Reprinted from the Preprint Volume, Ninth Conference on Fire and Forest Meteorology, April 21-24, 1987, San Diego, California. Published by the American Meteorological Society, Boston, Mass.

WILDFIRES AS A SOURCE OF FIRE BEHAVIOR DATA: A CASE STUDY FROM NORTHWEST TERRITORIES, CANADA

Martin E. Alexander

Fire Research Officer
Government of Canada, Canadian Forestry Service
Western & Northern Region, Northern Forestry Centre
5320 - 122 Street, Edmonton, Alta., Canada T6H 3S5

R.A. Lanoville

Fire Behavior/Science Officer
Government of Northwest Territories, Department of Renewable Resources, Territorial Forest Fire Centre
P.O. Box 7, Fort Smith, N.W.T., Canada X0E 0P0

1. INTRODUCTION

The importance of documented case studies or histories of wildfires (Alexander 1982) has been repeatedly emphasized by both fire managers and fire researchers (e.g., Schaefer 1961; Luke and McArthur 1978). For example, at the 4th Conference on Fire and Forest Meteorology, Chandler (1976) noted that "Time and time again case histories have proven their value as training aids and as sources of research data." We strongly support this notion and have endeavored to reflect it in our individual work areas in fire research and fire management, respectively (Alexander *et al.* 1983; Lanoville and Schmidt 1985; De Groot and Alexander 1986). The idea of relying on wildfires as a possible source of fire behavior data is especially pertinent to empirically-based schemes of quantitative fire behavior prediction such as employed in the Canadian (Alexander and others 1984; Lawson *et al.* 1985; Canadian Forestry Service 1987; Stocks 1986) and Australian (McArthur 1977; Luke and McArthur 1978; Cheney 1981, 1985) systems of forest fire danger rating; this fact is certainly significant at the extreme end of the fire intensity scale where experimental fires (e.g., Stocks 1987) are rather difficult to arrange.

There are many examples in Canada, United States and Australia where fire researchers have attempted to observe and document the behavior of wildfires, with varying degrees of data collection methods and monitoring equipment, on an *ad hoc* basis or in a more formal manner (e.g., Dibble 1960; Dieterich 1960; Chester and Adams 1963; Dell and Hull 1966; Sackett and DeCoste 1967; Cheney *et al.* 1968; McArthur and Cheney 1970; Walker and Stocks 1972; Stocks 1975; Barney *et al.* 1978; Norum 1982). For example, the Southern Forest Fire Laboratory in Macon, Georgia, maintained an organized, identified team(s) of fire research personnel for the purpose of documenting high-intensity wildfires in the southeastern United States (e.g., DeCoste *et al.* 1968) for many years.* Some limited documentation has also been undertaken by fire researchers serving as fire behavior officers on campaign fires (Chandler and Countryman 1959; Knutson 1962; Countryman and Chandler 1963; Dell 1966). Fire researchers have also been involved in many "after-the-fact" investigations of wildfire behavior (e.g., McArthur 1965; Billing 1985; Rothermel and Mutch 1986).

The purpose of this paper is to present a wildfire case study which exemplifies the basic premise that fire suppression personnel are often in the best position to record a few simple, yet "key" aspects of a fire's chronology. This opportunistic approach to documenting certain features of fire behavior is illustrated with an example of a free-burning, high-intensity crown fire (HY-36-81) which occurred near the town of Hay River, Northwest Territories (N.W.T.) (Fig. 1) in July 1981. The fire management terminology used here follows Merrill and Alexander (1987). Mountain Daylight Time (MDT) is used throughout the paper.

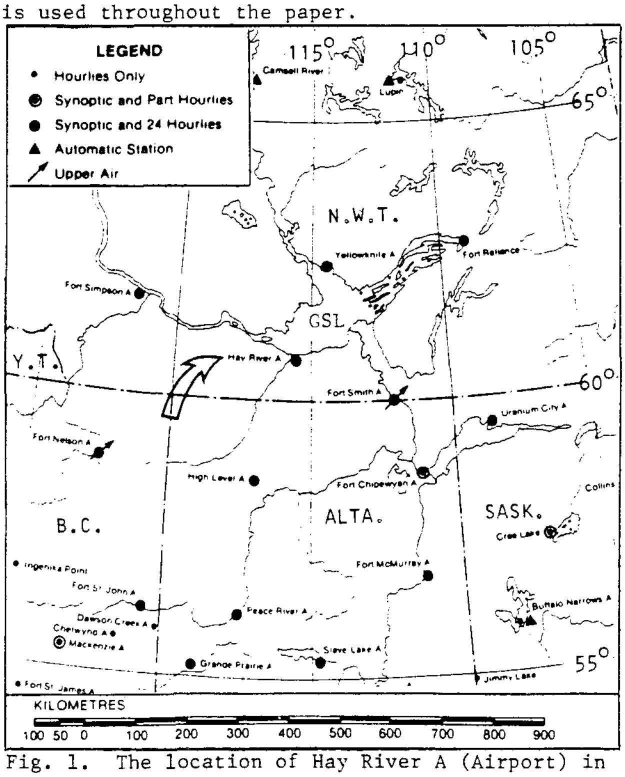

Fig. 1. The location of Hay River A (Airport) in the Northwest Territories and other meteorological stations in western and northern Canada, referred to in the text, operated by the Atmospheric Environment Service of Environment Canada (after Anon. 1977b). Great Slave Lake is denoted by GSL.

