for (a) identifying the needs of regional fire management agencies for meteorological services; (b) making recommendations of the services identified in sub-section (a); (c) monitoring the program and implementing changes, as required; (d) coordinating with the Development Committee; and (e) referring to the Development Committee those recommendations which the Regional Directors of DOE Services have been unable to implement.

The function of the Development Committee, referred to above, is to coordinate in consultation with the Regional Committees, the development of meteorological services for forest fire management through contacts, at the technical level, between research and development officers of AES and CFS, operations supervisors in the AES field establishments and technical representatives of fire management agencies.

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[1] Van Wagner, C.E. 1984. Forest fire research in the Canadian Forestry Service. Agriculture Canada, Canadian Forestry Service, Petawawa National Forestry Institute, Chalk River, Ont. Information Report PI-X-48. 45 p.

[2] These were aligned on the basis of the existing AES administrative boundaries: Pacific (British Columbia); Western (Yukon, Northwest Territories, and Alberta); Central (Saskatchewan, Manitoba, and northwestern Ontario); Ontario; Quebec; and Atlantic (Nova Scotia, New Brunswick, Newfoundland, and Prince Edward Island).

INTRODUCTION

The inaugural meeting of the Central Region Fire Weather Committee (CRFWC) was held at the Atmospheric Environment Service's (AES) Central Region office in Winnipeg, Manitoba, on January 26, 1976. CRFWC member agencies currently include the Saskatchewan Department of Parks and Renewable Resources, Manitoba Department of Natural Resources, Parks Canada - Prairie Region, AES - Central Region, and Canadian Forestry Service (CFS) - Western and Northern Region. In 1983, a "technical sub-committee" was formed; representatives of the Ontario Ministry of Natural Resources have begun to attend these meetings. The terms of reference prepared for the CRFWC Technical Sub-committee state that it ".... may (and is encouraged to) provide the opportunity for the presentation and discussion of scientific and technical papers on subjects relating to forest fire meteorology in the Region". The concept of a scientific and technical seminar series was originally initiated by the Western Region Fire Weather Committee in 1983[1] with subsequent gatherings in 1984[2] and 1986[3]. There have now been three seminars held in conjunction with the CRFWC Technical Sub-committee's annual spring business meeting; these have all taken place at the AES's Central Region office in Winnipeg. A list of the presentations from the first two seminars given on the inside back cover of this document. This report constitutes a summary of the four presentations which took place at the third seminar. An attendance list is appended. I sincerely hope that the CRFWC seminar series continues since it's felt that these sessions provide an excellent forum for the exchange of information, ideas, etc. on current and/or timely fire-weather related topics of direct interest to all CRFWC member agencies. The responsibility for coordinating the program has now been transferred to W.J. De Groot and K.G. Hirsch, Fire Research Officers with the CFS Saskatchewan and Manitoba District Offices in Prince Albert and Winnipeg, respectively. The partial financial support for the third seminar provided by the CFS Manitoba and Saskatchewan District Offices is gratefully acknowledged; special thanks to District Managers J.A. McQueen (Winnipeg) and J.J. Farrell (Prince Albert) in this regard. The continued assistance of D.A. Vandervyvere and C. Klaponski of AES with local arrangements is gratefully appreciated. Finally, I would like to thank S. Ratansi and J. Simunkovic for their fine efforts with the word processing associated with the production of this report.

Martin E. Alexander[4]
CRFWC Seminar Coordinator

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[1] Alexander, M.E. (compiler & editor). 1983. Proceedings of the first Western Region Fire Weather Committee scientific and technical seminar (Mar. 22, Edmonton, Alta.). Environment Canada, Canadian Forestry Service, Northern Forest Research Centre, Edmonton, Alta. Study NOR-5-191 File Report No. 5. 11 p.

[2] Alexander, M.E. (compiler & editor). 1985. Proceedings of the second Western Region Fire Weather Committee scientific and technical seminar (Mar. 6, 1984, Edmonton, Alta.). Agriculture Canada, Canadian Forestry Service, Northern Forest Research Centre, Edmonton, Alta. Study NOR-5-191 File Report No. 9. 29 p.

[3] Alexander, M.E. (compiler & editor). 1986. Proceedings of the third Western Region Fire Weather Committee scientific and technical seminar (Feb. 4, Edmonton, Alta.). Government of Canada, Canadian Forestry Service, Northern Forestry Centre, Edmonton, Alta. Study NOR-5-05 (NOR-5-191) File Report No. 15.

[4] Fire Research Officer, Northern Forestry Centre, Canadian Forestry Service, Western and Northern Region, 5320 - 122 Street, Edmonton, Alta., T6H 3S5.

A WEATHER NETWORK DESIGN FOR FOREST FIRE MANAGEMENT IN SASKATCHEWAN[1,2]

by

R.L. Raddatz[3]

ABSTRACT

A weather network which optimizes coverage, was designed for forest fire management in Saskatchewan. The forested area was divided into triangular sub-areas using Atmospheric Environment Service "mainline" stations as vertices. The provincial fire weather stations were then allocated to these triangles based on their relative areas, economic importance and on the relative spatial variability of daily rainfalls across each sub-area. Where possible the network was configured to monitor the gradients in the normal growing-season precipitation pattern. In general, with the existing number of fire weather stations, the optimum design apportions one site to each triangle.

INTRODUCTION

How many fire weather stations are required and how should they be distributed throughout a large forested area? These are primary considerations in the design of a fire weather station network for fire management. The answers to these questions depends on: (i) the spatial variability of the weather; (ii) the length of the sampling period; (iii) the accuracy that can be tolerated for estimates of weather parameters at ungauged points; and (iv) constraints which can't be overcome. The purpose of any observational network is to sample the weather so that the areal and temporal pictures can be determined. That is, to construct, from these discrete data-samples, continuous fields that accurately represent the actual fields, thereby, allowing estimates within acceptable limits to be made at ungauged points. In this application, the meteorological fields combine to yield an indicator(s) of the daily fire danger as expressed by the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1974; Canadian Forestry Service 1984; Van Wagner and Pickett 1985). The FWI System is highly sensitive to rainfall and wind speed (Turner and Lawson 1978). Furthermore, of the weather elements employed in the FWI calculations, daily precipitation is generally considered to vary the most from place to place (Williams 1963b). It follows that, a network dense enough to accurately represent the spatial variation in the rainfall field should suffice for the other parameters as well. Therefore, only the spatial variability of daily rainfall amounts during the growing season was considered in this study.

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[1] A presentation made at the Third Central Region Fire Weather Committee Scientific and Technical Seminar, April 3, 1986, Winnipeg, Manitoba.

[2] This paper represents a slightly condensed version of a report by the author (Raddatz 1985) on a study funded under the Canada/Saskatchewan Forest Resource Development Agreement for the Canadian Forestry Service and Saskatchewan Department of Parks and Renewable Resources (SDPRR).

[3] Scientific Services Meteorologist, Environment Canada, Atmospheric Environment Service, Central Region, 266 Graham Avenue, Room 1000, Winnipeg, Man. R3C 3V4.

Over the Canadian prairie provinces, growing season precipitation can be attributed to three types of atmospheric disturbances - synoptic cyclones, fronts/squall lines and unorganized convective showers/thundershowers (Longley 1972). These atmospheric perturbations have horizontal dimensions from 1 to 10^3 km (Holton 1972). The average spacing of the Atmospheric Environment Service (AES) "mainline" sites in and adjacent to the forested area of Saskatchewan (Richards and Fung 1969) whose observing programs are compatible with the input requirements of the FWI System, is about 160 km. Studies by Raddatz and Kern (1984), among others, have shown that this network density allows the spatial variation of daily rainfalls due to cyclones and organized frontal lines to be included in an estimated precipitation field. The mean station separation would have to be reduced by an order of magnitude for the network to resolve local or unorganized showers. For this reason, AES recommends (Anon. 1975) a station spacing of 25 km for rainfall measurements in rural areas without significant local climate controls. For a region as immense as the forested area of Saskatchewan, practical constraints impede the establishment of a fire weather station network based solely on the criteria for rainfall measurements. Major constraints which have an impact on the final network design include:

- present and planned networks, both internal and external to the one operated by the SDPRR
- budgetary limitations
- technical limitations
- infrastructure limitations (e.g., availability of service)

The question of network density is further complicated by studies (e.g., Beall 1950; Williams 1963a; King and Furman 1976; Furman 1984; Fujioka 1985) which have recommended station separations ranging from less than 25 to hundreds of kilometres for various fire danger indices depending on the region and the season. This study, therefore, left the network density decision to practical considerations. Instead, it asked how a given number of fire weather stations should be distributed across the forested area of Saskatchewan. The goal was to determine the spatial distribution which offers the most effective (i.e., optimum) coverage. The accuracy of precipitation estimates at ungauged points, derived from the AES data alone, was also quantified.

A detailed description of the methodology employed in this study is given in the next section. The third section of this paper describes the optimum fire weather network design for forest fire management in Saskatchewan assuming there is no change in the total number of stations. Finally, a summary of the results with recommendations is given. A method of determining the spatial distribution of sites which offers the optimum coverage for any number of fire weather stations is included.

METHODOLOGY

The approach was an adaptation of the procedures outlined by Fujioka and Fosberg (1981) for adding new weather observing sites to an area. The AES "mainline" sites in and adjacent to the forested area of Saskatchewan were treated as the existing or base network to which the fire weather stations were to be added. At present, there are 27 fire weather stations excluding the Cypress Hills region. However, the number of stations to be added to the base AES network does not have to be specified in advance. The results are equally applicable to any number of new sites.

A two-phase procedure was used to add fire weather stations to the existing AES network. The allocation phase apportioned new stations in light of the effectiveness of coverage of the existing network. Effectiveness was assessed in terms of the existing areal coverage, the spatial variability of daily precipitation and the economic values-at-risk. The configuration phase, where possible, sited the stations to monitor the normal gradients in the average growing season precipitation pattern.

Allocation Phase

The forested area of Saskatchewan was divided into triangular sub-areas using AES "mainline" stations as the vertices. The resultant triangles, numbered 1 through 24, are illustrated in Figure 1.

Areal Coverage

The area of each triangle, k = 1, ..., 24 was calculated as follows:

$$[1] \quad A_k = 0.5 \; | \vec{PQ} \times \vec{PR} |$$

where, $\vec{PQ} = Gm_{21} \{ (x_2 - x_1) \vec{i} + (y_2 - y_1) \vec{j} \}$, $\vec{PR} = Gm_{31} \{ (x_3 - x_1) \vec{i} + (y_3 - y_1) \vec{j} \}$, and (x_i, y_j), $i = j = 1,2,3$ are the coordinates of each triangle in the standard meteorological grid for the Northern Hemisphere, G is the grid-length which equals 381 km, and m is the map scale factor for the polar stereographic projection employed in this study (i.e., 1.866/[1 + SIN (LAT)].

The area of each triangle, compared to the total area, is a relative measure of the coverage by each of the station triplets. It follows that, if Q stations are to be added to the AES network, based solely on areal coverage, they should be allocated in the following proportions:

$$[2] \quad a_k = \frac{A_k}{\sum_{k=1}^{24} A_k}$$

The area of each triangle A_k (km^2) and its percentage of the total area a_k(%) are listed in Table 1.

Spatial Variability of Daily Rainfall Amounts

Let $f_{t,r}$ be a set of discrete observations of daily rainfall amounts measured without error at sites, r = 1, ..., n. For each triangle (n = 3), the spatial mean and variance of this meteorological element are given by the following equations:

$$[3] \quad \bar{f}_{t.} = \frac{1}{n} \sum_{r=1}^{n} f_{t,r}$$

$$[4] \quad S^2{}_{t.} = \frac{1}{n-1} \sum_{r=1}^{n} (f_{t,r} - \bar{f}_{t.})^2$$

Calculating $S^2{}_{t.}$ for several times t = 1, ..., N yields a sample of spatial variance values for each triangle. The comparison of these spatial variances is facilitated by a conversion to coefficients of variation as follows:

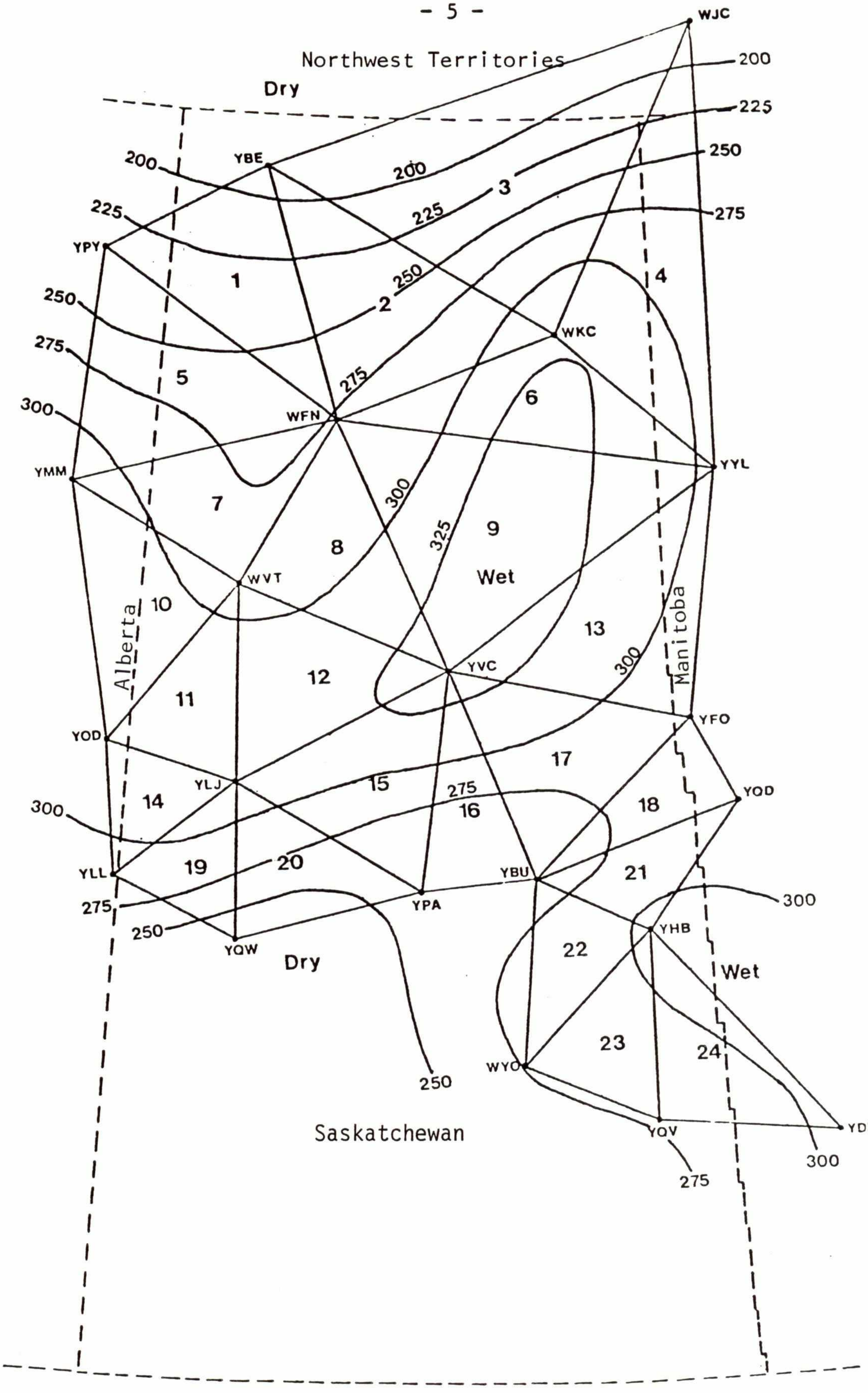


Figure 1. The forested area of Saskatchewan divided into triangular sub-areas (numbered from 1 to 24) using the network of Atmospheric Environment Service "mainline" stations (e.g., YPA = Prince Albert) as the vertices. The normal (1951-80 mean) growing-season (May - September) precipitation field (in mm) has been superimposed on the triangular sub-areas.

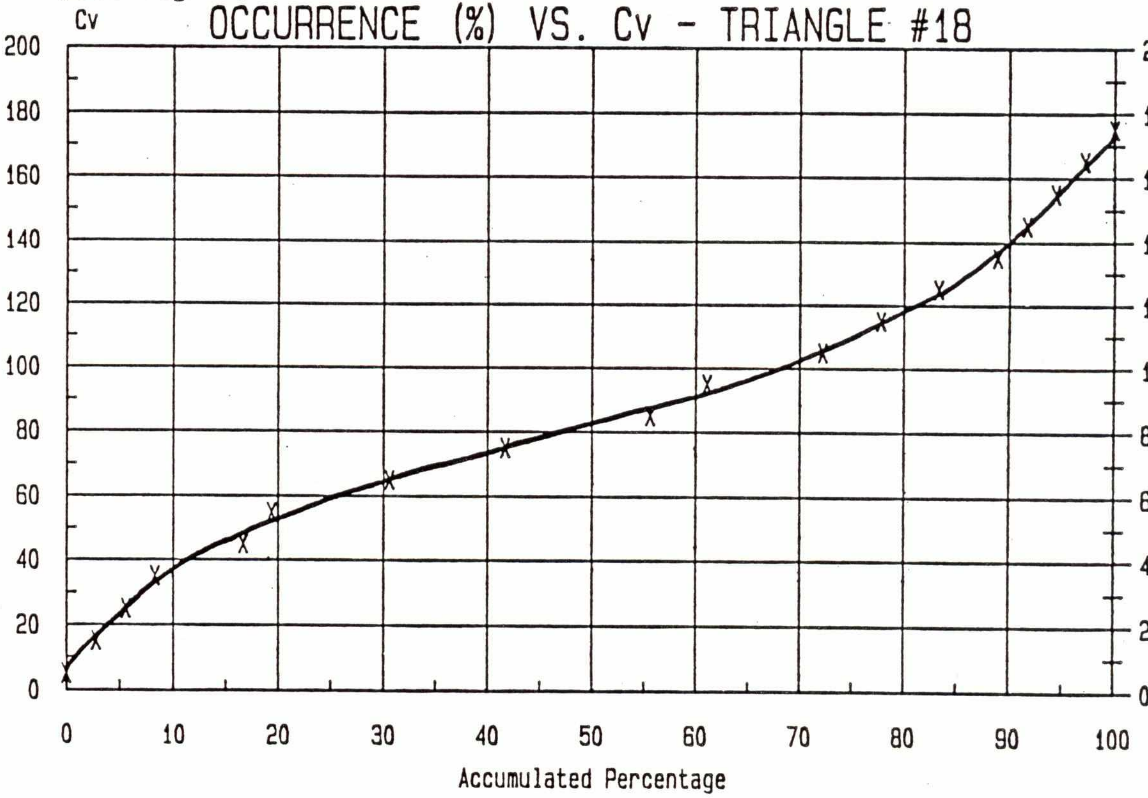
Table 1. Calculated parameters for each of the triangular sub-areas (see Fig. 1) delineated for the purposes of the present study: Area (A_k); Percent of Total Area (a_k); Coefficients of Variation at the 75% Level (Cv_k); Percentage of the Sum of the Coefficients of Variation (c_k); Annual Values-at-Risk (V_k); and Percentage of Total Value (v_k).

TRIANGLES						
Number[1]	$A_k(km^2)$	a_k(%)	Cv_k (%)*	c_k (%)	V_k ($)	v_k (%)
1	22,698.9	4.29	160	5.57		0.08
2	29,584.3	5.59	120	4.18		0.06
3	58,506.5	11.00	165	5.75	C	0.65
4	38,069.5	7.19	155	5.40		0.02
5	29,857.4	5.64	130	4.53	O	1.08
6	22,750.5	4.30	125	4.36		0.13
7	19,031.6	3.59	110	3.83	N	7.46
8	21,587.5	4.08	110	3.83		5.99
9	45,571.8	8.61	110	3.83	F	3.03
10	20,340.4	3.84	110	3.83		6.62
11	12,212.2	2.31	95	3.31	I	8.43
12	21,526.4	4.06	115	4.01		8.82
13	31,501.1	5.95	95	3.31	D	6.94
14	7,715.8	1.46	95	3.31		1.88
15	23,966.3	4.53	120	4.18	E	9.69
16	13,392.8	2.53	130	4.53		8.39
17	23,782.1	4.49	90	3.14	N	10.59
18	10,088.4	1.91	110	3.83		4.99
19	9,900.0	1.87	110	3.83	T	1.51
20	15,419.6	2.91	130	4.53		3.60
21	10,118.9	1.91	110	3.83	I	4.49
22	11,297.8	2.13	115	4.01		2.83
23	12,719.3	2.40	110	3.83	A	1.14
24	17,926.0	3.39	150	5.23		1.39
	529,564.9	100.00	2,870	100.00	L	

[1] Refer to Figure 1.