*D.D. Wade, Research Forester, USDA Forest Service, Southeastern Forest Experiment Station, Southern Forest Fire Laboratory, Macon, Ga., personal written communication, 15 September 1981.

2. ATTENDANT BURNING CONDITIONS

2.1 Fire Environment Characteristics

Topography.-- The fire area is situated at an elevation of 170 m above mean sea level (MSL). The terrain is flat.

Fire Weather.-- An upper ridge began developing over the fire area during the first few days of July 1981 (Janz and Nimchuk 1985). The ridge was weakened on July 3 as a short-wave upper trough (Fig. 2) and surface low (Fig. 3) moved across northern Alberta and the southern half of the N.W.T. Scattered wet thunderstorms and strong surface winds accompanied the passage of the low pressure system.

The 1800 h MDT vertical wind and temperature profiles at the Fort Nelson UA (Upper Air) station in British Columbia (B.C.) (elevation: 379 m MSL) are presented in Figs. 4 and 5; although Fort Smith UA is closer to the fire area (Fig. 1), the rawindsonde sounding from the B.C. station was deemed to be more representative in this particular case due to differences in air mass characteristics between the two UA sites in relation to the fire's location. The Fort Nelson UA soundings suggest: (1) that the lapse rate over the fire area during the afternoon and evening would produce a conditionally stable to unstable atmosphere, especially in the layer below 700 m and (2) there is strong indication of a low-level jet wind at about 500 m above the surface.

The cold front evident in Fig. 3 likely reached the fire area around 1700 h MDT as evident by the change in wind speed and direction at the Hay River airport meteorological station (elevation: 166 m MSL) which in the absence of any synoptic-scale disturbance is normally dominated by a northerly "inland sea-breeze" off Great Slave Lake during the daytime (Table 1).

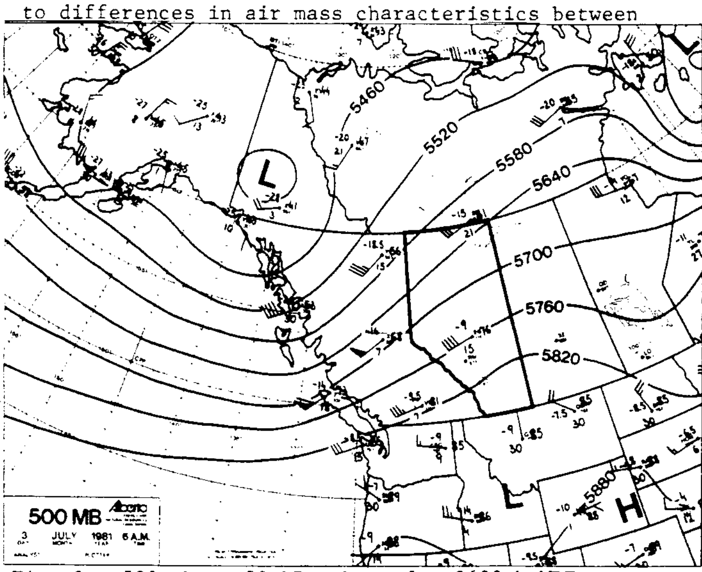

Fig. 2. 500 mb or 50 kPa chart for 0600 h MDT, July 3, 1981. The location of Hay River A is denoted by the three-letter identifier YHY, which is used for domestic purposes (Anon. 1977b), in Fig. 3.

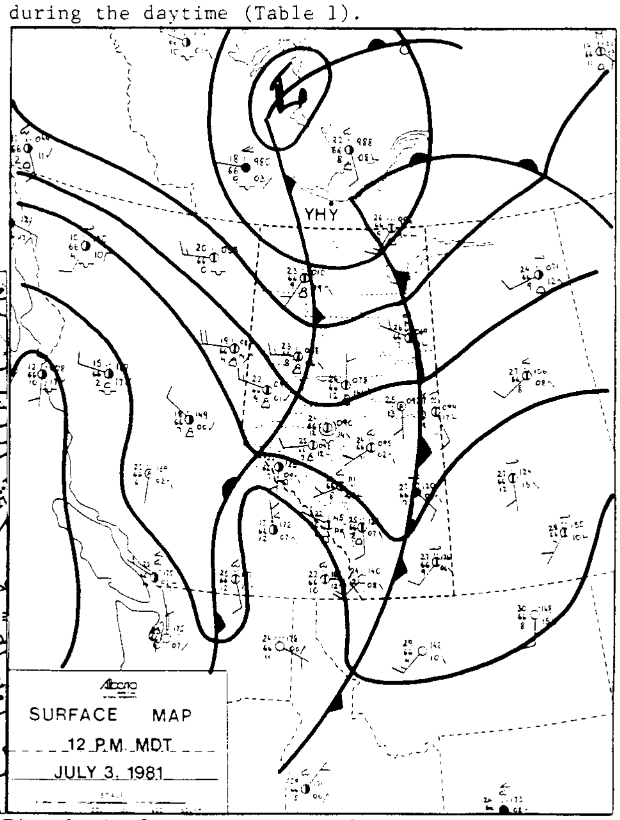

Fig. 3. Surface weather map for 1200 h MDT, July 3, 1981 (Hay River A location denoted by YHY).