[2] Given to the nearest 5%.

Figure 2. An example of the coefficients of variation (Cv) vs. cumulative frequency (%) charts for daily rainfall amounts derived for each triangular sub-area (see Fig. 1).



[5] $C_{vt} = (S_{t.}/\bar{f}_{t.}) \times 100$

Coefficients of variation for each triangle were calculated for a sample of 36 growing-season days with rain across part or all of the forested area of Saskatchewan. A C_{vt} value was not calculated for a triangle if precipitation wasn't recorded at any of the vertices. The percentage of stations which received a trace or more of precipitation on each rain-day ranged from 59-100%. This suggests that on the sample days the rain could be attributed to synoptic cyclones and/or fronts/squall lines (Fluto and Nova 1977). Rain-days with unorganized local showers were not included in the sample. Therefore, the coefficients of variation only apply to days with organized precipitation over all or part of the forested area of Saskatchewan. The cumulative frequency distributions of the C_{vt} values for each of the k = 1, ..., 24 triangles, give an indication of the confidence with which coefficients of variation, not exceeding specified magnitudes, can be expected at other times (Panchang and Narayanan 1962). A single example of the 24 triangle ogives presented in Raddatz (1985) is given in Figure 2. The 75 percent confidence values, labelled C_{vk}, are given in Table 1. The 75% values were abstracted because at higher confidence levels there was very little difference between the coefficients of variation for the various triangles.

The C_{vk} values are a quantitative measure of area average-to-point representativeness. The probability (Pr) that the average of the precipitation amounts recorded at the vertices of each triangular sub-area represents the rainfall at an ungauged point within that triangle can then be specified as follows (from Nappo 1983):

[6] $P_{rk} \{ | f_{t,r} - \bar{f}_{t.} | / \bar{f}_{t.} \leq C_{vk} \} = \delta$

where δ = 68% if the residuals, $| f_{t,r} - \bar{f}_{t.} |$, are assumed to be normally distributed. This is not an unreasonable assumption. The division of the forested area into triangular sub-regions resulted, in most cases, in climatologically and physiographically uniform areas where local systematic effects, such as topography are expected to be small. Thus, fire managers can be 75% confident that on 68% of the days with organized precipitation over all or part of the forested area of Saskatchewan, the rainfall at ungauged points will be within C_{vk} (%) of the average obtained from the three surrounding AES sites. For the 24 triangles, these coefficients of variation were relatively large, ranging from 90% for triangle #17 to 165% for triangle #3.

The C_{vk} value for each triangle, compared to the sum of the coefficients for the entire area, is a relative measure of the variablity of daily rainfall amounts across that sub-area compared to the other sub-areas. Alternatively, it is an indicator of how accurately daily precipitation amounts can be estimated for ungauged points within that triangle. Obviously, the addition of stations to the base network will reduce these estimation errors. Therefore, a second measure of how Q stations should be apportioned is determined as follows:

[7] $$c_k = \frac{C_{vk}}{\sum_{k=1}^{24} C_{vk}}$$

The ck (%) values for each triangle are given in Table 1.

Values-at-Risk/Economic Importance

The annual worth of the forest at risk from wildfire plus wildlife values, existing man-made structures, etc. which could also be threatened varies from one triangular sub-area to the next. The SDPRR assigned a dollar value V_k to each triangle for the purposes of this study. These values are not listed here as they are considered confidential. A triangle's V_k compared to the total value at risk, is a relative measure of the economic importance of that sub-area. Therefore, a third measure of how Q stations should be apportioned is determined as follows:

$$[8] \quad v_k = \frac{V_k}{\sum_{k=1}^{24} V_k}$$

The v_k (%) values are listed in Table 1.

Optimum Allocation Formula

A weighted average of the three allocation formulae [2], [7] and [8] gives the optimum apportionment of the stations to be added to the base network. The optimum allocation formula and the weighting employed were as follows:

$$[9] \quad qk = \frac{w_a \, a_k + w_c \, c_k + w_v \, v_k}{w_a + w_c + w_v}$$

with $w_a = 1$, $w_c = 5$ and $w_v = 4$. The relatively high weighting of the c_k and v_k values recognizes the significance of weather to the assessment of fire danger and acknowledges that a fire's importance can be rated in economic terms. The low weighting of the a_k values minimized the impact of a triangle's relative area. Nevertheless, the weighting was somewhat arbitrary. However, because of the relatively low between-triangle variation in the allocation measures, the final results were somewhat insensitive to the choice of weighting values. The recommended apportionment of the fire weather stations (i.e., the qk (%) values) are listed in Table 2 along with the existing apportionment for comparative purposes.

Assuming that the existing 27 fire weather stations in the provincially operated network are to be re-allocated and no additional sites are to be established, the optimum number of stations for each triangle has been calculated. These values are given in Table 2 along with the existing number of stations per triangle. It can be seen that some adjustments to the present network are required in order to achieve optimum allocation. The recommended configuration has one fire weather station in each of the 24 triangles except for two in triangles 12, 15, 16 and 17 and none in triangle 14. It is worth re-stating that the calculation of the optimum number of stations per triangle can be done for any number of sites. The optimum apportionment values qk (%) would remain unchanged and can be re-applied if and when additional stations are added to the network.

Table 2. Existing and optimum fire weather station apportionment in Saskatchewan. The number of stations per triangle assumes a total of 27 existing stations.

TRIANGLES				
	Existing Stations per Triangle		Optimum Stations per Triangle	
Number[1]	%	#	%	#
1	00	0	3.25	1
2	00	0	2.67	1
3	3.70	1	4.24	1
4	00	0	3.43	1
5	00	0	3.26	1
6	00	0	2.66	1
7	3.70	1	5.27	1
8	3.70	1	4.73	1
9	7.41	2	4.00	1
10	3.70	1	4.96	1
11	3.70	1	5.26	1
12	11.11	3	5.94	2
13	3.70	1	5.03	1
14	3.70	1	2.55	0
15	14.81	4	6.42	2
16	3.70	1	5.87	2
17	11.11	3	6.26	2
18	7.41	2	4.11	1
19	3.70	1	2.72	1
20	3.70	1	4.00	1
21	00	0	3.91	1
22	3.70	1	3.35	1
23	3.70	1	2.62	1
24	3.70	1	3.51	1
	100.00	27	100.00	27

[1] Refer to Figure 1.

Table 3. Adjustments to the current Saskatchewan fire weather station network in order to achieve the optimum network design.

Triangle Number[1]	No. of Stations to be added (+) or deleted (-)	General Siting within the Triangle
1	+1	NE portion
2	+1	Central
3	0	Stoney Rapids - general siting is OK
4	+1	E - Central (along boundary with #3)
5	+1	Central
6	+1	S - Central
7	0	La Loche - general siting is OK
8	0	Besnard Lake - relocate to Central portion of the triangle
9	-1	Missinipe - relocate to another triangle
10	0	Buffalo Hill - general siting is OK, however, could be a little further south
11	0	Meadow Lake Provincial Park - general siting is OK, however, could be a little further to the northwest
12	-1	Ile-a-la-Crosse - relocate to a different triangle
13	0	Pelican Narrows - general siting is OK
14	0	Loon Lake - nice to have but could be relocated to a different triangle
15	-2	Weyakwia Lake, Waskesiu Lake, Boundary and Big River - relocate two of these sites to different triangles
16	0	Needs two sites and only has one, but Little Bear (triangle #17, near boundary with 16), in effect, provides the second site
17	-1	Creighton - relocate to different triangle (assumes that AES, Flin Flon is used)
18	-1	Sqaw Rapids - relocate to a different triangle
19	0	Divide - relocate in Central portion of triangle
20	0	Chitek - relocate in Central portion of triangle
21	+1	S-Central portion
22	0	Greenwater (Porcupine Plain) - general siting OK
23	0	Usherville - general siting OK
24	0	Madge Lake (Duck Mountain) - general siting OK

[1] Refer to Figure 1.

Configuration Phase

This phase of the study was aimed at the general sitting of the stations apportioned to each triangle. An analysis of the long-term mean values of a meteorological variable reveals the locations of recurrent gradients - the result of persistent factors such as topography, storm tracks and scales. It follows that, in this application, stations should be sited so that the sampling interval is commensurate with the spatial rate of change of the normal (1951-1980 mean) growing-season (May to September) precipitation field. Figure 1 shows this 30-year normal rainfall pattern superimposed on the triangles. This study, for practical reasons, was aimed at achieving optimum rather than complete coverage and, in general, only one fire weather station was apportioned to each triangle. The siting of this station was, therefore, chosen in order to monitor the recurrent precipitation gradients, to the extent possible, in conjunction with the AES stations. Furthermore, since the analysis of the rainfall field is somewhat inexact, only the section of the triangle to which a station should be assigned and not its specific location could be specified in arriving at the optimum network design.

NETWORK DESIGN

The optimum network design was arrived at by apportioning the current provincially operated fire weather stations to the triangular sub-areas formed by the AES network. Allocations were based on a triangle's relative area, the relative values-at-risk and the relative spatial variability of daily precipitation across the sub-area. Where possible the stations were configured to monitor recurrent gradients in the long-term precipitation pattern. Table 3 lists the adjustments to the fire weather station network which are required to achieve the most effective coverage with the current number (i.e., 27) of stations. Obviously, this level of design does not zero in on specific locations for each fire weather station. Specific siting is left to the next level of design which must consider site accessibility, the availability of services and how well the site typifies the general area. Sites whose weather is unduly influenced by local effects such as lakes and topography should be avoided.

SUMMARY OF RESULTS WITH RECOMMENDATIONS

The results and recommendations arising from this study are listed below in point form:

1. The analysis of representativeness suggested that fire managers can be 75% confident that on 68% of the days with organized precipitation over all or part of the forested area of Saskatchewan, the rainfall at ungauged points will be within 90-165% of the average obtained from the three surrounding AES sites.

2. The optimum allocation values qk (Table 2) can be used to apportion any number of sites among the 24 triangles (Fig. 1) and the stations should be configured across the various triangles to monitor the gradients in the normal growing-season precipitation field. Table 3 lists adjustments to the network which are required to achieve optimum coverage if only the current number (i.e., 27) of fire weather stations are utilized.

3. If the total number of station changes to Q', the optimum number of sites per triangle n_k can be re-calculated using the following formula:

   [10] $n_k = (qk\ (\%) / 100) \times Q'$

   The stations would then have to be re-configured and specific sites would have to be determined for each new station.

4. An auxiliary recommendation arising from this study is that objective analysis techniques should be used to construct continuous meteorological fields from the set of discrete observations provided by the AES synoptic and provincial fire weather station networks. This approach would facilitate the estimation of fire weather parameters and fire danger indices at ungauged points. However, it may require a minor change in the mindset of forest fire managers. Rather than viewing a single station's FWI System values as being representative of the immediate region (e.g., a given radius from the station), a continuous FWI System component field could be constructed and used to estimate the fire danger at locations where the information is desired but where the required weather data is not measured[4].

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[4] Editor's note: An example is given in ANNEX I on p. 13. In this particular case, the map was produced by subjective (hand) analysis rather than by objective (computer) analysis.

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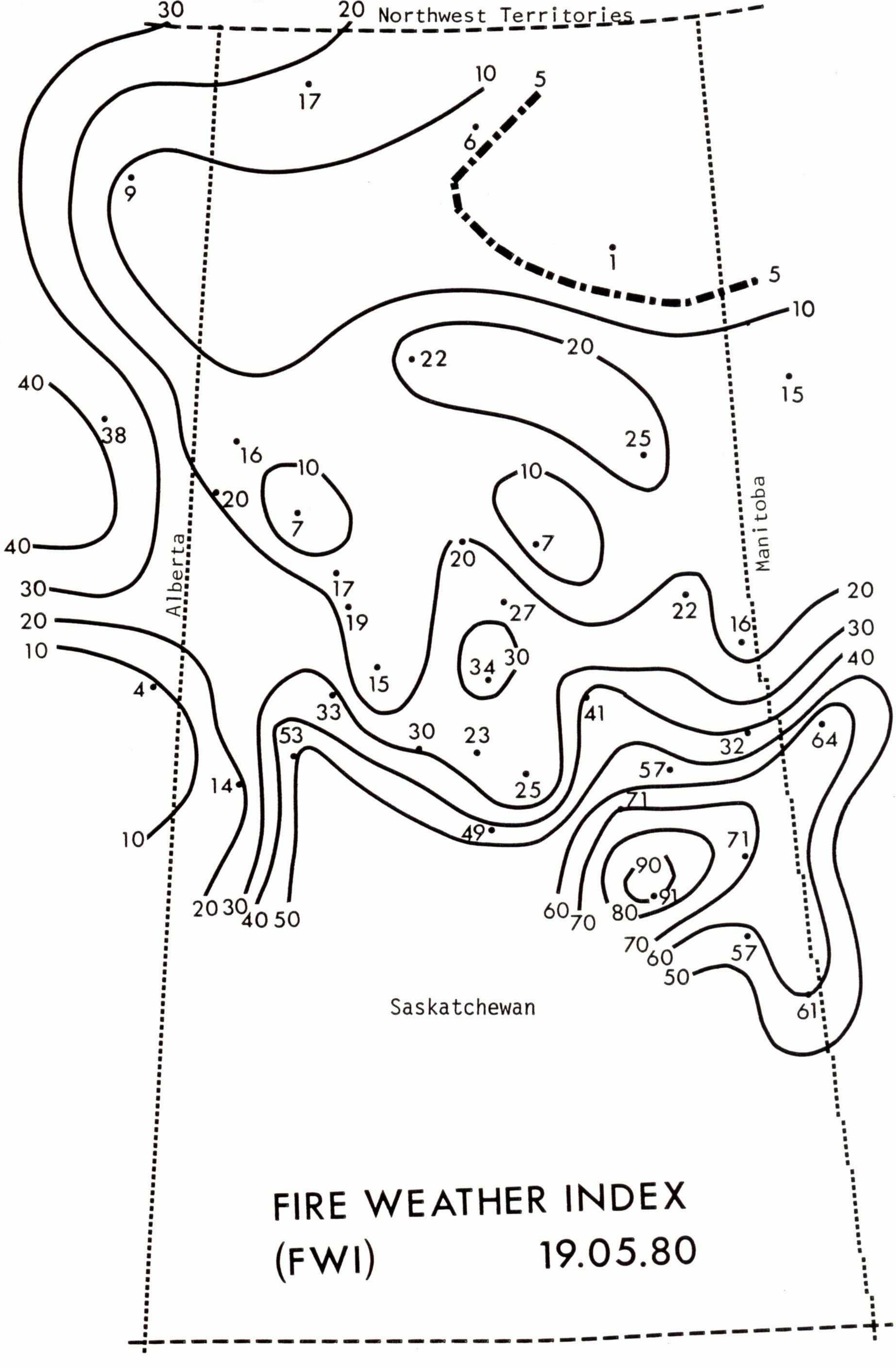
ANNEX I

Example of a map showing Fire Weather Index (FWI) isopleths (i.e., lines of equal value) and actual plotted station values for a single day.



FOREST FIRE MONITORING USING THE NOAA SATELLITE SERIES[1]

by

Michael D. Flannigan[2]

INTRODUCTION

Forest fires are a major concern in Canada where, in a single year, up to 5.3 million ha may be burned over, and control costs may exceed 135 MM dollars (Ramsey and Higgins 1986). Early detection of forest fires is imperative if control is to succeed. Manned towers and aircraft reconnaissance could be used for fire detection over vast areas of Canada's forest but would be inordinately expensive if conducted at the density and frequency for optimum fire control. This is particularly true over areas of low fire control priority where observations by conventional means are usually infrequent. The first meteorological satellite was launched in 1959. It confirmed the usefulness of viewing the weather from above. From that time meteorologists have used satellite data extensively. A quarter of a century later there are five space agencies operating meteorological satellites. Some are polar orbiting, the others geostationary. Both types transmit valuable information but the data produced by geostationary satellites is available at more frequent intervals. Observations from a National Oceanic and Atmospheric Administration (NOAA) satellite series using the Advanced Very High Resolution Radiometer (AVHRR) can be used to examine extensive land areas two to four times each day depending on the number of NOAA satellites in operation. In this paper the potential contribution of the NOAA satellite series to fire identification and size estimation is discussed. A more complete account is given elsewhere (Flannigan 1985). Two summaries have also been published (Flannigan and Vonder Haar 1986a, 1986b).

BACKGROUND INFORMATION

Satellite monitoring of forest fires has been possible for nearly two and a half decades (e.g., Singer 1962; Jayaweera and Ahlnas 1974; Stocks 1975; Ernst 1977; Bullas 1981). Every day the earth is observed by a growing number of satellites, but only a small percentage of these observations are appropriate for monitoring forest fires. For example, LANDSAT 5, with a resolution of 30 m, would be ideal for forest fire monitoring were it not for the 16 day gap between passes over the same area. However, ERTS and LANDSAT imagery have been used to calculate area burned by wildfires in Alaska after it was extinguished (e.g., Anon. 1975; Hall et al. 1979). The Geostationary Operational Environmental Satellite (GOES) which is excellent in terms of frequency of observations (i.e., every 30 minutes) has three major drawbacks. First, the resolution in the infrared channel is only 7 km at nadir, making it impossible to detect small fires. Second, GOES has only one infrared channel, thereby eliminating the possibility of a multispectral approach[3]. Finally,

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[1] A presentation made at the Third Central Region Fire Weather Committee Scientific and Technical Seminar, April 3, 1986, Winnipeg, Man.

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[3] Future GOES-I,J,K satellites will have multispectral capabilities as does the present VAS experiment on GOES.

GOES is of limited value north of latitude 60°N due to loss of resolution caused by the curvature of the earth (Clark 1983). However, it has been possible to detect fires indirectly by using the higher resolution (0.9 km at nadir) GOES visible channel to spot smoke plumes from larger fires. The best observational system for forest fire monitoring is that carried out by the NOAA satellites. It allows multispectral sampling (2-3 infrared channels), enabling identification of small fires and monitors the same area two to four times a day.

DATA SOURCES

Satellite Imagery

The NOAA satellites were designed to operate in a near polar, sun synchronous orbit at a nominal altitude of 833 km such that the local solar time of the satellite's passage remains essentially unchanged for any latitude. The orbital period is 104 minutes, which results in 14.2 orbits per day. The NOAA satellite series has a payload of six instruments with the AVHRR. The AVHRR, on board NOAA satellites since 1979, is a cross-track spin-scan radiometer with a scan rate of 360 rotations a minute. It records data within an angle of ± 55.4° from nadir, equivalent to a swath width of 2,600 km. Data are digitized onboard the spacecraft at a rate of 2,048 samples per scan per channel. The AVHRR provides one visible channel, one near-infrared channel and two or three infrared channels.

The instantaneous field of view of each channel is approximately 1.4 milliradians, representing a picture element (pixel) having a diameter of about 1.16 km at nadir for a nominal altitude of 833 km. The constant IFOV causes pixels along a scan line to become larger with respect to ground as distance increases from nadir. Also, the pixel's shape changes from nearly circular at nadir to highly elliptical at the extremities of the view angle. A complete description of the NOAA satellite series and the AVHRR can be found in Schwalb (1978, 1982) and Kidwell (1984).

NOAA-7 AVHRR data were obtained from the Atmospheric Environment Service ground station in Edmonton, Alberta. Data from day and nights passes were used during the period June 12 to June 21, 1982.

Forest Fire Information

The satellite and forest fire data for the period June 12 to June 21, 1982 were chosen to take advantage of a rapidly changing wildfire situation in the Slave Lake Forest region of central Alberta. On June 12 only a few small fires were still burning in Alberta's Slave Lake Forest. By June 21 there were over 30 fires burning out of control, with some exceeding 20 000 ha in size.

The Slave Lake Forest region of central Alberta extends from latitude 54.5°N to 57.5°N and from longitude 113°W to 117°W. The forest cover in this area consists of typical boreal species: trembling aspen, balsam poplar, lodgepole pine, jack pine, white spruce, and black spruce.