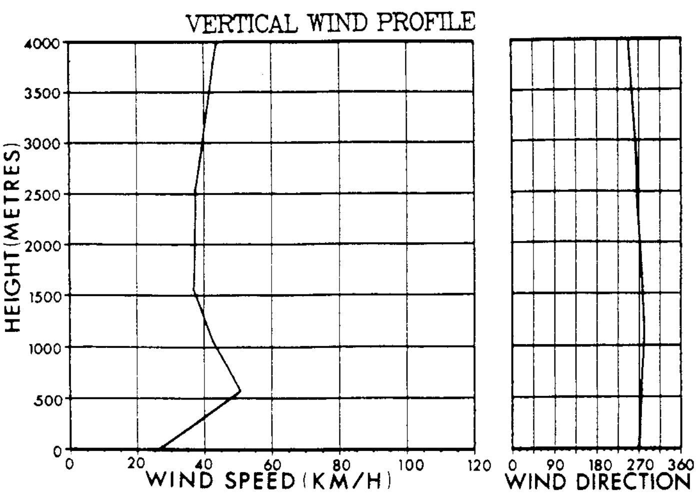

Fig. 4. Vertical wind profile above Fort Nelson UA, British Columbia, at 1800 h MDT, July 3, 1981.

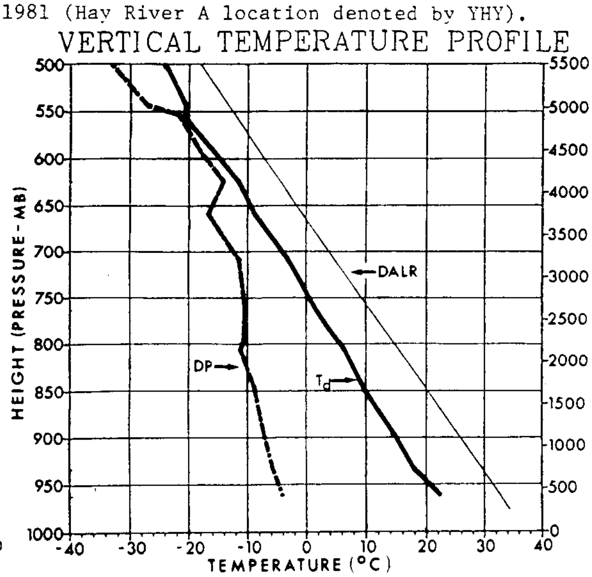

Fig. 5. Vertical temperature profile above Fort Nelson UA, British Columbia, at 1800 h MDT, July 3, 1981.

Table 1

Hourly weather observations and fire danger indices recorded at Hay River A, Northwest Territories, prior to and during the major run of the HY-36-81 Fire on July 3, 1981.

Local Time (h MDT)	Dry-bulb Temperature (°C)	Dew-point Temperature (°C)	Relative Humidity (%)	10-m Open Wind[a] Direction (deg.)	Speed (km/h)	Fine Fuel Moisture Code[b] (FFMC)	Initial Spread Index[b] (ISI)	Fire Weather Index[b] (FWI)
1400	21.2	7.7	42	60	22.2	89.7	12.3	42.1
1500	17.9	8.8	55	20	14.8	89.4	8.2	32.3
1508	-	-	-	10	7.4	-	-	-
1520	-	-	-	360	14.8	-	-	-
1600	19.8	8.7	50	320	13.0	89.4	7.4	30.1
1700	20.0	7.8	46	270	14.8	89.5	8.2	32.3
1706	-	-	-	270	22.2	-	-	-
1718	-	-	-	260	22.2	-	-	-
1800	19.8	9.8	52	270	18.5(41)	89.4	9.8	36.3
1900	20.7	3.1	32	300	33.3	89.7	21.5	59.7
2000	20.1	1.6	30	210	37.0(63)	90.0	27.1	68.7
2100	18.5	2.5	34	250	29.6	90.1	18.8	55.0
2200	17.5	2.9	38	260	9.3	90.1	6.8	28.5
2300	14.9	5.2	52	260	5.6	89.9	5.5	24.6
2400	13.4	3.9	53	210	14.8	89.7	8.4	32.8

[a]Hourly values represent the average for the preceding hour (e.g., the 1900 h MDT value is the mean wind speed for the period between 1800 h and 1900 h MDT (Anon. 1977a). Reported gusts are noted in parentheses.

[b]Based on hourly calculation of the FFMC as described by Van Wagner (1977) and Alexander *et al.* (1984).

Fuels.-- The fire area is located within the northern boreal forest region of Canada (Rowe 1972). Black spruce forests comprise the main fuel type; the deciduous element is minor. The overstory tree canopy in the fire area consisted of three density classes of black spruce (Fig. 6): fully, medium and sparsely stocked. The trees ranged from 5-15 m in height with their crowns extending to or near the ground; the fully-stocked stands exhibited a 1-2 m live crown base height. The understory flora consisted of a mixture of feathermosses, grasses and willows; the fully-stocked black spruce stands were however dominated by feathermosses. In most areas of N.W.T., the black spruce fuel complex represents a highly flammable fuel type.

Normally in early July, the accumulation of dead grass in the area would have been saturated with groundwater, but the two previous years (1979 and 1980) had experienced considerably below-normal precipitation (229.3 mm and 287.0 mm, respectively, compared to a 30-yr normal of 339.9 mm (Anon. 1982)) which resulted in a general lowering of the water-table, thereby exposing the dead grass material fully to the drying effects of daily weather; only 7.9 mm of precipitation had fallen since May 1st.

2.2 Fire Danger Indices

The surface weather observations during the major run of the HY-36-81 Fire are summarized in Table 1. The fire danger severity is expressed here in terms of the Canadian Forest Fire Weather Index (FWI) System (Turner and Lawson 1978; Canadain Forestry Service 1984; Van Wagner and Pickett 1985; Van Wagner 1987). The FWI System consists of six standard components. Computations are based on consecutive daily 1200 h local standard time observations of dry-bulb temperature, relative humidity, 10-m open wind speed and 24-h accumulated precipitation (if any). The first three components of the FWI System are fuel moisture codes representing the moisture content of fine surface litter, loosely compacted duff of moderate depth, and deep compact organic matter. The other three components are fire behavior indexes representing rate of fire spread, fuel available for combustion, and fire intensity on a relative rather than an absolute basis. The calculated components (Van Wagner and Pickett 1985) and fire weather observations for 1300 h MDT on July 3, 1981 based on the daily readings at the Hay River airport are as follows:

Dry-bulb Temperature - 20.8 °C
Relative Humidity - 42%
10-m Open Wind - ENE 9 km/h
Days Since Rain (≥0.6 mm) - 7

Fine Fuel Moisture Code (FFMC) - 90.7
Duff Moisture Code (DMC) - 128
Drought Code (DC) - 459

Initial Spread Index (ISI) - 8.3
Buildup Index (BUI) - 151
Fire Weather Index (FWI) - 33

Since its introduction in 1970, the FWI System has been used with increasing confidence in the N.W.T., as it has elsewhere (Kiil *et al.* 1986), as a guide in a variety of fire management applications. The FWI component is currently used as the principal indicator of fire danger in the N.W.T. The following fire danger classes, based on the frequency of occurrence (Van Wagner 1987), are presently used in the N.W.T.:

Fire Danger Class	Fire Weather Index
Low	0 - 4
Moderate	5 - 12
High	13 - 18
Very High	19 - 24
Extreme	25+

The Cumulative Daily Severity Rating (CDSR) (Harvey *et al.* 1986) on July 3 was 346.10. The fire danger indices for July 3, 1981 would have resulted in a

Perimeter Control Factor (PCF) of 42 m/min or the highest state of readiness and suppression resource build-up (Level 4) according to the new N.W.T. forest fire preparedness system (Lanoville 1986).

3. FIRE CHRONOLOGY AND DEVELOPMENT

The HY-36-81 Fire was started by lightning at approximately 1455 h MDT (Fig. 6); cloud-to-ground discharges were reported by the weather observer at the Hay River airport (8 km northwest of the fire area) at 1452 h MDT. The fire was discovered by commercial aircraft at 1500 h MDT and reported to the local fire management authorities in Hay River; the fire was located within a N.W.T. 'Fire Attack Zone' (Bailey 1985). Two 5-man helitack crews were dispatched to the fire scene at 1505 h MDT in a Bell 205A helicopter (w/ bucket) from the Hay River helitack base, 4.5 km from the fire's point of origin. By 1510 h MDT, the HY-36-81 Fire had developed into a crown fire and grown to about 0.5 ha in size. At 1545 h MDT, a Douglas DC-6B airtanker accompanied by a birddog plane joined the suppression efforts after actioning other nearby fire starts in the Hay River area. The fire was estimated by the birddog officer (BDO) to be about 12 ha in size at this time. Several 35 mm slies taken by the BDO (Fred Lepine) between 1550-1610 h MDT show the typical elliptical shape of a wind-driven fire spreading over flat country.

The initial attack action, although rapid, was hampered from the start by moderate, gusty winds which switched from the WNW to the WSW during the first hour or so following ignition. These winds were associated with thunderstorm activity to the north of the fire area. By 1630 h MDT, the crowning and associated spotting had resulted in a forward spread distance of approximately 1.4 km; the fire's rate of spread had increased with the stronger and gustier WSW winds which were associated with the passage of the approaching cold front. The combined efforts of the helitack crews and the DC-6B airtanker had no effect in containing the fire's growth; the aerial fire retardant drops were ineffective at the fire's head and so the flanks were worked. The air attack operations on the fire were abandoned at 1830 h MDT and the fire continued to spread freely while additional fire control resources were mustered to fight what was now deemed to be a campaign fire.

From 1700 h to 1900 h MDT the WSW winds remained moderate and gusty. During this time, the fire crowned first through the medium-stocked black spruce stands, which encompassed over one-half of the major run, and then through the fully-stocked ones, which formed a band along Sandy Creek (Fig. 6). After 1900 h MDT, the wind shifted to the SW and generally died down. The fire continued spreading in the surface fuels while intermittently torching the sparse tree cover and small intermingled, fully-stocked black spruce thickets.