The forest fire data for this region were supplied by the Alberta Forest Service's (AFS) Forest Protection Branch. The data, in the form of daily situation reports (SITREPS), list by AFS administrative 'Forest', the name, location, size, and status of the fire, and the resources in terms of men and equipment committed to control the fire. Almost all fires studied were ignited by lightning and only a few were man-caused. The location and size of each fire was determined usually by late afternoon or early evening (1600-2000 MDT h) using aerial reconnaissance (i.e., visible mapping and/or aerial photography).

SATELLITE OBSERVATIONS OF FIRE

Dozier (1981) developed a technique using AVHRR Channels 3 and 4, to find the temperature of a heat source and the percentage of the pixel covered by a hot target. Matson and Dozier (1981) used this multispectral approach to identify steel mills in the midwestern United States and gas flares from oil fields in the Middle East. The U.S. National Weather Service has used the infrared channels from the NOAA satellites since 1981 for forest fire surveillance in the Western United States (Matson et al. 1984).

PROCEDURE

To calculate fire size and temperature within a pixel as viewed by the satellite, Dozier's (1981) multispectral approach was utilized. With this approach the percentage of the pixel covered by fire and the temperature of the fire was calculated.

The identification of forest fire activity was accomplished for each pixel through a temperature differentiation technique. The effective infrared temperature of each cloud-free pixel was calculated for both Channels 3 and 4. If the calculated temperature exceeded the mean background temperature of the forest and if the Channel 3 temperature was greater than that of Channel 4 by a critical value, fire was assumed to be present. Selected threshold values for the temperature differences were 8°K for night passes, and 10°K for day passes. Plots of Channel 3 and 4 temperatures along Line 131 of NOAA-7 pass 5102 are shown in Figure 1 and the corresponding images are shown in figures 2 and 3 respectively. The presence of a forest fire near pixel 325 is clearly indicated by the large difference in the response of the two channels. Contiguous pixels indicating fire presence were grouped together as one fire. The fire area in any given pixel was calculated by the described multispectral technique except for areas in which a "fire pixel" was surrounded by other "fire pixels". In such a case, it was assumed that the pixel represented an area which was totally burned (Flannigan 1985).

The "contamination" of daytime Channel 3 data by reflected solar radiation constitutes a potential source of error which led, traditionally, to elimination of the use of the channel during daylight hours (Deschamps and Phulpin 1980; Llewelyn-Jones et al. 1984). Although less than 1% of solar radiation is received in the 3.5-4.0 μm, region, this amount intercepted by a surface is of the same order of magnitude as the radiation emitted by the surface (Hillger 1983, Llewelyn-Jones et al. 1984). Pixels which contain some cloud are assumed to be contaminated by the reflection of solar radiation at 3.5 - 4.0 μm (Kondrat'ev 1973). These pixels were identified by the cloud discrimination technique of Coakley and Bretherton (1982) and discarded.

In cloud-free areas, the albedo of the forest in the 3.5 - 4.0 μm region was required to determine if the data were contaminated. Although little information is available on the albedo of the forest in this wavelength region, Lee (1978) was able to show the reflectivity, absorption, and transmissivity of a typical hardwood leaf based on data from Gates (1965). For the wavelength range 3.5 - 4.0 μm there is total absorption and no reflection. Further evidence is provided by Wong and Blevin (1967) who studied reflectances of plant leaves and found that, for wavelengths greater than 3.0 μm, reflectances are less than 0.05 for the majority of leaves. It is concluded that the amount of solar radiation reflected by the forest in the Channel 3 wavelength region is insignificant and therefore, Channel 3 data can be used during daylight hours.

Three class sizes were chosen for verification of the fire identification technique: Class 1 - < 4 ha; Class 2 - 4-40 ha; and Class 3 - > 40 ha, but due to the small sample sizes in Classes 1 and 2, verification of fire size estimates were in only two categories, less than or greater than 40 ha. Actual fire sizes ranged from 0.5 to over 20 000 ha. Day and night passes were analyzed separately.

RESULTS

Examples of processed Channel 3 and 4 imagery for the same 360 000 km^2 (600 x 600 km) region are shown in Figures 2 and 3. The enhancement scale is such that black represents warm temperatures and white represents cool temperatures. An example of "solar contamination" is evident in Figure 2 where the clouds located near the center of the image appear warm (i.e., black) due to reflected solar radiation. The same clouds appear cool (i.e., white) on Figure 3 as one would expect, because there is no significant solar radiation at the longer wavelengths. North of the cloud field one of many forest fires has been identified in Figure 2. Not all the black areas in Figure 2 are forest fires. Some are agricultural areas such as the Peace River district on the left side of the image and some are burns from previous years such as the large black area on the upper right of the image.

There was a potential total of 355 fire observations during satellite passes in this study according to information provided by the AFS and was taken as the "ground truth". Of these many were repeat observations of the same fire during several satellite passes. Table 1 shows that only 41% of the total potential fire observations were unobscured by cloud or smoke (visible to the satellite). The remainder were obscured by smoke and cloud. The fraction of potential day and night observations was about the same. Fifty one percent of the largest fires were observable versus only 34% for Class 2 and 18% for Class 1.

Only 33% of the total potential fire observations were actually identified by satellite (Table 2). For the smaller fires the percentage was 12-14% increasing to 46% for the larger fires. A greater percentage of fire observations were identified during the day (37%) as compared to the night (29%). The better performance of fire identification during the day (afternoon passes) can be accounted for by the generally more vigorous burning due to lower relative humidities, higher temperatures and stronger winds during the day.

Table 1. Fraction of total potential and unobstructed fire observations detected by the NOAA satellite.

Sample Period	Fire Size Class			
	< 4 ha	4-40 ha	> 40 ha	Total
Total Visible Observations[1]				
Day	7/36 (19%)	9/30 (30%)	62/117 (53%)	78/183 (43%)
Night	5/32 (16%)	15/41 (37%)	49/99 (49%)	69/172 (40%)
Total	12/68 (18%)	24/71 (34%)	111/216 (51%)	147/355 (41%)
Total Identified Observations[2]				
Day	4/36 (11%)	5/30 (17%)	59/117 (50%)	68/183 (37%)
Night	4/32 (13%)	5/41 (12%)	41/199 (41%)	50/172 (29%)
Total	8/68 (12%)	10/71 (14%)	100/216 (46%)	188/355 (33%0
Unobstructed Observations Identified[3]				
Day	4/7 (57%)	5/9 (56%)	59/62 (95%)	68/78 (87%)
Night	4/5 (80%)	5/15 (33%)	41/49 (84%)	50/69 (73%)
Total	8/12 (75%)	10/24 (42%)	100/111 (90%)	118/147 (80%)

[1] $$\text{nn/NNN} = \frac{\text{number of fire observations visible to the satellite}}{\text{total fire observations}}$$

[2] $$\text{nn/NNN} = \frac{\text{number of fire observations visible by satellite}}{\text{total fire observations}}$$

[3] $$\text{nn/NNN} = \frac{\text{number of fire observations identified by satellite}}{\text{number of fire observations visible to the satellite}}$$

Table 2. Statistics associated with the fire size determination.

Type of Grouping	Mean (ha)	Bias (ha)
Day	2875	-1034
Night	1843	-1160
Small Fire (≤400 ha)	186	+135
Large Fire (≥400 ha)	4336	-2059
Total	2467	-1084

The fraction of unobstructed fire observations identified by satellite is shown in Table 3. Of the fire observations without cloud and smoke cover 80% were identified. Once again the larger fires had a higher percentage identified (90%) as compared to the smaller fires (42-75%). A greater percentage of fire observations were identified during the day (87%) than during the night (73%).

The mean fire size as calculated from satellite monitoring is given in Table 4. The bias referred to in Table 4 is the difference between the area observed by the AFS and the satellite estimate. The estimated fire size was about 70% too large for small fires and about 50% too small for large fires. The statistics on fire size were significantly affected by a few large outliers, where there were significant errors in estimated size.

FUTURE RESEARCH NEEDS

Man-machine interaction combined with "masks" for agricultural, urban and previously burned areas, would permit the monitoring of cloud and smoke areas for more subtle clues than can be handled automatically. The fire monitoring technique should be tested at the ground station closest to the trial region where many components needed by the monitoring technique, such as programs for instrument calibration and temperature and radiance calculations are already in place. Transmission of fire size and location as well as the actual images could be sent from the ground station to the appropriate fire control agency in almost real time. A second approach would be to have the image data transmitted directly to the user for processing. To obtain a valid test, the operational trial should monitor forest fires in forested regions with a high fire potential (i.e., occurrence and behavior). Information from the satellite images could help in fire control by identifying where a fire is most active. For example, hot spots where the fires are burning most vigorously can be identified near the center of Figure 4.

IMPLICATIONS FOR FIRE MANAGEMENT

Fire monitoring using the NOAA satellite series is not intended to be a substitute or replacement for existing fire detection or surveillance systems. Information gained from the fire monitoring technique described herein could be used to compliment existing information available to fire control agencies. During this study, in the absence of cloud and smoke cover, 80% of fire observations reported by the Alberta Forest Service were identified by satellite. The mean estimated fire size was within 50% of the reported mean fire size for large fires. This additional information could be of significant value in the protection of life, property, timber resources, etc.

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WILDFIRE BEHAVIOR ON THE CANADIAN SHIELD:
A CASE STUDY OF THE 1980 CHACHUKEW FIRE, EAST-CENTRAL SASKATCHEWAN[1]

by

William J. De Groot[2] and Martin E. Alexander[3]

INTRODUCTION

Saskatchewan averages about 430 wildfires a year which burn over an area of about 274 000 ha according to provincial records for 1960-85. Many fires occur in the Precambrian Shield region of the province. A small number of these fires have exhibited extreme fire behavior and subsequently developed into 'Class E' (i.e., >200 ha.) or campaign fires. In response to a concern expressed by local fire managers about certain so-called "unique" aspects of rating fire danger in the Shield country, a case study of wildfire behavior was recently completed by the first author, with particular emphasis on the associated climatic and meteorological conditions, and the applicability of the Canadian Forest Fire Danger Rating System (CFFDRS) (Alexander 1982a, 1985b, 1986a). This paper documents the results of the analyses.

The 1980 Chachukew Fire occurred in the east-central region of the province, 6 km north of the town of Pelican Narrows (Fig. 1). This fire was selected for analysis because documentation was readily available from a review, completed shortly after the fire was declared out, by W. E. Dodds at the request of the Saskatchewan Department of Parks and Renewable Resources (SDPRR). The format of the case analysis is similar to that of Alexander et al. (1983).

FIRE CHRONOLOGY

The Chachukew Fire (#116) was first detected on July 8 at 1900 h Central Standard Time (CST) by a commercial aircraft and reported to the SDPRR Resource Office at Pelican Narrows as being 0.1 ha in size. This lightning fire was suspected to have started within the 12 hours prior to detection. Two Grumman S2F Trackers dispatched from La Ronge (150 km west of the fire area) dropped long-term fire retardant at the head of the fire (four sets of paired drops) within an hour of detection, and it was held to approximately 0.2 ha. By 0900 h CST the next morning, the initial attack crew had secured the perimeter of the fire with hand tools and the center of the fire appeared to be gradually

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[1] A presentation made by the first author at the Third Central Region Fire Weather Committee Scientific and Technical Seminar, April 3, 1986, Winnipeg, Man.

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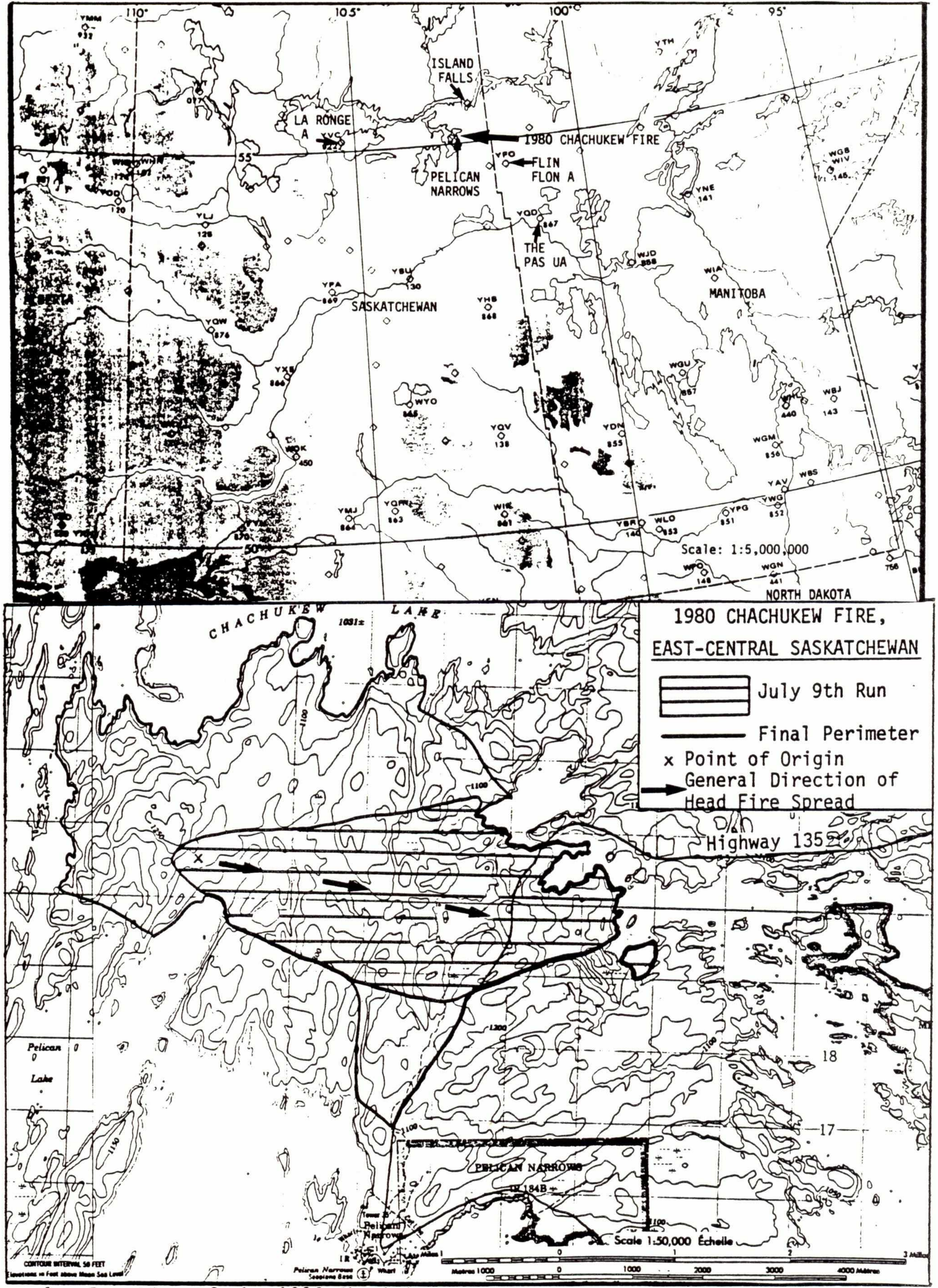

Figure 1. Location of the 1980 Chachukew Fire in east-central Saskatchewan and weather stations utilized in the case study analysis (*top*). The approximate boundary of the major run on July 9 and final perimeter are portrayed on a reduced National Topographic System 1:50 000 scale map of the fire area (*bottom*).

burning itself out. However, at 1100 h CST, the central area of the fire began producing increasing amounts of smoke. Due to a multiple-fire start situation in the province at that time, the airtankers were committed to initial attack action on other unmanned fires. Soon afterwards, torching was experienced at the fire's center. At 1400 h CST the fire jumped the line of held perimeter and quickly became an active crown fire. By 1800 h CST the fire had crossed Highway 135 to the east of the fire's origin, while at the same time cutting power and telephone service to the town of Pelican Narrows (Fig. 1). By 1900 h CST the fire had travelled a total distance of 5.9 km and burned an area approximately 1115 ha in size with an estimated perimeter length of 18.3 km (Figs. 1 and 2). The Chachukew Fire was deemed to be under control on July 20 and was finally declared out on August 15. Final size: 2550 ha.

FUELS AND TOPOGRAPHY

The Chachukew Fire area is located within the Northern Coniferous Forest Section (B.22a) of Canada's Boreal Forest Region according to Rowe (1972) and in the Northern Coniferous Ecodistrict (2b) - Northern Boreal Ecoregion of Saskatchewan as described by Harris and others (1983). The predominant forest cover in the vicinity of the major run on July 9 consisted of black spruce (Picea mariana Mill B.S.P.) and jack pine (Pinus banksiana Lamb.) stand mixtures on the drier knolls, interspersed with pockets of pure black spruce stands and treed muskeg in the lowland sites (Fig. 2). Tree heights averaged 10-15 m, and crown closure was chiefly in the 60-70% class. A small percentage of the area was comprised of mixedwood stands, hardwood stands, brush and grassland.

Pelican Lake is situated at an elevation of 314 m MSL, and the highest point in the fire area is 381 m MSL (Fig. 1). The majority of the area has less than a 7-8% grade, although there are a few slopes in the 10-20% range. Because of shallow slopes and rolling topography, it was therefore concluded that the effect of ground slope on fire behavior would be minimal.

ANTECEDENT CLIMATIC CONDITIONS

During the three months prior to the fire's occurrence, most of east-central Saskatchewan experienced below-normal precipitation (Fig. 3). Island Falls (elevation: 299 m MSL) is the closest year-round Atmospheric Environment Service (AES) climatological station (Fig. 1) to the fire (55 km northeast) and it recorded 32% of normal precipitation (Anon. 1982). Flin Flon airport (elevation: 304 m MSL), 90 km southeast of the fire (Fig. 1), and La Ronge airport (elevation: 375 m MSL), 150 km west of the fire area (Fig. 1), recorded 59% and 44% of normal precipitation during the same period, respectively. Air temperatures during the four-month period prior to the fire were also consistently higher than the 30-year normals (Anon. 1982).

SYNOPTIC WEATHER PATTERN

During the two days prior to the main run of the Chachukew Fire, a weak arctic front moved back and forth across the fire area. A major incursion of the modified arctic air occured on July 7, as indicated by the sharp dip in the 500 mb anomaly chart (see Figure 9). The main characteristic of this modified arctic air mass was the lack of moisture associated with it as indicated by the dew-point temperatures which were generally in the 5-7°C range (Countryman 1971). The front retreated north of the fire area on July 8 alowing maritime

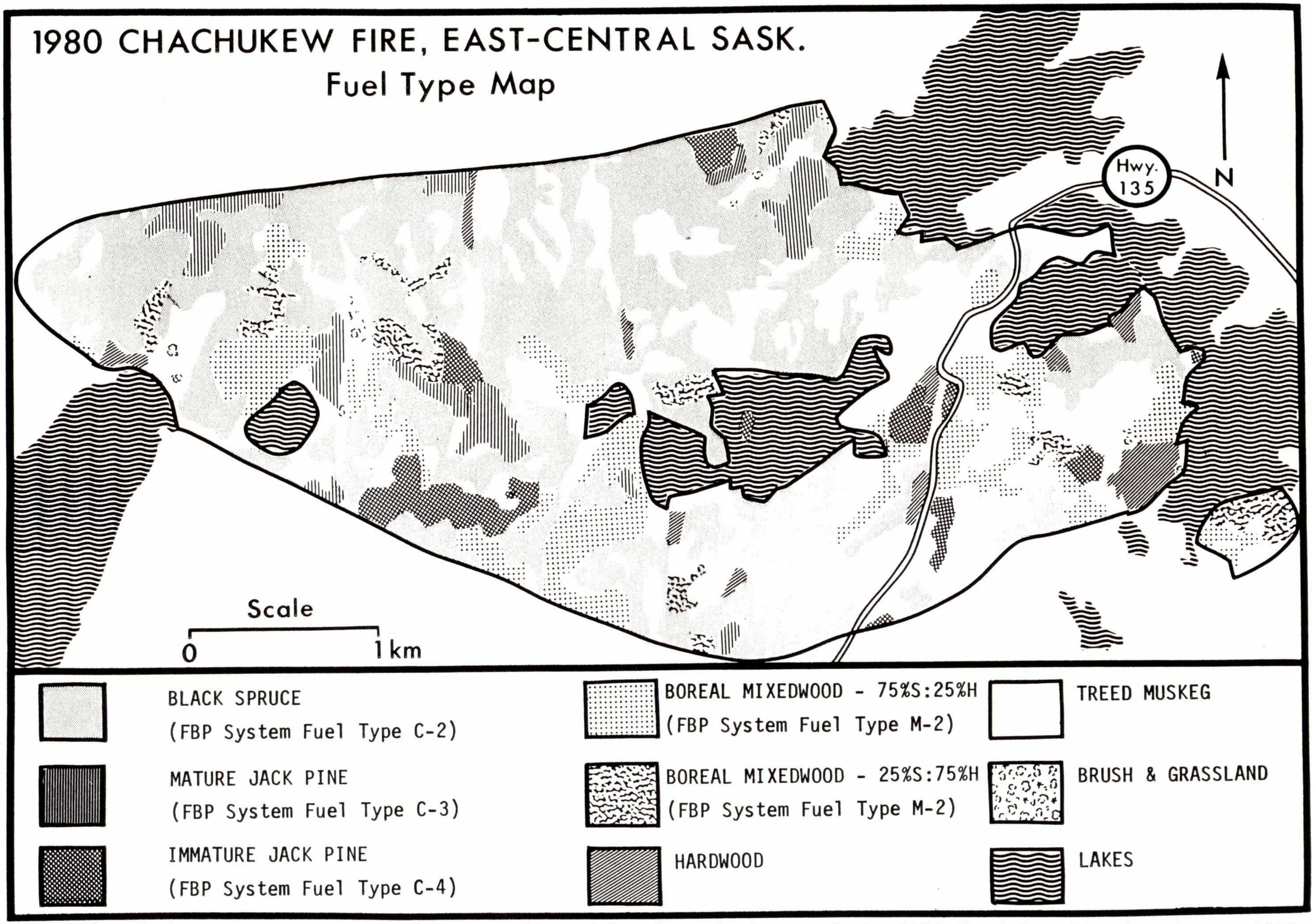

Figure 2. A forest cover map for the area affected by the July 9 run of the 1980 Chachukew Fire based on a 1973 provincial inventory maintenance map (1972 aerial photography). The corresponding fuel types presently recognized in the Canadian Forest Fire Behavior Prediction (FBP) System have also been identified, were applicable.