At around 1900 h MDT, crawler tractors, working in two groups of three, started building fireguard from west to east along the north and south flanks of the fire which were producing very low flames and exhibiting very little lateral movement, thus allowing the tractors to work in close proximity to the fire's edge. The burnout crews had limited success igniting the remaining unburned fuels between the fireguard and the fire's edge. The tractors worked throughout the night building fireguard and making openings in the forest canopy for the construction of helispots.

Light rainshowers associated with the cold front passage started falling after midnight and continued until noon the next day (3.5 mm of rain was recorded at the Hay River airport at 1300 h MDT on July 4). The HY-36-81 Fire was easily mopped-up over the next week.

The HY-36-81 Fire travelled a total distance of nearly eight kilometres (Table 2) and burned over a final area of 1009 ha with an estimated perimeter length of 16.77 km. The fire's length-to-breadth

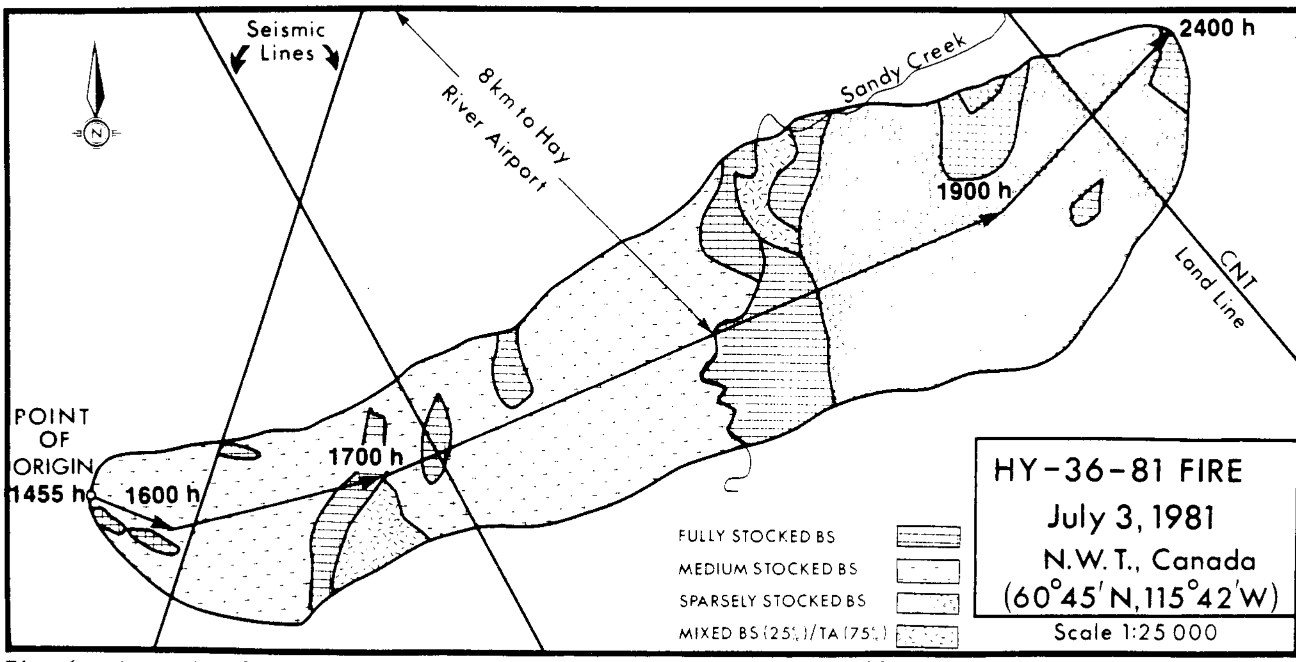

Fig. 6. Composite fire progress and forest cover type map for the HY-36-81 Fire. The generalized stocking classes were interpreted from vertical 1:25 000 scale black & white aerial photographs (BS = black spruce and TA = trembling aspen).

Table 2

Analysis of rate of spread associated with the main run of the HY-36-81 Fire during its first major burning period on July 3, 1981.

Fire Observation Interval	Time Interval (h MDT)	Interval Duration (h:min)	Elapsed Time (h:min)	Forward Spread Distance Interval (m)	Forward Spread Distance Cumulative (m)	Head Fire Spread Rate Interval (m/h)	Head Fire Spread Rate Cumulative (m/h)
A	1455 - 1600	1:05	1:05	696	696	644.6	644.6
B	1600 - 1700	1:00	2:05	1368	2064	1368.0	992.3
C	1700 - 1900	2:00	4:05	4186	6250	2093.0	1531.9
D	1900 - 2400	5:00	9:05	1690	7940	338.0	874.4

(L/B) ratio (Alexander 1985) was calculated to be 3.9:1. The fire's overall rate of area and perimeter growth were 111 ha/h and 30.8 m/min or 1.85 km/h, respectively.