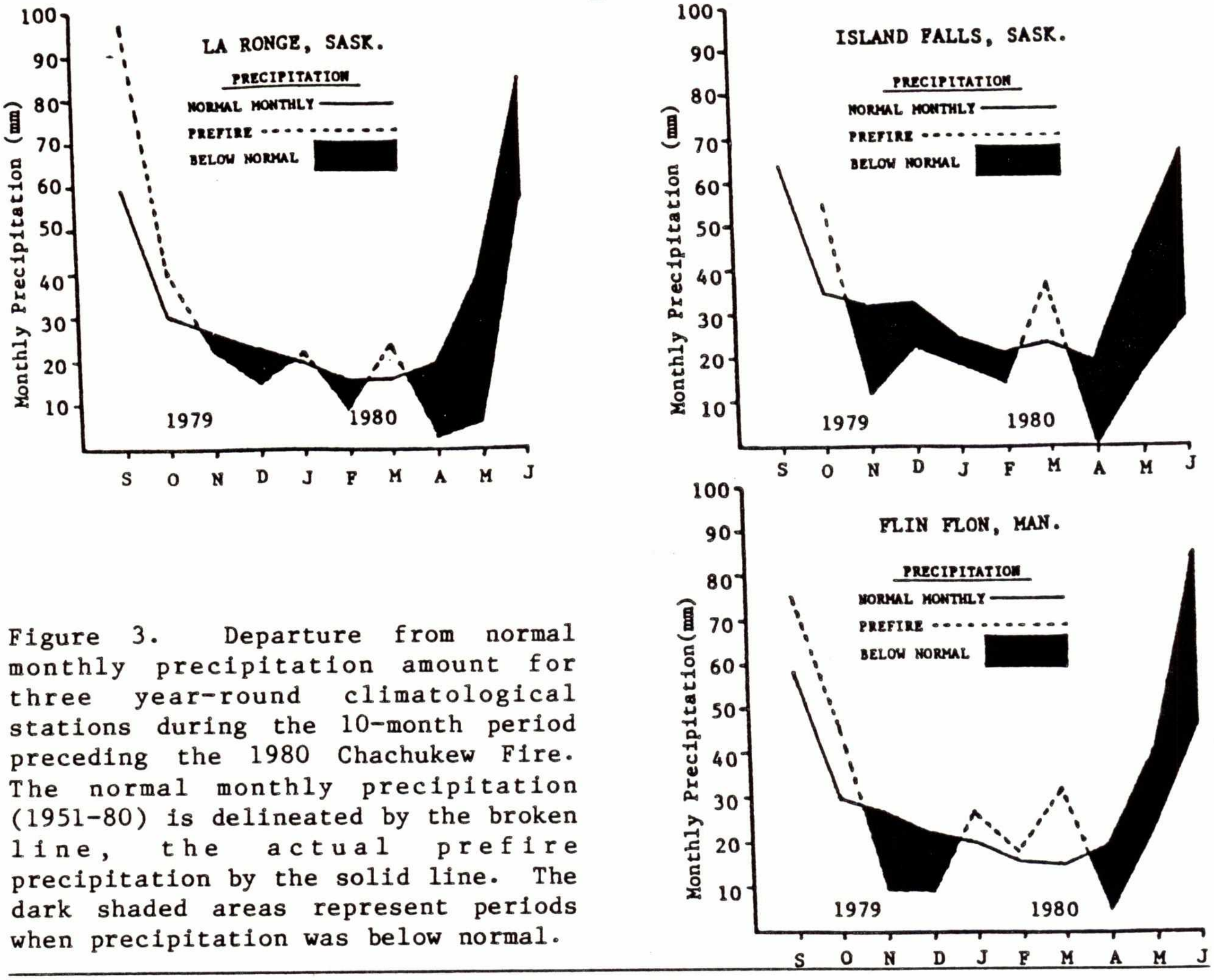

Figure 3. Departure from normal monthly precipitation amount for three year-round climatological stations during the 10-month period preceding the 1980 Chachukew Fire. The normal monthly precipitation (1951-80) is delineated by the broken line, the actual prefire precipitation by the solid line. The dark shaded areas represent periods when precipitation was below normal.

air with typical dew points in the 11-17°C range to return. On July 9 a minor trough at 500 mb moved southeastward through northern Manitoba (Fig. 4). This was accompanied by a southward push of the weak arctic cold front which moved through the fire area around 1200 h CST (Fig. 5). During the morning, dew points in the fire area were typical of the maritime air mass (i.e., ~ 15° C) rising to 19.6°C at Flin Flon around 1300 h CST (Table 1 and Fig. 6). As the arctic air pushed southward the dew point at Flin Flon dropped to below 10°C by 1500 h CST and a further 5+°C by 1700 h CST. Thus, the dew point was a phenomenal 15°C lower at the height of the burning period than it was at 1300 h CST. Another feature of this modified arctic air mass is that it remained quite shallow over the fire area. Thus, it did not have a major influence in lowering surface temperatures. Flin Flon recorded a maximum temperature of 28.7°C (Table 1 and Fig. 6). Combined with the low dew points, this resulted in relative humidities in the low 20s at the height of the burning period. This was undoubtedly the main weather factor contributing to the fire run. However, the timing of the cold frontal passage was also critical. If the cold front had passed through the fire area after the height of the burning period, as it did at The Pas around 2000 h CST, dew points would have remained in the mid teens and relative humidities would have remained in the 30s.

Atmospheric stability and winds aloft often contribute to extreme fire behavior (Byram 1954, 1955, 1959; Schroeder 1961; Taylor 1962; Edie 1969; Schroeder and Buck 1970; Steiner 1975, 1976; Alexander et al. 1983; Feunekes 1983; Simard et al. 1983; Burrows 1984; Street 1985; Street and Birch 1986). The nearest AES upper air station to the fire area is located at The Pas UA, Manitoba, 190 km southeast (elevation: 271 m MSL). The rawinsonde soundings

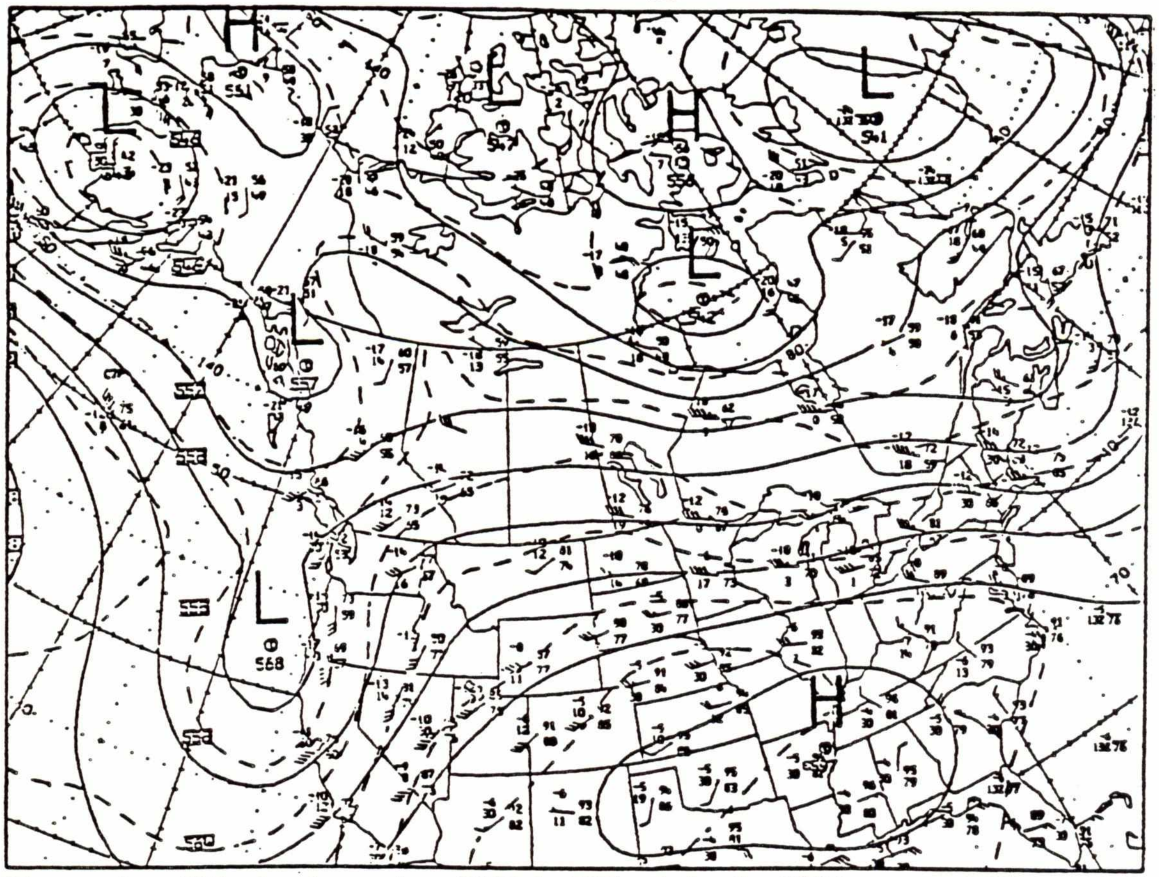

Figure 4. 500 mb chart for 0600 h CST, July 9, 1980.

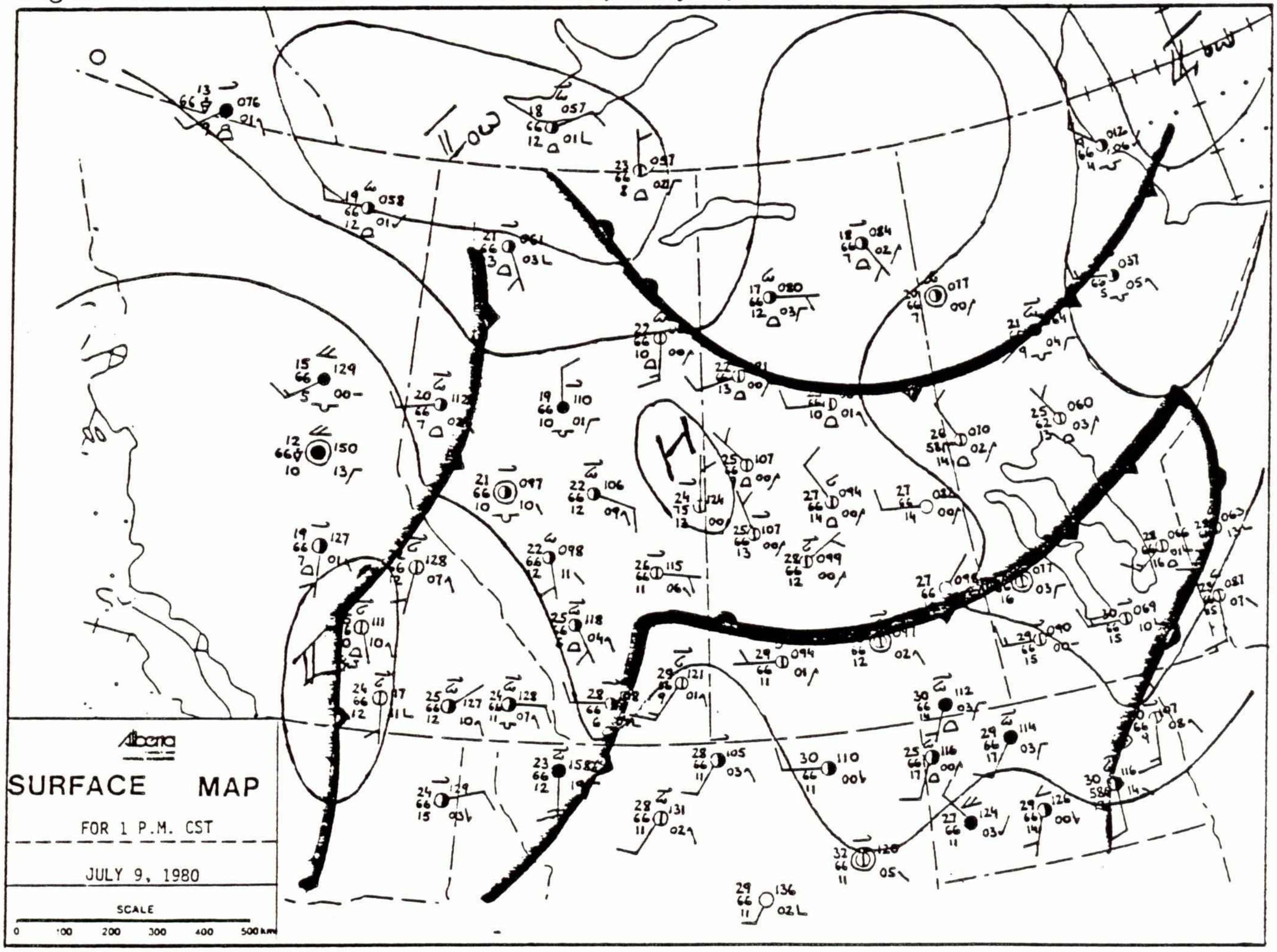

Figure 5. Surface weather map for 1300 h CST, July 9, 1980.

Table 1. Hourly weather observations and fire danger conditions recorded at Flin Flon A, Manitoba, during the major run of the Chachukew Fire on July 9, 1980.

Local time (h CST)	Dry-bulb temperature (°C)	Dew-point temperature (°C)	Relative humidity (%)	10-m open wind		FWI System components[1]		
				Direction (°)	Speed (km/h)	FFMC	ISI	FWI
1100	24.5	15.7	58	270	13(24)[2]	82.7	3.0	11
1200	25.4	17.2	61	290	9	83.3	2.6	10
1300	26.6	19.6	66	290	20	83.7	4.8	16
1400	27.0	10.3	35	270	20(33)	85.3	6.0	19
1500	28.3	9.8	32	270	17	86.8	6.3	20
1600	28.7	7.3	26	280	20(33)	88.3	9.2	26
1700	28.6	4.6	22	300	19(33)	89.7	10.6	28
1800	27.8	4.8	23	310	22(37)	90.7	14.3	35
1900	26.8	5.8	26	320	22(39)	91.3	15.5	37
2000	21.3	12.4	57	20	22(33)	90.7	14.3	35
2100	20.2	12.1	60	-	calm	90.5	4.6	16
2200	17.2	13.4	78	-	calm	89.8	4.1	14

[1] Abbreviations of selected Canadian Forest Fire Weather Index (FWI) System components: FFMC - Fine Fuel Moisture Code; ISI - Initial Spread Index; and FWI - Fire Weather Index. Calculations based on the equations for the 1984 version of the FWI System (Van Wagner and Pickett 1985).

[2] Reported gusts in parentheses.

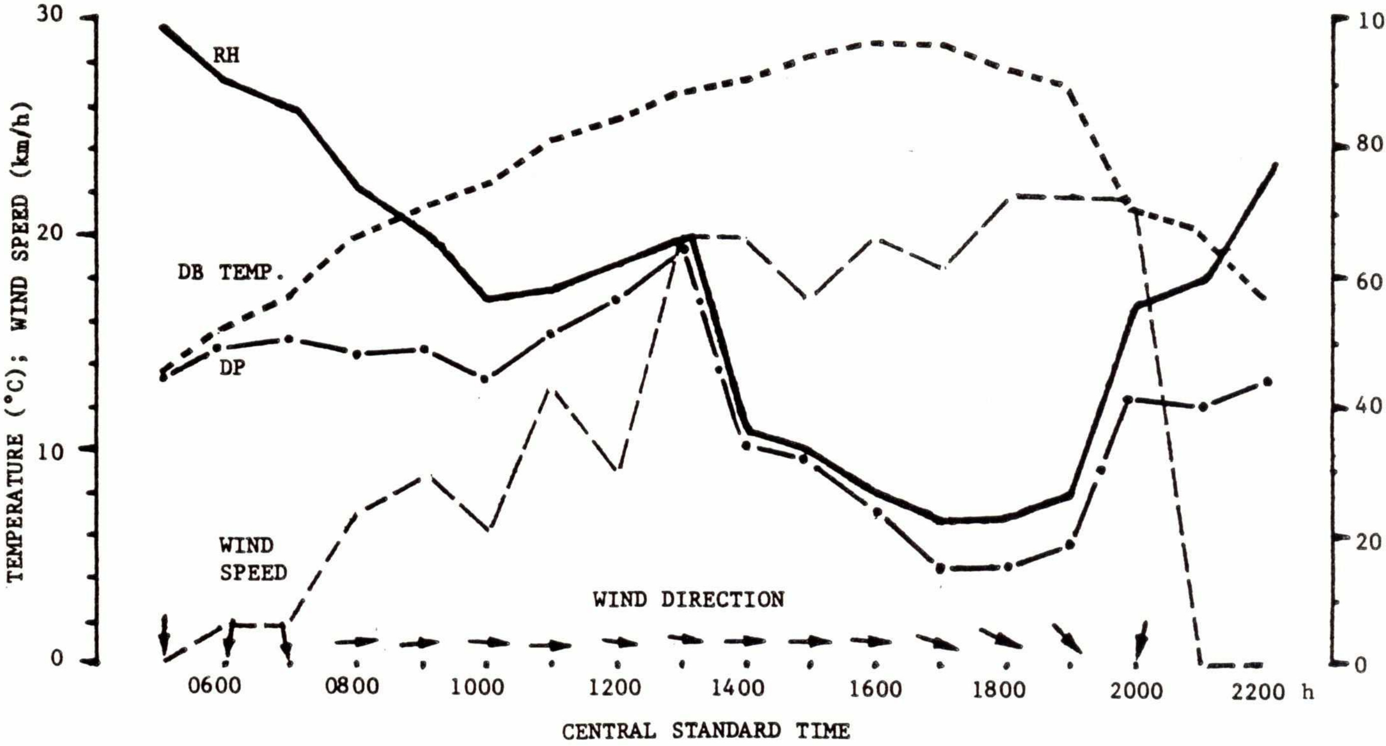

Figure 6. The diurnal trends in dry-bulb temperature, dew-point temperature (DP), relative humidity (RH), wind direction, and wind speed at Flin Flon A, Manitoba, during the major run of the Chachukew Fire on July 9, 1980.

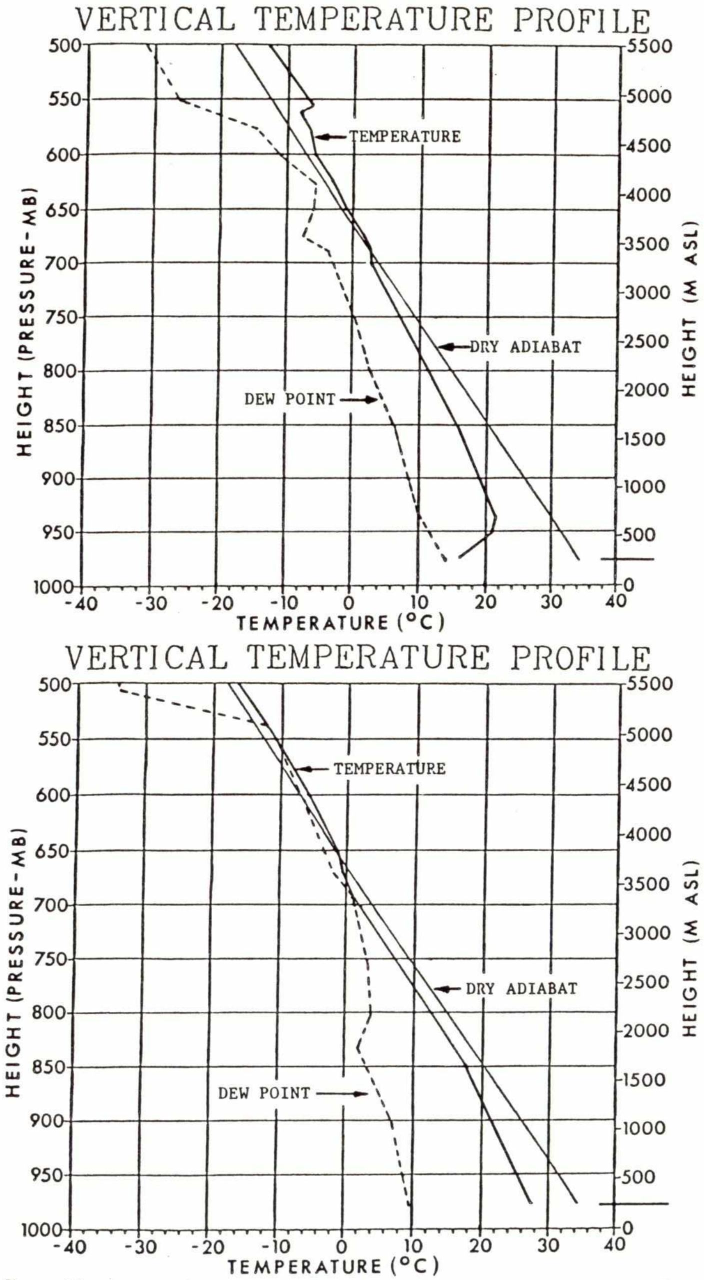

Figure 7. Vertical temperature profile above The Pas UA, Manitoba, at 0600 h CST *(top)* and 1800 h CST *(bottom)*, July 9, 1980. Note the shallow temperatures inversion near the surface. The evening sounding indicates very dry air below 2000 m as evident by the wide separation between temperature and dew point; temperature is very near the dry adiabatic lapse rate, indicating a relatively unstable atmosphere.

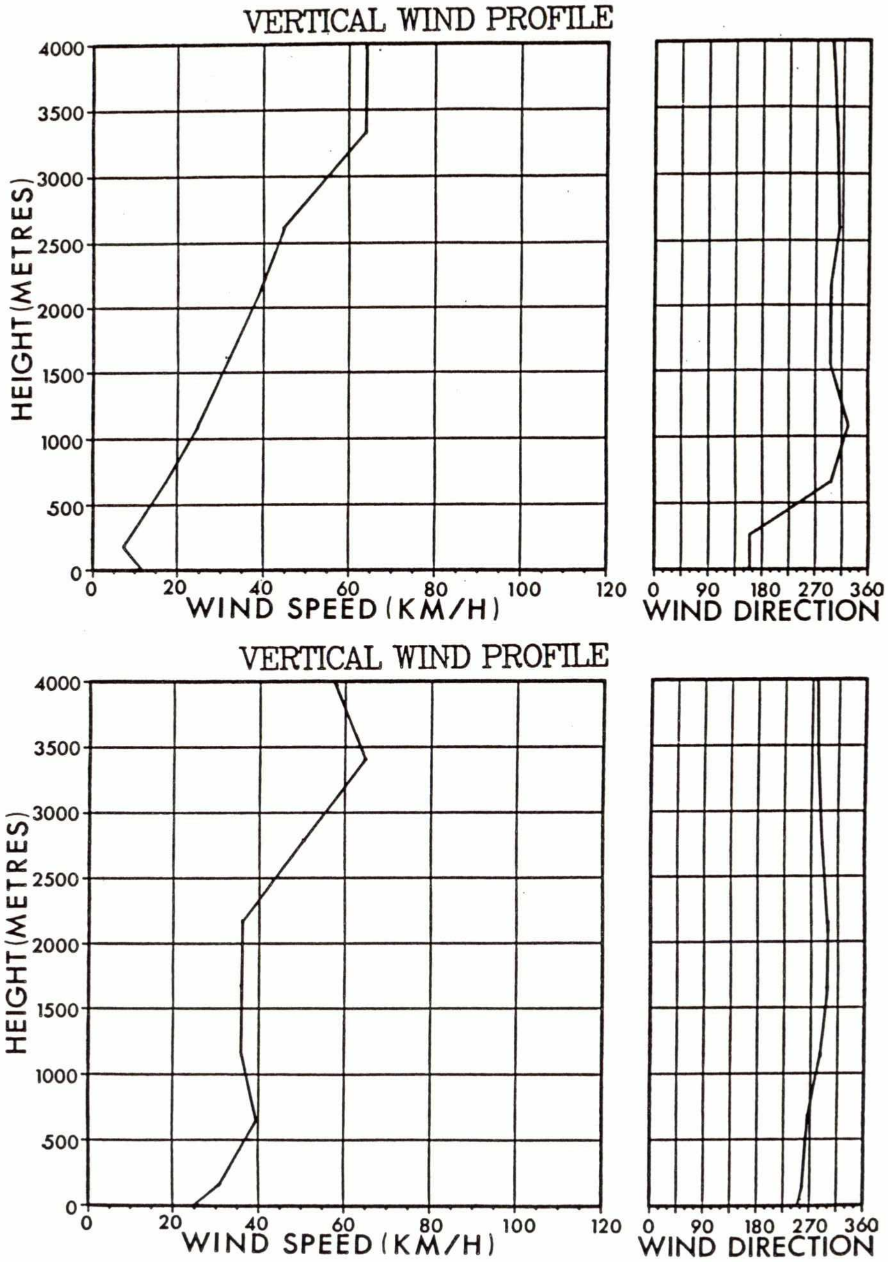

Figure 8. Vertical wind profile above The Pas UA, Manitoba, at 0600 h CST *(top)* and 1800 h CST *(bottom)* July 9, 1980. There is no evidence of a pronounced low-level jet wind (LLJW), which is often associated with extreme fire behavior. However, there may have been a minor LLJW south of the weak, advancing cold front.

for July 9 are presented in Figures 7 and 8. Unfortunately, the winds and lower levels of the temperature profile are probably not representative of the fire area due to the differences in air mass characteristics between the two locations.

The 500 mb anomaly chart (Fig. 9) indicates a slightly above-normal height level above The Pas UA, Manitoba station at the time of the fire run on July 9. However, in this particular case, there was no major breakdown of an upper ridge which can usually be predicted 24 to 48 hours in advance, and which often signals the onset of extreme fire behavior (Nimchuk 1983; Janz 1985; Janz and Nimchuk 1985). A corresponding seasonal display chart of fire danger indexes often show high and/or increasing values during a period of positive anomaly.

The Forestry Area Forecast or "FAF" (Vandervyvere 1985) for Hudson Bay, Saskatchewan issued by the AES's Prairie Weather Centre in Winnipeg for 0700 h CST on July 9 to 0700 h CST on July 10 indicated a maximum dry-bulb temperature of 30°C, a minimum relative humidity of 35%, 5.0 mm rain affecting 20% of the forecast area, and W-SW winds at 15 km/h until 0900 h CST then reaching 30 km/h until 2000 h CST when they would then become light and variable. The public weather forecast (also received at the SDPRR provincial fire control centre) indicated isolated showers in the evening of July 8 and overnight, and that July 9 would be clear with high temperatures.

FIRE DANGER CONDITIONS

The burning conditions during the major run of the 1980 Chachukew Fire are expressed here in terms of the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1974, 1987; Turner and Lawson 1978; Canadian Forestry Service 1984; Van Wagner and Pickett 1985). The FWI System consists of six standard components. Computations are based on consecutive daily 1200 h LST observations of dry-bulb temperature, relative humidity, 10-m open wind speed, and 24-h accumulated precipitation. The first three components of the FWI System are fuel moisture codes representing the moisture content of fine surface litter (Fine Fuel Moisture Code - FFMC), loosely compacted duff of moderate depth (Duff Moisture Code - DMC) and deep compact organic matter (Drought Code - DC). The other three components are fire behavior indexes representing rate of fire spread (Initial Spread Index - ISI), fuel available for combustion (Buildup Index - BUI) and fire intensity (Fire Weather Index - FWI). More specifically, the ISI represents the combined effect of wind and FFMC on fire spread rate. The BUI is a combination of the DMC and DC which represents the total fuel available to a spreading fire. The FWI is a combination of the ISI and BUI, and represents the energy output rate per unit length of an advancing fire front. In Saskatchewan, the FWI component is currently used as the principal indicator of fire danger. The following fire danger classes, based on the frequency of occurrence (Alexander 1982a), are presently recognized in Saskatchewan:

Fire Danger Class	Fire Weather Index
Low	0-5
Moderate	6-16
High	17-30
Extreme	31+

The July 9 fire weather and danger forecast issued for the SDPRR Pelican Narrows station (elevation: 320 m MSL) by the AES Prairie Weather Centre

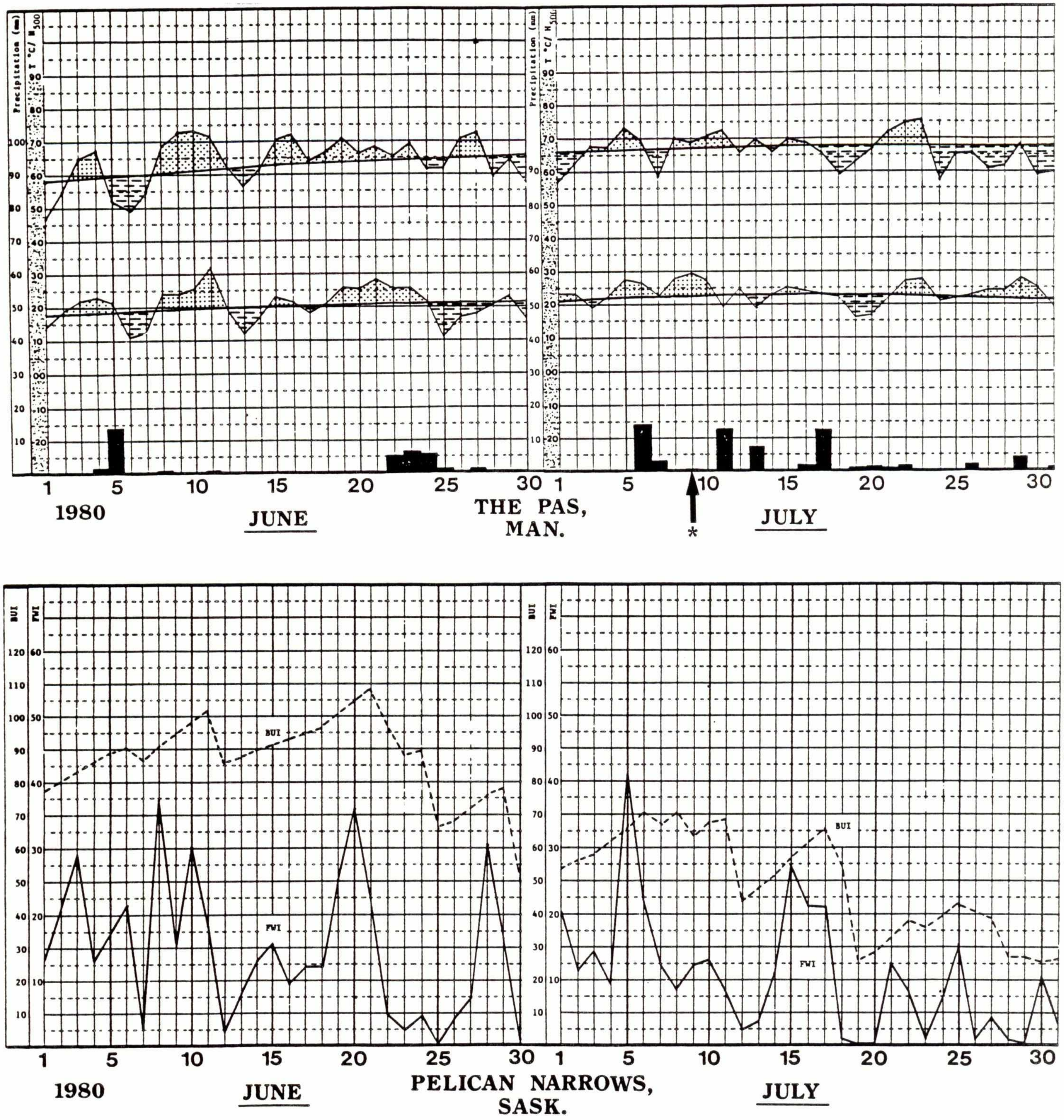

Figure 9. Charts of 500 mb height/maximum surface temperature anomalies with daily precipitation amounts at The Pas, Manitoba (*top*) and fire danger indexes at Pelican Narrows, Saskatchewan (*bottom*) during June and July, 1980. The main run of the Chachukew Fire occurred on July 9, 1980(*). The 500 mb mean height contour curves were constructed from the basic statistical data given in Titus (1973) for The Pas UA, Manitoba station. Alternatively, map data could have been used (e.g. Harley 1980).

(Raddatz and Atkinson 1982) during the afternoon of July 8 indicated slightly moderated conditions from those contained in the FAF:

DB Temp. (°C)	RH (%)	10-m Wind (km/h)	Rain (mm)	FWI System components[4]					
				FFMC	DMC	DC	ISI	BUI	FWI
21.0	56	15	0.0	86	46	426	5	73	16

The 0800 h CST weather observations at Pelican Narrows on July 9 show a dry-bulb temperature of 18°C, relative humidity of 74%, wind speed of 15 km/h, and an 18-h precipitation total of 0.3 mm. On the morning of July 9, a revised forecast was issued for Pelican Narrows, using the 18-h precipitation amount. The increased temperature and considerably decreased humidity was somewhat offset by the lower predicted wind speed which resulted in fairly similar FWI System values to those contained in the previous forecast:

DB Temp. (°C)	RH (%)	10-m Wind (km/h)	Rain (mm)	FWI System components[4]					
				FFMC	DMC	DC	ISI	BUI	FWI
23.0	39	3	0.3	88	47	427	4	74	13

It's worth noting that the FWI System values contained in the forecast are deemed applicable for 1600 h LST by applying the 1200 h LST weather readings to a "normal" diurnal pattern of the measured parameters. For example, the predicted relative humidity for 1200 h CST on July 9 was 39%. However, by mid to late afternoon, the RH could quite possibly reach the low 30s or even the high 20s, especially if the temperature reached 30°C as predicted in the FAF. This would suggest that unsecured fires would undoubtedly experience control problems. The only factor preventing "explosive" burning conditions was the low wind speed prediction. The FAF predicted winds of 30 km/h for most of the day, although the July 9 0800 h CST fire danger forecast was projecting only light winds (i.e., 3 km/h).

The actual fire weather observations and calculated FWI System values for the Pelican Narrows station on July 9, 1980 by the AES Prairie Weather Centre are as follows:

DB Temp. (°C)	RH (%)	10-m Wind (km/h)	Rain (mm)	FWI System components[4]					
				FFMC	DMC	DC	ISI	BUI	FWI
25.0	44	20	3.0	80	38	420	3	62	11

As indicated above, an additional 2.7 mm of rain fell at Pelican Narrows between 0800 and 1200 h CST for a 24-h total of 3.0 mm. A trace of rain was reported by the SDPRR ground suppression crew at the fire scene on the previous evening, although there is no account of any other rain occurring at the fire site on July 9. The Pelican Narrows fire weather network station is located about 6 km south of the fire's origin. Apparently, the isolated thundershower activity predicted in the previous day's forecast did materialize over Pelican Narrows but missed the fire site.

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[4] Note: These calculations, which were actually made in 1980, are based on the equations for the 1976 version of the FWI System (Van Wagner and Pickett 1975).

The nearest AES synoptic network weather station is located at Flin Flon A, Manitoba. The hourly records show that relative humidities climbed between 1000 and 1300 h CST and then dropped from 66% at 1300 h CST steadily to 35% at 1400 h CST (Table 1 and Fig. 6). The relative humidity continued to decrease and stayed in the mid to low 20s until 2000 h CST, when it again sharply increased. The temperature at Flin Flon reached a high of almost 29°C around 1600 h CST. Winds near 20 km/h were maintained from 1300 to 2100 h CST. All of these factors contributed to the extreme burning conditions experienced at the fire site.

For this case study analysis, the daily 1200 h CST fire weather observations for the SDPRR network station at Pelican Narrows were acquired and all weather data were then processed by computer using the most current edition (1984) of the FWI System (Van Wagner and Pickett 1985). The results were used in the plotting of the FWI/BUI seasonal display chart. The spring starting values of the DC was also adjusted for overwinter precipitation (Turner and Lawson 1978; Alexander 1982c, 1983a, 1983b; Lee and Alexander 1982). The DC on the last day (September 6) of calculations in the fall of 1979 was 267 at the Pelican Narrows fire weather station. This early closing date was approximately seven weeks prior to a continuous covering of snow. The snow cover is usually gone in the spring around May 1 but as late as May 17 and as early as April 10 (Potter 1965). However, in 1980 complete snowmelt occurred considerably earlier than normal. The total overwinter precipitation for the Pelican Narrows area was judged to be about 212.4 mm (water equivalent) between September 7 and April 12 based on observations at Island Falls and Flin Flon. The initial spring DC starting value was computed to be 39 based on a $DC_F = 267$, $P = 212.4$ mm, fall carry-over fraction **a** = 0.75, and a precipitation effectiveness fraction **b** = 0.50. Based on the 1200 h CST weather observations at Flin Flon A, an additional 21 DC units were estimated to have accumulated between April 16 and April 22, the actual spring starting date at Pelican Narrows. Thus, the final result was $DC_S = 60$. The spring starting value of the DMC was estimated to be 15.

Assuming that the area burned on July 9 did not receive any significant rain (i.e., greater than a trace or 0.1 mm) and that fire weather conditions occurring at Flin Flon are representative of the fire site (this is generally a very reasonable assumption in the boreal forest, particularly for temperature and relative humidity, given the level terrain and minor differences in elevation), a new set of FWI System calculations could have been undertaken. Turner and Lawson (1978) state that when sudden weather changes occur, revised calculations for the day is warranted. In this particular case, the relative humidity didn't follow a normal diurnal pattern and a recalculation for the day could have been undertaken due to the sharp drop in RH around 1400 h CST. Using the 1400 h CST weather observations from burning Flin Flon and a 24-h precipitation of 0.1 mm, the probable burning conditions for the fire site are as follows:

DB Temp. (°C)	RH (%)	10-m Wind (km/h)	Rain (mm)	FWI System components[5]					
				FFMC	DMC	DC	ISI	BUI	FWI
27.0	35	20	0.1	91	49	450	13	77	33

The values given in Table 1 and above are certainly more indicative of the

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[5] Note: Calculations based on the FORTRAN program for the 1984 verison of the FWI System (Van Wagner and Pickett 1985).

burning conditions actually experienced at the fire site than the original calculations for Pelican Narrows in 1980, although they can not be considered as strictly representative. However, similar trends in the fluctuations of the parameters probably did occur, but they most likely were not identical. It's worth noting that the location of the Pelican Narrows fire weather station on the shore of Pelican Lake (Fig. 1) in relation to a westerly wind would likely indicate a slightly lower temperature and higher relative humidity. The somewhat abnormally high DC and BUI values for July are undoubtedly a reflection of the below-normal precipitation and above-normal temperatures during the previous three months.

Note that the FWI System values given in Table 1 are based on the assumption that no rain fell at the site of the Chachukew Fire. The required 1100 h CST FFMC starting value is based on the standard daily FFMC at Pelican Narrows on July 8 and the FFMC diurnal adjustment table (Alexander 1982d). Subsequent computations were determined on the basis of the hourly FFMC (Van Wagner 1977a; Alexander et al. 1984).