4. FIRE DOCUMENTATION

In preparation for a campaign fire situation, the officer-in-charge of the HY-36-81 Fire (Don Brewer) coordinated fire suppression operations from an Allouette II helicopter. With the helicopter at his disposal, he was mobile over the entire fire to supervise the location and construction of helispots along the flanks of the fire, to locate and direct the stocking of aviation fuel caches, to evaluate water sources for helicopter bucketing, and to select access routes for the crawler tractors from the highway west of the fire area. While these activities were taking place, he maintained continual surveillance of the fire by mapping its progress and noting its behavior at more or less regular intervals. Because the HY-36-81 Fire was burning adjacent to a settlement, accurate, timely reports on its growth and behavior were needed for public information purposes. The location of the fire's head was updated every hour or two by mapping its position from the helicopter on vertical 1:25 000 scale black & white aerial photographs. Both natural and man-made features showed clearly on the photos. The natural features included Sandy Creek, numerous bogs, and the general forest cover type patterns. Man-made features included seismic lines (i.e., lines cleared of tree cover in order to move seismological equipment through the forest for gas and oil exploration purposes (Kiil 1970)), and the abandoned Canadian National Telephone (CNT) land line (Fig. 6). By using all of the identifiable landmarks, the fire's origin and subsequent spread was easily located on the photos and thus mapped with a high degree of accuracy.

5. APPLICATIONS IN FIRE MANAGEMENT AND RESEARCH

Wildfire case histories are an invaluable aid in the preparation of classroom training exercises (Cooper 1986) and in initial attack planning scenarios and analyses (Newstead and Potter 1982). The HY-36-81 Fire story has been utilized in many annual fire management courses in the N.W.T. since 1982.

The observations of the initial attack fire boss permitted the retrospective calculation of three sustained head fire spread rates in the lowland black spruce type (Tables 2 and 3) which were eventually used in the development of the rate of spread (ROS) relationship for Fuel Type C-2 (Fig. 7) in the 1984 interim edition of the Canadian

Table 3

Contributions of the HY-36-81 Fire to the Canadian Forest Fire Behavior Prediction System data base for Fuel Type C-2 (Boreal Spruce).

Fire Observation Interval	Initial Spread Index (ISI)	Head Fire Rate of Spread (m/min)	Head Fire Rate of Spread (km/h)
A	8.3	10.7	0.64
B	9.0	22.8	1.37
C	15.7	34.9	2.09

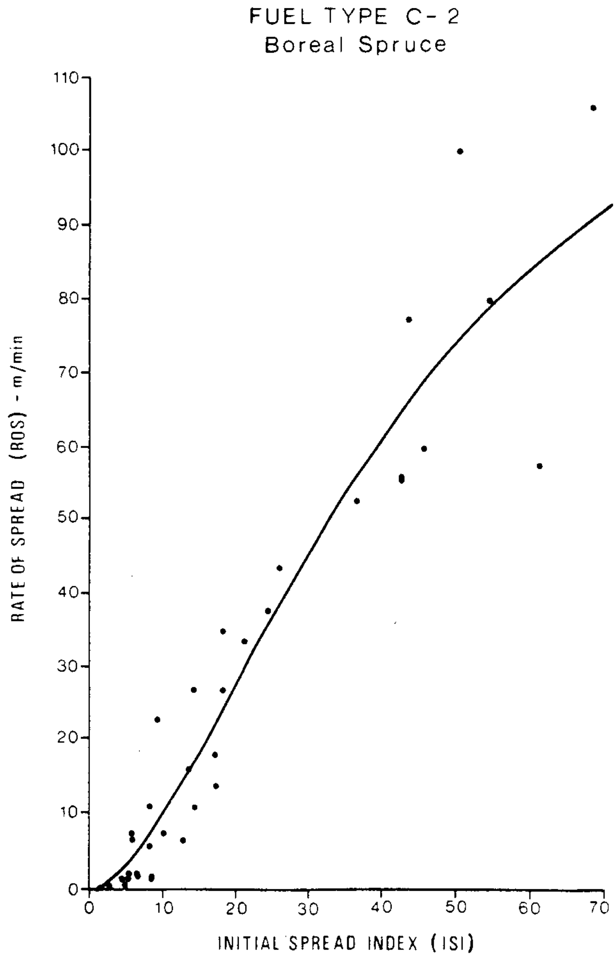

Fig. 7. Scattergram of Initial Spread Index (ISI) versus head fire rate of spread (ROS) observations from experimental and wild fires in Fuel Type C-2 (Boreal Spruce) in the 1984 interim edition of the Canadian Forest Fire Behavior Prediction System.

Forest Fire Behavior Prediction System (Alexander and others 1984; Lawson *et al.* 1985) upon which rests the basis for other means of predicting fire growth (e.g., McAlpine 1986; Feunekes and Methven 1987). The ROS value for observation A (Table 3) is undoubtedly at least partly influenced by the fire's initial period of acceleration (Luke and McArthur 1978; Cheney 1981, 1985).

6. CONCLUDING THOUGHTS

While a number of well-documented wildfires were used in developing the interim edition of the FBP System, much more information remains to be collected in order to evaluate the existing ROS relationships (and to allow for the future expansion of the system to include other important Canadian fuel types); a few well-documented spread rates, especially near the mid to high end of the Initial Spread Index range, would probably do more to improve the existing relationships than a mass of fire report data of low individual reliability. The highest priority for documentation should be wildfires which occur near established weather stations. There is also a more general need by fire managers to gather ROS data in a systematic and reliable fashion in order to rationally verify and/or adjust their fire behavior predictions in both initial and extended burning period situations. This is certainly not an easy task for fire managers or fire researchers, primarily because wildfire occurrence is unpredictable as to time and place, and numerous logistical problems arise when attempting to observe and monitor wildfire behavior. However, fire suppression personnel are generally "in the right place at the right time" to make certain critical observations, especially during the earlier stages of a wildfire, and if properly trained, to document them in a consistent manner; on campaign fires, a designated fire behavior officer generally fulfills the role of "historian" (Anon. 1985).