FIRE BEHAVIOR PREDICTION

A projection of free-burning growth for the 1980 Chachukew Fire run of July 9 using the 1984 interim edition of the Canadian Forest Fire Behavior Prediction (FBP) System (Alexander and others 1984; Lawson et al. 1985) and a simple elliptical model (Alexander 1985a, 1986b; McAlpine 1986) is summarized in Figure 10. The FBP System projection for Fuel Type C-2 underpredicted the forward spread distance, but the area burned prediction was very close. The Fuel Type C-4 projection overestimated the total area burned, but accurately predicted the forward spread distance. Underpredictions of fire perimeter length is a recognized feature of the simple elliptical fire growth model (Alexander and others 1984; Alexander 1985a; Lawson et al. 1985; McAlpine 1986). The lakes on the eastern half of the fire obviously influenced the somewhat irregular shape of the July 9 run (see Figure 1).

The CFFDRS does effectively integrate the influence of moisture conditions on potential fire behavior. Its sensitivity to the occurrence of precipitation as reflected by the isolated rainshowers in the area surrounding the Pelican Narrows fire weather station is illustrated in Figure 11. Note that the chart given in Figure 11 does represent a prototype format for one possible means of presenting, in management-useable form, the frontal fire intensity component of the FBP System which is due for completion in 1987 and could be used for plotting actual or forecast indices for one or several network fire weather stations.

The concepts presented in the 'intensity rank chart' (Fig. 11) can also be used to display the hourly changes in fire behavior and the corresponding fire suppression requirements to achieve control. The diurnal pattern shown in Figure 12 is based on a "no rain" BUI at Pelican Narrows of 77 and the ISI values contained in Table 1. For several hours, the Chachukew Fire exceeded the limits of control by conventional means available to fire management personnel.

The average forward rate of advance of the Chachukew Fire during the afternoon of July 9 was 1.2 km/h or 19.7 m/min. Based on the BUI level and boreal forest fuel types involved, the available fuel consumed (W) probably amounted to about 2.5 kg/m^2 -- i.e., 1.5 kg/m^2 for ground and surface fuels + 1.0 kg/m^2 for crown fuels. Using a head fire rate of spread (r) figure of 0.33 m/sec (i.e., 19.7 m/min ÷ 60) and a net heat of combustion value (H)

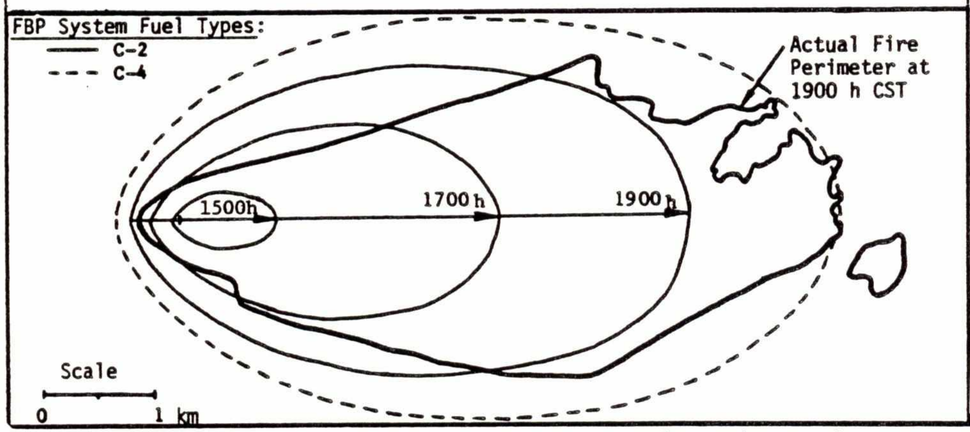
Page 1 of 1

CANADIAN FOREST FIRE BEHAVIOR PREDICTION (FBP) SYSTEM WORKSHEET

Fire Number/Name CHACHUKEW #116 (SASK.) Date & Time 09.07.80 1400 h CST

Prediction Date & Time Interval 09.07.80 from 1400 h to 1900 h CST

		1400-1500h	1500-1700h	1700-1900h		
1	Prediction Point	1 P.I.	1 P.I.	1 P.I.		
	Fuel Type Information					
2	FBP System Fuel Type	C-2	C-2	C-2		
3	Softwood Species Composition (%)	-	-	-		
4	Hardwood Species Composition (%)	-	-	-		
5	Cured/Dead Grass (%)	-	-	-		
6	Grass Fuel Weight (t/ha)	-	-	-		
	Fine Fuel Moisture Code (FFMC) Time & Slope/Aspect Adjustments					
7	Standard Daily FFMC	91	91	91		
8	Time "T"	1400	1600	1800		
9	FFMC at Time "T"	90	91	90		
10	Aspect (N, E, S, or W)	-	-	-		
11	Ground Slope (%)	0	0	0		
12	Adjusted FFMC	90	91	90		
	Rate of Spread (ROS) Calculations					
13	10-m Wind Speed (km/h)	20	20	20		
14	Initial Spread Index (ISI)	12*	14*	12*		
15	Spread Factor (SF)	1.00	1.00	1.00		
16	ROS on Level (m/min or km/h)	14	17	14		
17	ROS[16] x SF[15] (m/min or km/h)	14	17	14		
		* CROWN FIRE				
	Fire Size Calculations					
18	Elapsed Time (min or h)	60	120	120		
19	Spread Distance (m or km)	840 +	2040 +	1680		
20	Area Shape Factor (K_A)	0.54	0.54	0.54		
21	Area Burned (ha)	38	448	1123		
22	Length/Breadth Ratio (L/B)	1.76	1.76	1.76		
23	Perimeter Shape Factor (Kp)	3.54	3.54	3.54		
24	Perimeter Length (m or km)	2974	10195	16142		
	Fire Area Plotting 1:50 000					
25	Map Conversion Factor (cm/km)	2.00	2.00	2.00		
26	Map Distance (cm)	1.8/1.1	6.3/3.6	10.0/5.7		
27	Wind Direction	W	W	W		



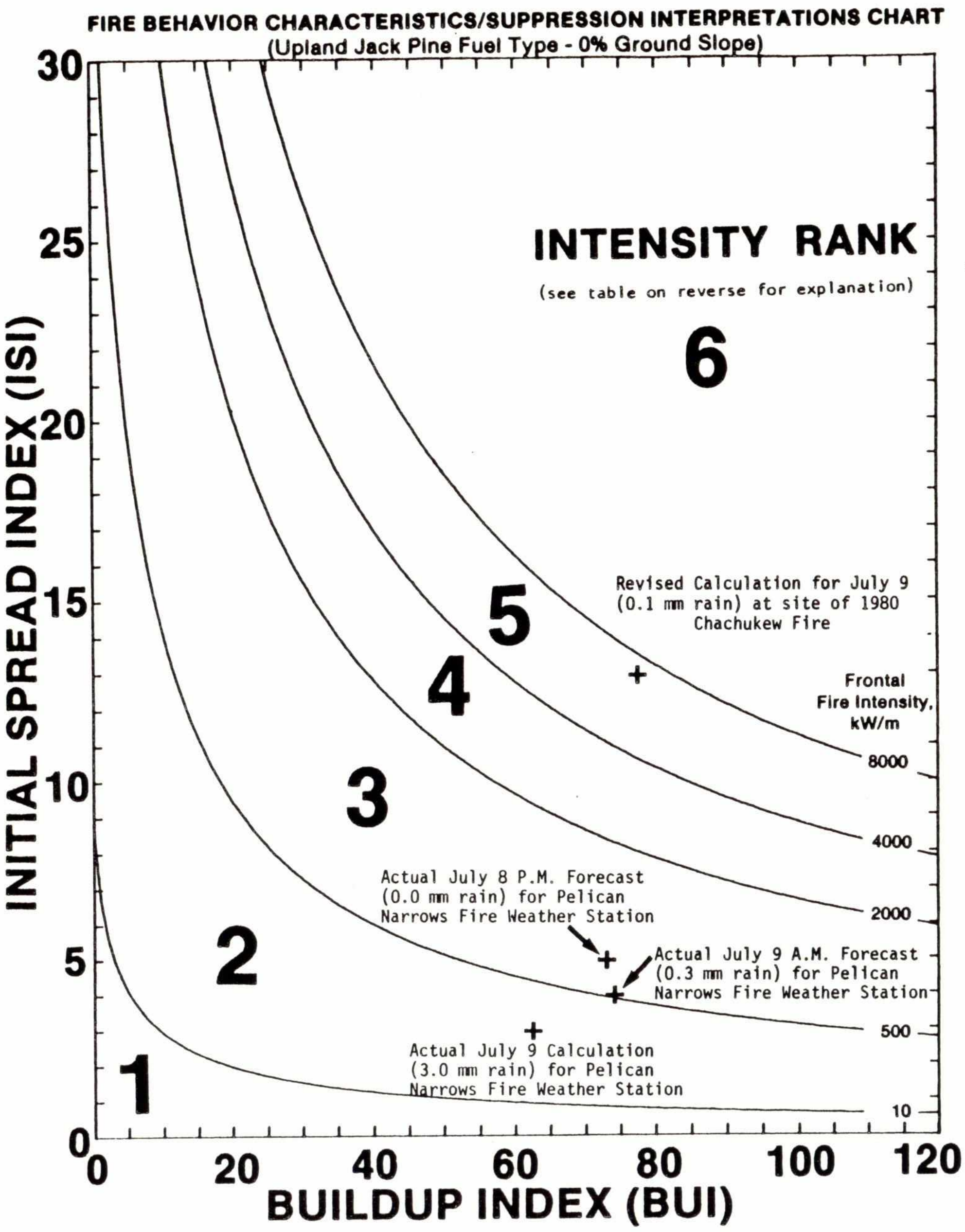
NOTES:

The Area and Perimeter Shape Factors are from Tables 14 and 15, respectively of Alexander (1986a) which indirectly account for backfire spread.

The Area Burned, Perimeter Length, and Map Distance computations for 1500-1700 h and 1700-1900 h CST are based on the cumulative forward Spread Distances (i.e., 2880 m and 4560 m, respectively).

The plotting of the elliptical fire areas displayed at left are based on the procedures described in Alexander (1986a) which take into account the backfire spread. Map distances refer to the NTS 1:50 000 scale topographic map.

Figure 10. After-the-fact projection for the main run of the 1980 Chachukew Fire utilizing the worksheet and procedures for plotting fire growth from a point ignition contained in the user guide to the 1984 interim edition of the Canadian Forest Fire Behavior Prediction (FBP) System. The 5-h prediction of fire growth is based on the 1400 h CST fire weather observations and fire danger ratings at Flin Flon, Manitoba and FBP System Fuel Type C-2 (Boreal Spruce), assuming that no rain fell at the fire site. An additional prediction for Fuel Type C-4 (Immature Jack Pine) is also given.



CFS Fire Danger Group, January 1986

Chart Rank	Frontal Fire Intensity (kW/m)	Head Fire[1] Flame Length (m)	Head Fire[1] Flame Height (m)	Description of Fire Behavior Characteristics and Fire Suppression Interpretations	Fire Weather Index[2] (FWI)
1	<10	<0.2	<0.1	Smouldering ground or creeping surface fire. Firebrands and going fires tend to be virtually self-extinguishing unless high Drought Code (DC) and/or Buildup Index (BUI) values[3] pervail, in which case extensive mop-up is generally required.	0-3
2	10-500	0.2-1.4	0.1-1.0	Low vigour surface fire. Direct manual attack at fire's head or flanks by fire-fighters with hand tools and water possible. Constructed fire guard should hold.	4-13
3	500-2000	1.4-2.6	1.0-1.9	Moderately vigorous surface fire. Hand-constructed fire guards likely to be challenged. Heavy equipment (bulldozers, pumpers, retardant aircraft, skimmers, helicopter w/bucket) generally successful in controlling fire.	14-23
4	2000-4000	2.6-3.5	1.9-2.5	Highly vigorous surface fire or passive crown fire (torching). Control efforts at fire's head may fail.	24-28
5	4000-8000	3.5-4.8	2.5-3.4	Extremely vigorous surface fire or active crown fire. Very difficult to control. Suppression action must be restricted to fire's flanks. Indirect attack with aerial ignition (i.e., helitorch and/or AID dispenser) may be effective.	29-33
6	>8000	>4.8	>3.4	"Blow-up" or "conflagration" type fire run; violent physical behavior probable. Suppression actions should not be attempted until burning conditions ameliorate.	>34

[1] Applicable to surface fire only; flame height based on flame length and a 45° flame angle.

[2] Applicable to mature jack pine stands on level ground.

[3] DC >300 and/or BUI >40.

Prepared by: Martin E. Alexander, CFS-NoFC, Edmonton, Alta.

Figure 11. Differences in probable wildfire potential and fire control requirements/difficulty as a result of isolated rain-shower activity in the Pelican Narrows area of east-central Saskatchewan during the afternoon of July 9, 1980.

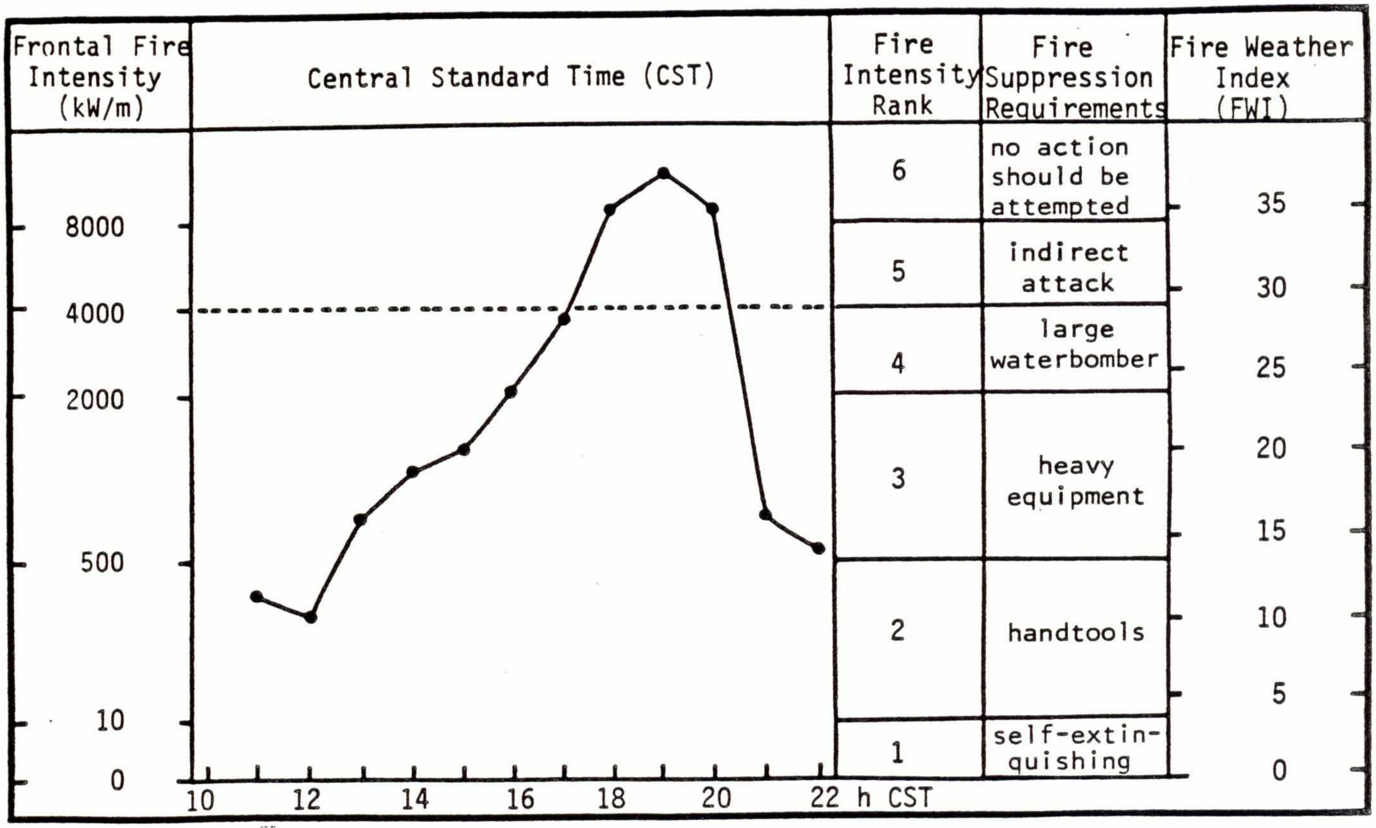
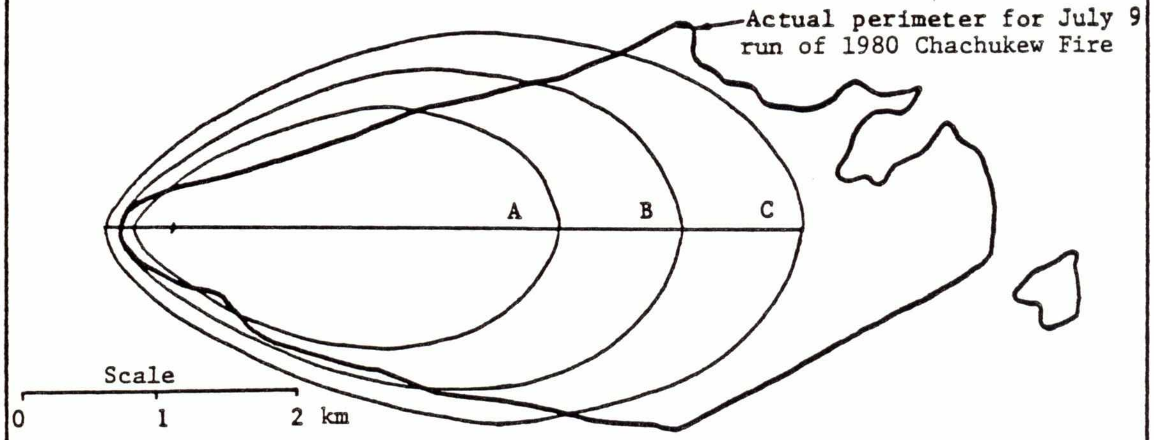


Figure 12. Diurnal pattern in probable fire potential and fire control requirements during the major run of the Chachukew Fire on July 9, 1980.

	Temperature (°C)		RH	FFMC	ISI	Head Fire ROS
	Dry-bulb	Wet-bulb	(%)			(m/min)
CASE A	24.5	17.5	51	87.6	8.4	10.4
CASE B	25.0	17.0	46	88.8	9.9	13.7
CASE C	25.5	16.5	41	89.8	11.4	16.8



NOTE: The free-burning fire growth predictions given above are based on no rain FFMC calculation, 10-m open wind of 20 km/h, 0% ground slope, FBP System Fuel Type C-4, burning conditions (i.e., fire weather observations & fire danger ratings) recorded at the Pelican Narrows fire weather station, and an elapsed time of 5 hours.

Figure 13. An example of the possible outcomes in FBP System projections which could occur when dry-and wet-bulb temperature observations are rounded to the nearest whole degree Celsius (°C) based on the 1980 Chachukew Fire run of July 9.

of 17 000 kJ/kg, this translates into 14 025 kW/m as an estimate of the "peak" frontal fire intensity (I) (Byram 1959; Alexander 1982b) for the Chachukew Fire run of July 9. This level of intensity is substantiated by several 35 mm slides taken by a Pelican Narrows RCMP officer as the Chachukew Fire crossed Highway 135. The above calculation ($I = Hwr$) is of course for a full-fledge <u>active crown fire</u> (Van Wagner 1977b; Merrill and Alexander 1987). For a surface fire, prior to the onset of crowning (Van Wagner 1977b), the calculated frontal intensity is 8 910 kW/m (i.e., H = 18 000 kJ/kg, w = 1.5 kg/m^2, and r = 0.33 m/sec). This is moderately higher than that suggested by the 'fire intensity rank chart and table' (Fig. 11), although it's impossible to quantify the effect crowning had on the final spread rate (Van Wagner 1977b). The predicted frontal fire intensity for an ISI 13 and BUI 77 is ~ 7270 kW/m.