Some general guidelines with respect to traditional approaches of documenting fire spread and obtaining the necessary weather observations to complete the analysis were offered in the interim FBP System user guide (Alexander and others 1984, p. 61-62) and will therefore not be repeated here. There is certainly the need to examine the application of existing and new technology in this regard as well. Thermal infrared scanning from fixed- and/or rotary-wing aircraft (Lawson 1975; Warren and Wilson 1981) would provide more accurate maps of fire growth (spread rate, size, shape, etc.), including spot fire behavior (e.g., maximum distances), than conventional visual methods would allow. Hourly wind data is a prerequisite to any detailed ROS analysis; the WM-680 Wind Monitor (anemometer and display unit) produced by Forest Technology Systems (FTS) Ltd. of Victoria, B.C.† (the first author of this paper provided FTS with the initial concept for the device), is a portable, simple to use and relatively inexpensive instrument for obtaining the average wind speed and peak gust at 10-min intervals. The development of remote (RAWS) and portable remote (PRAWS) automatic weather stations permits the transmission of observations on a preplanned or "on request" basis (Warren and Vance 1981; Ward 1983). Field portable equipment is available for obtaining "on-site" vertical temperature and/or wind profiles (Silversides 1974; Turner and Markes 1974). Other aspects of fire behavior and related phenomena such as flame size, convection column dynamics, fire whirls and horizontal roll vortices can be documented by various photographic means (Anon. 1971; Lyons 1978; Sutton 1984), including the use of video and time-lapse cameras; lookouts have obtained good photographic records of wildfire development with a 35 mm camera in the past.

†The exclusion of certain manufactured products does not imply rejection nor does the mention of other products imply endorsement by the Canadian Forestry Service or the GNWT Department of Renewable Resources.

Acknowledgments.-- The authors wish to thank M.E. Maffey and R.M. Smith of the Northern Forestry Centre for their assistance in the preparation of this paper. Special thanks are due to Ben Janz of the Alberta Forest Service for the preparation of Figs. 2 and 3. Finally, Neil Parker of the Atmospheric Environment Service (AES) Western Region and the AES Canadian Climate Centre were helpful in providing the basic meteorological data used in this paper.

REFERENCES

Alexander, M.E., 1982: Bibliography of wildfire case histories and studies. Can. For. Serv., North. For. Res. Cent., Edmonton, Alta., Study NOR-5-191 File Rep. No. 4, 9 pp. [last revised April 1987].

Alexander, M.E., 1985: Estimating the length-to-breadth ratio of elliptical forest fire patterns. *Proc. Eighth Conf. Fire and Forest Meteorology* (Apr. 29-May 2, Detroit, Mich.). Soc. Am. For., Bethesda, Md., SAF Publ. 85-04, p. 287-304.

Alexander, M.E., B. Janz and D. Quintilio, 1983: Analysis of extreme wildfire behavior in east-central Alberta: a case study. *Preprint Vol. Seventh Conf. Fire and Forest Meteorology* (Apr. 25-28, Fort Collins, Colo.), Am. Meteor. Soc., Boston, Mass.

Alexander, M.E., B.D. Lawson, B.J. Stocks and C.E. Van Wagner (listed in alphabetical order), 1984: User guide to the Canadian Forest Fire Behavior Prediction System: rate of spread relationships. Interim ed. Can. For. Serv., Fire Danger Group, 73 pp. + Supplements [1st printing - July 1984; Revision & 2nd printing - Sept. 1984].

Alexander, M.E., B.S. Lee and C.Y. Lee, 1984: Hourly calculation of the Fine Fuel Moisture Code, Initial Spread Index, and Fire Weather Index with the Texas Instruments model 59 hand-held calculator. Can. For. Serv., North. For. Res. Cent., Edmonton, Alta., Study NOR-5-191 File Rep. No. 7, 17 pp.

Anon., 1971: Photography from lightplanes and helicopters. Eastman Kodak Co., Rochester, N.Y., Kodak Publ. No. M-5, 24 pp.

Anon., 1977a: Manual of surface weather observations. 7th ed. Environ. Can., Atmos. Environ. Serv., Cent. Serv. Direct., Toronot, Ont., n.p.

Anon., 1977b: METSTAT: Meteorological stations in Canada. Environ. Can., Atmos. Environ. Serv., Cent. Serv. Direct., Toronto, Ont., n.p.

Anon., 1982: Canadian climate normals - temperature and precipitation, 1951-1980: The North -- Y.T. and N.W.T. Environ. Can., Atmos. Environ. Serv., Downsview, Ont., 55 pp.

Anon., 1985: Fire behaviour officer M-200 course manual. Ont. Min. Nat. Resour., Aviation & Fire Manage. Cent., Sault Ste. Marie, Ont., n.p.

Bailey, R., 1985: Managing large fires in the Northwest Territories. *Proc. Intermountain Fire Council 1983 Fire Management Workshop* (Oct. 22-24, 1983, Banff, Alta.). Can. For. Serv., North. For. Res. Cent., Edmonton, Alta., Inf. Rep. NOR-X-271, p. 41-43.