Disregarding the frontal fire intensity implications for a moment, if the two S_2F Trackers based at La Ronge had been available, could they have contained the escape at 1400 h CST on July 9 simply on the basis of their line-building capability (Martell et al. 1984; Mees 1985; Loane and Gould 1986; Smith 1986)? Note that the normal cruise speed of a loaded Tracker is ~ 300 km/h (Grigel et al. 1975; McDonald 1976; Anon. 1981). It's estimated that it would take 40 min for the Trackers to deliver their loads (i.e., minimum 30 min travel time + at least 10 min for take off and climb to cruise speed plus time to assess the fire prior to dropping). According to the FBP System, the projected area and perimeter length of the fire at 1440 h CST would have been about 16.9 ha and 1982 m, respectively. If 40% of the perimeter must be contained in order to control the fire (Potter et al. 1981), then the two Trackers must be capable of jointly constructing at least 793 m of retardant line. According to the best estimates available from research (e.g., Newstead and Lieskovsky 1986) and operational experience, the combined maximum possible "fireguard" that could be delivered would be in the form of four 2-door string drops for a total of 172 m of effective line (R.G. Newstead, pers. comm.). What about allowance in the area and perimeter length computations for the time required of the fire to reach its equilibrium spread rate (Cheney 1981)? Using a semi-theoretical approximation, the fire is estimated to have an area of 8+ ha with a perimeter length of 1300+ m at 40 min elapsed time since ignition. Therefore, at least 550 m of fireguard must be built to contain the fire.

FIRE MANAGEMENT IMPLICATIONS

The CFFDRS is not only sensitive to precipitation, but to all of the required fire weather elements. Examination of the fire danger records for the Pelican Narrows fire weather station revealed that temperatures were being rounded to the nearest whole degree Celsius. The impact of such observing practices on FBP System projections is summarized in Figure 13. Case B represents the values recorded at 1200 h CST prior to the main run of the Chachukew Fire. Cases A and C represent the two extremes which could have been recorded instead of Case B. The difference in fire area predictions for Case A and C is over 550 ha. The fact that 0.5°C has this effect on the CFFDRS illustrates not only the significance of proper observation and recording practices, but also the importance of ensuring that weather stations meet location and instrument exposure standards (Turner and Lawson 1978), fire weather observers receiving fundamental training, and that quality control criteria are established and maintained (e.g., annual equipment checks).

Isolated showers can cause calculated FWI System component values to indicate conditions that are only valid for a very limited area, even though the information is being used for an entire district. For fire weather stations receiving precipitation from isolated shower activity, a second, "no-rain" calculation of the FWI System could be made to more accurately reflect burning conditions in those areas which did not receive rain. The resulting values could also be used for FBP System projections. In addition, if a significant change in the weather occurs after the noon LST weather observations, then another recalculation of the FWI System components could be done with new observations (the original "noon" fire weather observations, including rain from isolated showers, would still be used for the following day's calculation. Thus, fire managers at the district level must be able to do FWI System calculations, whether by tables (Canadian Forestry Service 1984) or computer (Van Wagner and Pickett 1985). In the same vein, fire danger forecasts issued by AES should also be updated whenever forecasted weather conditions drastically change.

The conclusion from this single case study is that there appears to be nothing out of the ordinary about fire behavior in terms of the fuel component of the fire environment on Saskatchewan's portion of the Canadian Shield. In fact, the FBP System would appear to produce reasonably accurate predictions of fire growth and intensity. However, the Shield's terrain undoubtedly affects local surface wind conditions in complex ways (Buck 1964; Schroeder and Buck 1970).

If the fire manager understands how the CFFDRS works, and appreciates the sensitivity of the subsystems, then he is in a better position to apply common sense adjustments to accommodate local, site-specific conditions. This fine-tuning of CFFDRS applications is the 'art' required to make the danger rating 'science' an accurate and useful tool for fire operations.

CONCLUDING REMARKS

Case studies of selected wildfires have a value in their own right in terms of training material and as a data source for research (Alexander 1982e). The Chachukew Fire case study has already been used in several SDPRR courses this year by the first author. In addition, the head fire spread rate and attendant burning conditions for the July 9 run have now been incorporated into the data base associated with the continuing development of the FBP System.

ACKNOWLEDGMENTS

Appreciation is extended to Fred Luciow of AES Central Region office, Winnipeg for his assistance in acquiring weather data and maps utilized in this paper. Ben Janz of the Alberta Forest Service (AFS) fire weather section and Al Schmidt of the AES Prince Albert Weather Office were very helpful with interpreting the synoptic-scale weather features associated with the 1980 Chachukew Fire run. Dick Smith, Canadian Forestry Service (Edmonton), completed the final copy of Figure 2. The AFS fire weather section kindly provided Figure 5.

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WILDFIRE ACTIVITY IN RELATION TO FIRE WEATHER AND FIRE DANGER IN NORTHWESTERN MANITOBA ... AN INTERM REPORT[1]

by

Kelvin G. Hirsch[2]

INTRODUCTION

The Canadian Forest Fire Weather Index (FWI) System (Canadian Forestry Service 1984; Van Wagner and Pickett 1985; Van Wagner 1987) provides a uniform method for rating fire danger across Canada. It was developed for a standard fuel type (i.e., mature jack or lodgepole pine stand) which is found in an almost continuous band across Canada (Van Wagner 1987). The FWI System, however, does not account for differences in fuel type, topography or latitude. To ensure its proper application, it is necessary to determine the historical relationship between the values of the components of the FWI System and specific. Measures of wildfire activity either from personal experience and/or by conducting a "calibration and assessment study". Previous studies have been conducted for various parts of Canada (e.g., Stocks 1971, 1974; Turner 1973; Fahnestock 1975; Kiil et al. 1977; Marks 1979; Shortt 1982; B.C. Ministry of Forests 1983; Harvey et al. 1986) and on a national basis (e.g., Simard and Valenzuela 1972; MacHattie 1973; Simard 1973, 1975; Simard et al. 1979; Harrington et al. 1983), but no study of this nature has been undertaken specifically for any portion of Manitoba. However, some analysis and related work was carried out with the 1956 edition of the Canadian system of fire danger rating (Anon. 1957) in the 60s (e.g., Adams 1964; Cayford and Adams 1964; Williams 1964; Capel and Teskey 1970; Valenzuela and Kourtz 1970) and there is of course a historical precedent for fire danger performance studies in Manitoba (i.e., Beall 1939a, 1939b, 1941, 1946).

METHODS

This study was based on five years of fire weather and fire report data (i.e., 1980-1984) for a 63 400 km^2 area in northwestern Manitoba (Fig. 1). The area had 537 fires during this time period but 45 early spring and late fall fires were excluded due to missing information. A total of 492 fires, which comprised 15.8% of the total number of fires in the province during the 1980-84 fire seasons, were used in the analysis. These fires accounted for 211 000 ha of the area burned or 18.6% of the provincial total. The associated suppression costs were 6.8 MM$. Coincidentally, Canadian Forest Fire Behavior Prediction (FBP) System fuel type mapping has been completed for the study area (Dixon et al. 1984).

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[1] A presentation made at the Third Central Region Fire Weather Committee Scientific and Technical Seminar, April 3, 1986, Winnipeg, Man.

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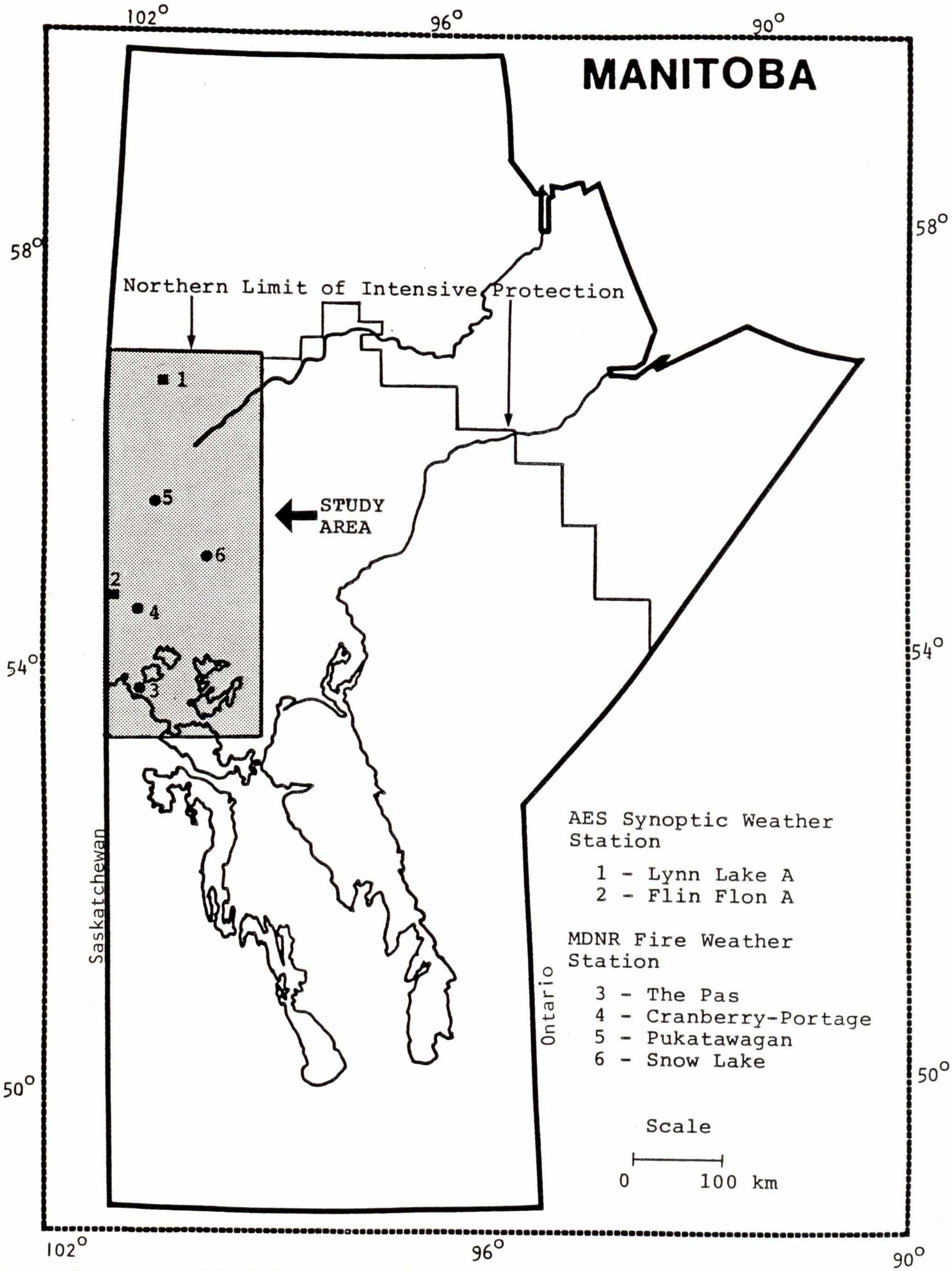

Figure 1. Geographical location and extent of the study area in northwestern Manitoba. Note locations of Atmospheric Environment Service (AES) and Manitoba Department of Natural Resources (MDNR) network weather stations.

Fire weather observations were obtained from two Atmospheric Environment Service (AES) stations (Lynn Lake and Flin Flon) and four provincial network fire weather stations The Pas, Cranberry Portage, Pukatawagan and Snow Lake (Fig. 1); an evaluation of the stations operated by the Manitoba Department of Natural Resources was recently undertaken by Hirsch (1986). The 1200 h Central Standard Time (CST) observations were used to compute the values of components of the FWI System (Van Wagner and Pickett 1985) and generally covered a period from mid-May to mid-September each year. spring Drought Code (DC) starting values for each year were calculated with overwinter precipitation information from the AES climatological station nearest each weather station (Alexander 1983). Wind speeds at the two AES stations were multiplied by a factor of 0.6 for use in the calculation of the FWI System values (Turner and Lawson 1978) in order to approximate a 10-m open wind in forested areas (Simard 1972; Silversides 1978).

The fire weather and danger rating data was then merged with individual fire report information obtained from the provincial forestry branch (Tuinhof and Nicholls 1978). Each fire was assigned a daily fire weather danger rating record from the nearest station based on the date and location of the fire's origin (it's recognized that the burning conditions prevailing on the day of ignition may not be necessarily coincide with fire run(s) which actually contributed to most of the final area burned). The majority of the fires fell within a 40-km radius of the nearest weather station, with some in the 40-80 km range, and only a few beyond 80 km. This compiles with the traditional opinion that reasonably reliable correlations with various measures of "fire business" for an area can be made within a 40-km radius of a fire weather station (Beall 1950; Williams 1963). Fires occurring beyond the northern protection limit (Fig. 1) were not included as part of the analysis.

RESULTS AND DISCUSSION

Man-caused vs. Lightning Fires

Traditionally, lightning fires have been considered the 'problem' fires in this area and in other parts of Manitoba (Nicholls 1979). LaDochy and Annett (1983) have identified the frontal thunderstorm as the synoptic weather type to produce the most intense electrical activity and severe lightning damage in southern Manitoba. Table 1 substantiates this since man-caused fires accounted for 35% of the total number of fires but only 2% of the area burned and 8% of the suppression costs. Also, the maximum size of a man-caused fire was 440 ha compared to 47 600 ha for a lightning fire and the average man-caused fire size was 39 times smaller than the average lightning fire size.

Time of year: Spring vs. Summer

The definition of the "spring fire season" adopted for this study was the period from snow melt up to and including June 10 (Kiil et al. 1977). Thus, the "summer fire season" was defined as the period from June 11 until the end of record keeping in September. Table 2 indicates that the number of lightning and man-caused fire is lower in the spring than in the summer; but the average fire size is higher in the spring regardless of fire cause. This is especially true for lightning fires which are, on average, six times larger in the spring compared to the summer.

Table 1. Forest fire statistics by major causative agent for the northwestern Manitoba study area during the 1980-84 fire seasons.

Statistic	Fire Cause	
	Lightning	Man
Number of fires	320	172
% of total	65	35
Area burned (ha)	208 000	3000
% of total	98	2
Average fire size (ha)	650	16.5
Maximum fire size (ha)	47 600	440
Suppression costs ($)	6 300 000	575 000
% of total	92	8
Average suppression costs per fire ($)	19 700	3330
Maximum suppression costs per fire ($)	520 500	68 500

Table 2. Forest fire statistics by major causative agent and time of year for the northwestern Manitoba study area during the 1980-84 fire seasons.

Statistic	Lightning Fires		Man-caused Fires	
	Spring	Summer	Spring	Summer
Number of fires	29	291	67	105
% of total	9.1	90.9	39	61
Area burned (ha)	77 900	130 300	1375	1451
% of total	37.4	62.6	48.7	51.3
Average fire size (ha)	2687	448	20.5	13.8
Maximum fire size (ha)	47 600	36 390	410	440

The more favourable burning conditions in the spring are due to a number of reasons including: low coniferous foliar moisture content, lack of deciduous foliage, the presence of cured and highly flammable fire surface fuels, and increased fire weather severity. The combination of these factors facilitate a wildfire's rate of spread, increasing its intensity, thus making control and suppression more difficult. Evidence of increased fire weather severity in the spring is found in Table 3 which shows that man-caused and lightning fire occurrence days have higher average ISI values in the spring than during summer portion of the fire season. This is also the case for the FWI with lightning fires and the FFMC with man-caused fires. Wind speed is a major factor influencing each of these FWI System components and Table 3 shows that the average wind speed is approximately 4.5 km/h higher for spring fires than for summer fires. The influence of the higher wind speeds during the spring portion of the fire season maybe the primary cause of the increased fire weather severity. It's worth pointing out that during the 60s and early 70s, Alberta considered problem fires to be almost entirely restricted in the spring fire season. However, the 80s conclusively showed that the summer and fall can be such as disastrous (Kiil et al. 1986).

Three other points in Table 3 are worth noting. First, the average Buildup Index (BUI) for spring fires is lower than for summer fires, but fire intensity, represented by the FWI, is at a near equal or increased level. This implies fuel loading is less critical to the spring fire problem and the BUI may not be a suitable indicator of the spring fire potential. Second, the average dry-bulb temperature is much lower, on days with fires, in the spring compared to the summer. This illustrates that the use of temperature as a direct indicator of fire potential could be misleading since severe fire weather can exist at low temperatures due to a depressed relative humidity. Third, it is common to have significant amounts of precipitation (i.e., greater than 0.6 mm) on lightning fire occurrence days. This is not unexpected but it shows the need for a higher density of weather stations in this area than is presently the case. Increasing the number of stations would not eliminate this problem but would certainly improve the situation.

Fire Danger Classes

Fire danger classes have been used by fire management agencies as the basis for a variety of operational activities. These include: presuppression, suppression, detection, prevention, public information and prescribed burning activities. A fire danger class is, by definition (Canadian Committee on Forest Fire Management 1987), "A segment of a fire danger index scale identified by a descriptive term (e.g., Nil or Very Low, Low, Moderate, High, Very High or Extreme), numerical value (e.g., I, II, III, IV or V) and/or a color code (e.g., green, blue, yellow, orange or red)." Since the introduction of the FWI System into Manitoba in the early 1970s, fire danger classes have been determined as a function of the FWI. For this province, the number of classes and their upper and lower limits (see Table 4) were determined on the basis of a predetermined percentage of days occurring in each class over a given number of fire seasons using the summaries generated by Simard and Valenzuela (1972) based on a 10-year data base (i.e., 1957-1966). The fire danger classes given in Table 4 are still in use today, however, their current relevancy has not been formally analyzed. Table 5 provides an alternative set of FWI values associated with each fire danger class. These values were designated in an objective manner based on some recent development and application work associated with the FBP System (Lawson

Table 3. Mean values of daily fire weather observation and Canadian Forest Fire Weather Index (FWI) System components on fire occurrence days by major causative agent and time of year in the northwestern Manitoba study area during the 1980-84 fire seasons.

Parameter	Lightning Fires		Man-caused fires	
	Spring	Summer	Spring	Summer
1300 h CST Fire Weather Observations				
Dry-bulb temperature (°C)	18.9	22.7	15.9	21.5
Relative humidity (%)	52.0	52.9	41.4	49.3
10-m open wind (km/h)	15.0	10.6	16.3	11.8
24-h accumulated rainfall (mm)	1.7	1.8	0.2	1.2
% days with rain (>0.6 mm)	38	27	6	21
FWI System components				
Fire Fuel Moisture Code (FFMC)	80.1	82.3	87.3	84.6
Duff Moisture Code (DMC)	34.4	31.9	26.2	40.4
Drought Code (DC)	111.5	246.6	69.9	270.1
Initial Spread Index (ISI)	6.6	4.8	8.7	5.4
Buildup Index (BUI)	38.4	46.3	27.7	56.6
Fire Weather Index (FWI)	12.7	11.1	13.8	14.0

Table 4. Fire danger class scheme, based on frequency of occurrence, used in Manitoba since the 1972 fire season.

Fire Danger Class[1]	Percentage of days	Fire Weather Index	Buildup Index
Low	45	0-5	0-24
Moderate	35	6-16	25-61
High	15	17-30	62-99
Extreme	5	31+	100+

[1] Determined by preselecting the % of days in a fire season which should fall into each class and applicable to only the FWI.

Table 5. An alternate fire danger class scheme based on the fire intensity rank concept in the FBP System (see Figure 2a & b).

Fire Danger Class	Fire Intensity Rank	Fire Weather Index	Percentage of days[1]
I	1	0-3	42.4
II	2	4-13	38.5
III	3	14-23	14.7
IV	4-6	24+	4.4

[1] The actual % of days falling into each class based on the 1980-84 fire seasons in the northwestern Manitoba study area.

et al. 1985) (Fig. 2a and b).[3] The Low, Moderate, High, and Extreme classes given in Table 4 were equated to fire intensity ranks 1, 2, 3, and 4-6, respectively. They were also designated as I, II, III, and IV to avoid any possible confusion with the present fire danger classification scheme used in Manitoba. Although two extremely different methodologies were used to derive the FWI values associated with each fire danger class, there are only minor shifts in the percentage of days in each class. This allows for a direct comparison between Tables 4 and 5, and more specifically, the FWI values in each class. The difference in the FWI values is quite significant and causes the suitability of the original fire danger classes (Table 4) to perhaps be questioned. However, the mathematical basis for the two classifications must be kept in mind (Table 4 and 5).

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[3] Editor's Note: The chart and accompanying table were prepared initially for distribution at the 1986 Annual Meeting of the Canadian Committee on Forest Fire Management held January 21-23 in Ottawa, Ontario, in order to solicit comments, etc. on the concept. The prototype example, which was prepared for illustration purposes only, is in this case deemed applicable to upland jack pine stands on level ground. The key conceptual point incorporated into the chart/table is that the frontal fire intensity, expressed in kilowatts per metre (kW/m) (see Alexander 1982), determines the difficulty of controlling a fire (i.e., what kind(s) of fire suppression resources would or would not be effective). What is not considered is the "containment capability" required (i.e., the forces required for constructing fireguard in order to exceed the rate of perimeter growth and/or resistance to fireguard construction due to fuel and site characteristics). The assumption is made that the fire has reached a 'steady-state condition'. The Initial Spread Index (ISI) and Buildup Index (BUI) inputs can be determined on the basis of the standard daily FWI System calculations at 1200 h LST or an updated Fine Fuel Moisture Code and 10-m open wind speed. How do you use the chart/table? Give the ISI and BUI, determine the Intensity Rank (e.g., ISI = 10 and BUI = 40, then Rank = 3 and then refer to the table for a descriptive explanation based on the numerical rating between 1 and 6 (e.g., Rank 3: Moderately vigorous surface fire. Hand constructed ...). Note the corresponding intensities and approximate flame sizes, as well as the associated Fire Weather Index values for upland jack pine. Several possible applications of the Intensity Rank chart are foreseen. For example, actual or forecasted ISI and BUI values from an agency's fire weather station network could be plotted on a daily basis to assist in presuppression planning. The chart could also be used to evaluate the potential fire behavior of a going campaign fire. The proposed chart format is considered a convenient way of portraying the frontal fire intensity component of the FBP System for the generalist and would also serve as a quick reference for the fire behavior specialist as well. The approach does avoid the mathematical necessity of calculating frontal fire intensity using the $I = Hwr$ formula. User agencies may wish to replace or supplement the numerical ratings of 1 to 6 with generalized symbols (e.g., back-pack pump, fire shovel/Pulaski, helicopter with bucket, airtanker, flying drip torch, towering or wind-driven convection column), agency specific symbols (e.g., rappel crews, CL-215), color codes (e.g., Brown and Davis 1973, p. 245 -- green, blue, yellow, orange, and red) and/or typical fire behavior illustrated with representative photographs. When the first complete edition of the FBP System is issued, there will be a "customized" chart for each fuel type, included in the system, and/or fuel type/ground slope class (e.g., Fuel Type C-3/10-20% Ground Slope). The present example of the chart/table is based on readily available information (e.g., intensive review of world literature).

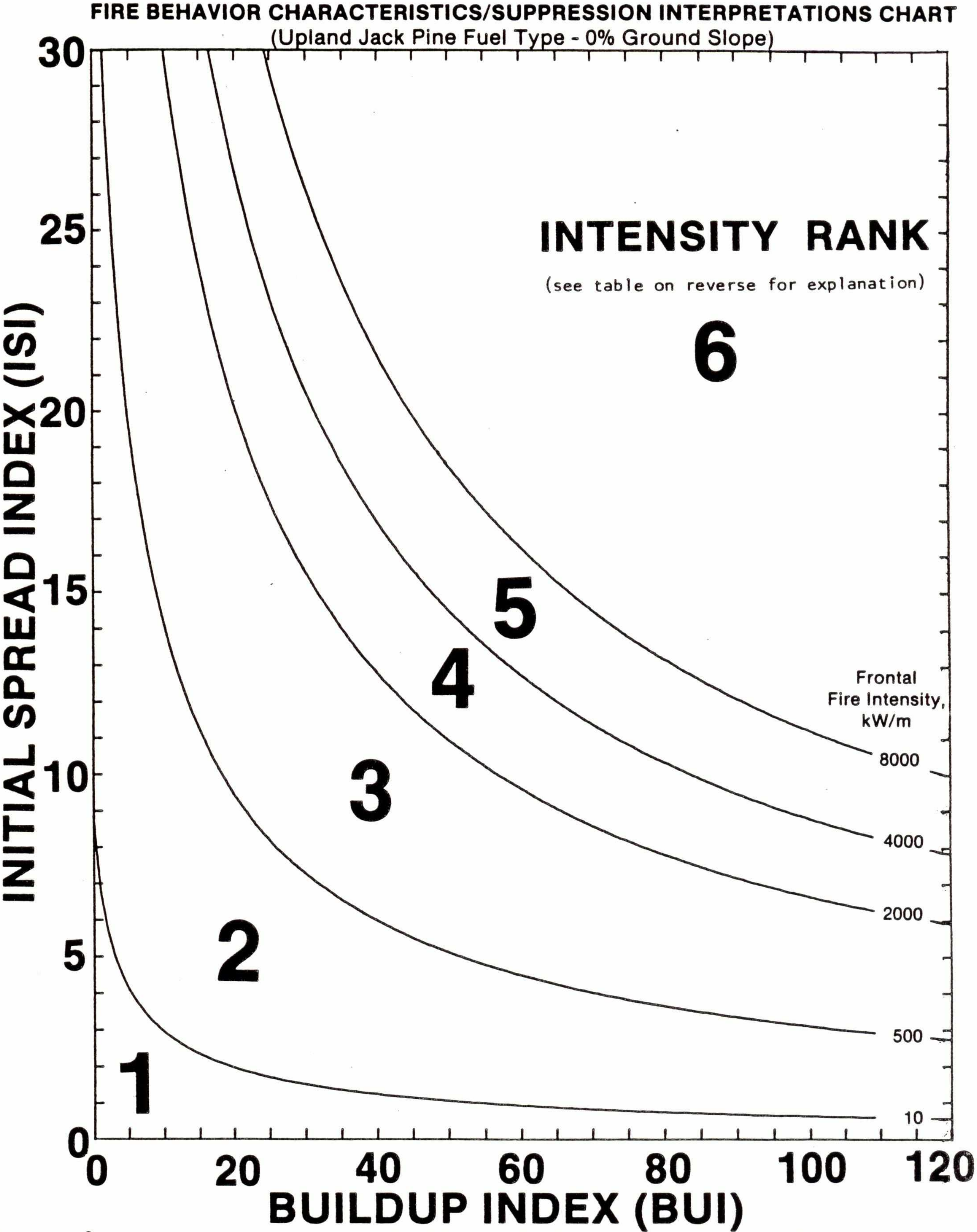

Figure 2a. Example of proposed fire behavior characteristics/fire suppression interpretations chart associated with the frontal fire intensity component in the Canadian Forest Fire Behavior Prediction (FBP) System.

Chart Rank	Frontal Fire Intensity (kW/m)	Head Fire[1] Flame Length (m)	Head Fire[1] Flame Height (m)	Description of Fire Behavior Characteristics and Fire Suppression Interpretations	Fire Weather Index[2] (FWI)
1	<10	<0.2	<0.1	Smouldering ground or creeping surface fire. Firebrands and going fires tend to be virtually self-extinguishing unless high Drought Code (DC) and/or Buildup Index (BUI) values[3] pervail, in which case extensive mop-up is generally required.	0-3
2	10-500	0.2-1.4	0.1-1.0	Low vigour surface fire. Direct manual attack at fire's head or flanks by fire-fighters with hand tools and water possible. Constructed fire guard should hold.	4-13
3	500-2000	1.4-2.6	1.0-1.9	Moderately vigorous surface fire. Hand-constructed fire guards likely to be challenged. Heavy equipment (bulldozers, pumpers, retardant air-craft, skimmers, helicopter w/bucket) generally successful in controlling fire.	14-23
4	2000-4000	2.6-3.5	1.9-2.5	Highly vigorous surface fire or passive crown fire (torching). Control efforts at fire's head may fail.	24-28
5	4000-8000	3.5-4.8	2.5-3.4	Extremely vigorous surface fire or active crown fire. Very difficult to control. Suppression action must be restricted to fire's flanks. Indirect attack with aerial ignition (i.e., helitorch and/or AID dispenser) may be effective.	29-33
6	>8000	>4.8	>3.4	"Blow-up" or "conflagration" type fire run; violent physical behavior probable. Suppression actions should not be attempted until burning conditions ameliorate.	>34

[1] Applicable to surface fire only; flame height based on flame length and a 45° flame angle.

[2] Applicable to mature jack pine stands on level ground.

[3] DC >300 and/or BUI >40.

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Figure 2b. Example of proposed fire behavior characteristics/fire suppression interpretations table associated with the frontal fire intensity component in the Canadian Forest Fire Behavior Prediction (FBP) System.

Fire Occurrence

Fire occurrence is commonly related to fire weather and fire danger through the use of fire danger classes[4]. Table 7 shows the percentage of fires occurring in each of the fire danger classes has given in Table 5. Theoretically, most fires should occur in class IV but Table 7 shows that the highest percentage of fires occur in class II. This is due to the greater percentage of days during the fire season which fall into class II. For instance, only 4.4% of all the days during the fire season fall into the class IV, compared to 38.5% for class II, meaning there is simply less chance for fires occurring in Fire Danger Class IV. Therefore, a more representative value is one which compares the number of fires in each class to the number of days occurring in each class. This standardized summary is given in Tables 6 and 7, however, the information presented in Table 8 is in relative terms where Fire Danger Class I is considered unity. According to Table 9, lightning fire occurrence is, on a relative basis, 4 times higher in the Fire Danger Class IV as compared to Fire Danger Class I.

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[4] Editor's Note: Strictly speaking, the Fire Weather Index (FWI) is a measure of fire intensity, the Initial Spread Index (ISI) of fire spread rate, and the Buildup Index (BUI) of fuel consumption. In other words, these three indexes represent fire behavior after ignition has taken place. The three fuel moisture codes --Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC), and Drought Code (DC)--on the other hand, represent fuel moisture, and should therefore be related to flammability and ease of ignition. None of the FWI System components says anything about the presence or level of activity of fire-starting agents, in other words, fire risk. And yet it will usually be found that, over a period of time, daily wildfire occurrence is fairly well related to one or more of these fire danger indices. This relation can only hold if short-term fluctuations in fire-starting activity (i.e., lightning and man) are averaged out over a long enough time. If the trend in fire-starting activity were to change permanently in one sense or other, then any previously established relation would obviously no longer hold. Within one fire season, human activity may vary with month, daily weather, and day of the week. The point to be made is that any comparison between real fire occurrence and the FWI System combines both flammability and risk. The FWI and its associated components can measure flammability, but cannot account for fire risk. Since a fire start depends most of all on the flammability of the fine surface fuel, the FFMC is the FWI System component most likely to compare well with wildfire occurrence. The FFMC has an important role in the ISI, and a lesser but still substantial role in the FWI. These two indices should therefore also correlate fairly well with daily fire occurrence. The BUI, DMC, and DC, on the other hand, may often have high values when the relative humidity is high, or after a light rain. They should therefore not be expected to compare as well with daily wildfire occurrences. It has been found, however, that lightning fire starts, which often involve more than the fine surface fuel, depend to some extent on the DMC and DC as well as on the FFMC. While the correlation between, say, FFMC and fire occurrence may be fairly good over the long run, an estimate of actual fire occurrence from day to day could be considerably improved by a subjective estimate of the daily fire-starting activity at the local level, to be used in combination with the FFMC or other component of the FWI System. It is hoped that a formal, yet simple national system or scheme(s) for man-caused and lightning fire occurrence prediction will be developed within the near future.

Table 6. Percentage of fires occurring in the northwestern Manitoba study area by fire danger class and major causative agent based on data for the 1980-84 fire seasons.

Fire Danger Class[1]	% Fire occurrence by cause	
	Lightning	Man
I	20.0	9.3
II	48.5	44.8
III	23.0	33.7
IV	8.5	12.2

[1] Corresponds to Fire Intensity Ranks 1, 2, 3, and 4-6, respectively (see Fig. 2).

Table 7. Daily fire occurrence rate in the northwestern Manitoba study area by fire danger class and major causative agent based on data for the 1980-84 fire seasons.

Fire Danger Class[1]	Number of fires per day by cause		
	Lightning	Man	Total
I	0.04	0.01	0.05
II	.11	.05	.16
III	.13	.11	.24
IV	.16	.13	.29

[1] Corresponds to Fire Intensity Ranks 1, 2, 3 and 4-6, respectively (see Fig. 2).

Table 8. Relative fire occurrence between fire danger classes by major causative agent for the northwestern Manitoba study area based on data for the 1980-84 fire seasons.

Fire Danger Class[2]	Relative fire occurrence[1]		
	Lightning	Man	Total
I	1	1	1
II	2.8	5	3.2
III	3.3	11	4.8
IV	4	13	5.8

[1] The ratio of percentage of days to percentage of fires for Fire Danger Class I was converted to 1. The relative fire occurrence for each successive class is proportional to the value for Fire Danger Class I.

[2] Corresponds to Fire Intensity Ranks 1, 2, 3 and 4-6, respectively (see Fig. 2).

SUMMARY AND CONCLUSIONS

Fire weather conditions and fire danger ratings are related to wildfire activity in a variety of ways. Below is a summary of the key points discussed in this paper:

(1) Lightning fires account for nearly all of the area burned (98%) and suppression costs (98%) but comprise only 65% of the total number of fires.

(2) Fire-weather severity is greater during the spring portion of the fire season than during the summer. This is due, in part, to higher speeds which in turn result in higher rates of fire spread.

(3) The BUI is not a suitable indicator of certain aspects of potential fire behavior during the spring portion of the fire season.

(4) Perhaps more objective fire danger classes can be determined on the basis of the latest findings in fire behavior science by employing the frontal fire intensity concept.

(5) The fire danger classification scheme presently used in Manitoba may no longer be appropriate given current and foreseen applications (e.g., establishing preparedness activity levels).

(6) On a relative basis, fire occurrence increases as the level of fire danger increases but the greatest percentage of fires occur in the "moderate" fire danger class.

The initial results of this study suggest that there is a great deal to be gained by analyzing fire weather and fire danger data in relation to wildfire activity in order to assist Manitoba fire managers in their planning and operational decision making activities[5].

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[5] Editor's Note: Correlating the FWI System components with the observed behavior of a particular wildfire in a specific fuel complex (e.g., Simard et al. 1986) is not the intent of a "calibration and performance study", but rather it is to guide the general prediction of certain aspects of total fire business (particularly fire load) for an administrative area based on historical evidence. Empirical correlations with various wildfire statistics can prove useful in establishing prevention and other presuppression activity levels. However, the results obtained by using this approach do of course require careful scrutiny and proper interpretation in relation to local conditions and changing fire management standards (e.g., policy on intensive protection). For example, a five-year record may be the minimum period of time required to reflect the expected variation in fire climate, but perhaps fire control technology during that period may have changed to such an extent that it obscures the important weather-related trends and effects. Any derived relationships would also be at least partly obscured because of: (1) the variation in fire risk with fire weather severity and (2) the general inclination by a fire management agency to gradually adjust their prevention, detection and preparedness activities as fire danger conditions worsen.

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LIST OF SEMINAR ATTENDEES

Name	Title	Affiliation[1]
Alexander, Marty	Fire Research Officer	CFS, NoFC, Edmonton
Armstrong, Jack	Systems Programmer	AES, PRWC, Winnipeg
Ball, Jim	Research Coordinator	CFS, MDO, Winnipeg
Balshaw, Mike	Regional Director	AES Central Region, Winnipeg
Banting, Wayne	Conservation Officer	MDNR, Winnipeg
Baver, Don	Officer-in-Charge	AES, WO, Saskatoon
Boughton, Bryan	Staff Officer-Meteorology	DND, CFB, Winnipeg
Cameron, Don	Operations Officer	CIFFC, Winnipeg
De Groot, Bill	Fire Research Officer	CFS, SDO, Prince Albert
Dmytriw, John	Sr. Staff Officer-Meteorology	DND - ACHQ, Winnipeg
Dube, Dennis	Superintendent of Forestry	Winnipeg Parks & Recreation Dept.
Flannigan, Mike	Forest Meteorologist	CFS, PNFI, Chalk River, Ont.
Fluto, Ken	Chief-Weather Services	AES Central Region, Winnipeg
Frosst, Robert	Instructor	DND - CFSM, Winnipeg
Gauthier, Tim	Helitac Offcier	MNDR, Eastern Region, Beausejour
Gorham, Keith	Planning & Tech. Serv. Officer	SDPRR, FMB, Prince Albert
Gravel, Jack	Weather Technician	OMNR, Algonquin Region, Hunstville
Henry, Dale	A/Chief-Forecast Operations	AES Central Region, Winnipeg
Hirsch, Kelvin	Fire Research Officer	CFS, MDO, Winnipeg
Hunter, Fraser	Officer-in-Charge	AES, WO, Regina
Klaponski, Carol	Project Officer	AES, PRWC, Winnipeg
LaDochy, Steve	Instructor	Univ. of Winnipeg, Geography Dept.
Legal, Louis	Supervisory Meteorologist	AES, PRWC, Winnipeg
Marchant, Tom	Fire Control Officer	MDNR, Interlake Region, Gimli
McLean, Dwayne	Meteorological Inspector	DND-ACHQ, Winnipeg
McQueen, John	District Manager	CFS, MDO, Winnipeg
Muddy, George	Meteorologist	AES, PRWC, Winnipeg
Pierce, Marv	Officer-in-Charge	AES, WWO, Winnipeg
Ostry, Tom	Sr. Develop. Meteorologist	AES, PRWC, Winnipeg
Raddatz, Rick	Sci. Serv. Meteorologist	AES Central Region, Winnipeg
Schaefer, Garry	Chief-Scientific Services	AES Central Region, Winnipeg
Schafer, David	Regional Fire Ranger	MDNR, Eastern Region, Lac Du Bonnet
Schroder, Bill	Meteorologist	AES, PRWC, Winnipeg
Shipley, Bill	Fire Management Officer	MDNR, FM&C, Winnipeg
Ulrich, Ken	Conservation Officer	MDNR, Hadashville
Vandevyere, Dan	Sr. Meteorologist	AES, PRWC, Winnipeg

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[1] Abbreviations: CFS = Canadian Forestry Service; NoFC = Northern Forestry Centre; AES = Atmospheric Environment Service; PRWC = Prairie Weather Centre; MDO = Manitoba District Office; MDNR = Manitoba Department of Natural Resources; WO = Weather Office; DND = Department of National Defence; CFB = Canadian Forces Base; CIFFC = Canadian Interagency Forest Fire Centre; SDO = Saskatchewan District Office; ACHQ = Air Command Headquarters; PNFI = Petawawa National Forestry Institute; CFSM = Canadian Forces School of Meteorology; SDPRR = Saskatchewan Department of Parks & Renewable Resources; OMNR = Ontario Ministry of Natural Resources; WWO = Winnipeg Weather Office; and F&MC = Fire Management and Communications section.

PREVIOUS PROCEEDINGS IN THE CENTRAL REGION FIRE WEATHER COMMITTEE SCIENTIFIC

SCIENTIFIC AND TECHNICAL SEMINAR SERIES

Alexander, M.E. (compiler & editor). 1985a. Proceedings of the First Central Region Fire Weather Committee Scientific and Technical Seminar (Apr. 17, 1984, Winnipeg, Man.). Government of Canada, Canadian Forestry Service, Northern Forest Research Centre, Edmonton, Alta. Study NOR-5-191 File Report No. 10. 26 p.

- Review of Operational Weather Forecast Procedures for the 1984 Fire Season -- Daniel A. Vandervyvere
- Day-1 Forecasting in Forest Fire Danger Rating -- Peter M. Paul
- Synoptic Fire Weather Climatology -- Roger B. Street
- Canadian Forest Fire Danger Rating System: an update -- Martin E. Alexander
- The Ash Wednesday Bushfires of 16 February 1983 in south-eastern Australia: video tape -- overview by Martin E. Alexander

Alexander, M.E. (compiler & editor). 1985b. Proceedings of the Second Central Region Fire Weather Committee Scientific and Technical Seminar (Apr. 17, Winnipeg, Man.). Government of Canada, Canadian Forestry Service, Northern Forest Research Centre, Edmonton, Alta. Study NOR-5-05 (NOR-5-191) File Report No. 11. 31 p.

- Daily People-Caused Forest Fire Occurrence Prediction -- David L. Martell, Samuel Otukal, and Brian J. Stocks
- The Lightning Location & Protection (LLP) System: Alberta's operational experience -- Nicholas Nimchuk
- Operational Lightning Fire Occurrence Prediction in Ontario -- Richard A. White
- Use of the 500 mb Height Anomaly Chart in Fire Management -- Ben Janz
- Addendum to the Literature on Australia's 1983 "Ash Wednesday" Fires -- compiled by Martin Alexander

Median Date of First Snow Cover
(2.5 cm or more)
for 20 Winters