Barney, R.J., N.V. Noste and R.A. Wilson, 1978: Rates of spread of wildfire in Alaskan fuels. USDA For. Serv., Pac. Northwest For. & Range Exp. Stn., Portland, Oreg., Res. Note PNW-311, 12 pp.

Billing, P., 1985: The Avoca Fire, 14 January 1985. Dep. Conserv., For. & Lands, Fire Prot. Branch, Melbourne, Vic., Res. Rep. No. 23, 9 pp.

Canadian Forestry Service, 1984: Tables for the Canadian Forest Fire Weather Index System. 4th ed. Can. For. Serv., Ottawa, Ont., For. Tech. Rep. 25, 48 pp.

Canadian Forestry Service, 1987: Canadian Forest Fire Danger Rating System: users' guide. Can. For. Serv., Fire Danger Group, Three-ring binder (unnumbered publication).

Chandler, C.C., 1976: Meteorological needs of fire danger and fire behavior. *Proc. Fourth Natl. Conf. Fire and Forest Meteorology* (Nov. 16-18, St. Louis, Mo.). USDA For. Serv., Rocky Mt. For. & Range Exp. Stn., Fort Collins, Colo., Gen. Tech. Rep. RM-32, p. 38-41.

Chandler, C.C., and C.M. Countryman, 1959: Use of fire behavior specialists can pay off. *Fire Control Notes*, 20(4), 130-132.

Cheney, N.P., 1981: Fire behaviour. *Fire and the Australian Biota*. Aust. Acad. Sci., Canberra, A.C.T., p. 151-175.

Cheney, N.P., 1985: New approaches to fire danger and fire behaviour. *Proc. Fire Weather Services Conf.* (May 13-14, Adelaide, S.A.). Aust. Dep. Sci., Bureau Meteor., Melbourne, Vic. p. 12.1-12.9.

Cheney, N.P., R. Hooper, D.A. McArthur, D.R. Packham and R.G. Vines, 1968: Techniques for the aerial mapping of wild fires. *Aust. For. Res.*, 3(4), 3-20.

Chester, G.S., and J.L. Adams, 1963: Checklist of wildfire observations and checklist of equipment for wildfire observation. Can. Dep. For., For. Res. Branch, Winnipeg, Man., Rep. 63-MS-19, 3 pp.

Cooper, A.N., 1986: Training using simulated forest fires. *Commonw. For. Rev.*, 65(2), 131-139.

Countryman, C.M., and C.C. Chandler, 1963: The fire behavior team approach in fire control. *Fire Control Notes*, 24(3), 56-60.

DeCoste, J.H., D.D. Wade and J.E. Deeming, 1968: The Gaston Fire. USDA For. Serv., Southeast. For. Exp. Stn., Asheville, N.C., Res. Pap. SE-43, 36 pp.

De Groot, W.J., and M.E. Alexander, 1986: Wildfire behavior on the Canadian Shield: a case study of the 1980 Chachukew Fire, east-central Saskatchewan. *Proc. Third Central Region Fire Weather Committee Sci. and Tech. Seminar* (Apr. 3, Winnipeg, Man.). Can. For. Serv., West. & North. Reg., North. For. Cent., Edmonton, Alta., Study NOR-5-05 (NOR-5-191) File Rep. No. 16, p. 23-45.

Dell, J.D., 1966: The fire-behavior team in action -- the Coyote Fire, 1964. *Fire Control Notes*, 27(1), 8-10, 15.

Dell, J.D., and M.K. Hull, 1966: A fire-behavior team field unit. *Fire Control Notes*, 27(3), 6-7.

Dibble, D.L., 1960: Fireclimate survey trailer. *Fire Control Notes*, 21(4), 116-120.

Dieterich, J.H., 1960: Operations plan - fire behavior case history study. USDA For. Serv., Intermt. For. & Range Exp. Stn., North. For. Fire Lab., Missoula, Mont., 16 pp.

Feunekes, U., and I.R. Methven, 1987: A cellular fire growth model to predict altered landscape patterns. *Proc. Perspectives on Land Modelling Workshop* (Nov. 18-22, 1986, Toronto, Ont.). Environ. Can., Ottawa, Ont. [*in press*].

Harvey, D.A., M.E. Alexander and B. Janz, 1986: A comparison of fire-weather severity in northern Alberta during the 1980 and 1981 fire seasons. *For. Chron.*, 62(6), 507-513.

Janz, B., and N. Nimchuk, 1985: The 500 mb anomaly chart - a useful fire management tool. *Proc. Eighth Conf. Fire and Forest Meteorology* (Apr. 29-May 2, Detroit, Mich.). Soc. Am. For., Bethesda, Md., SAF Publ. 85-04, p. 233-238.

Kiil, A.D., 1970: An assessment of fire hazard on seismic lines in Alberta. Can. For. Serv., For. Res. Lab., Edmonton, Alta., Inf. Rep. A-X-32, 13 pp.

Kiil, A.D., D. Quintilio and M.E. Alexander, 1986: Adaptation of a national system of fire danger rating in Alberta, Canada: a case study in technology transfer. *Proc. 18th IUFRO World Congress* (Sept. 7-21, Ljubljana, Yugoslavia), Division 6: General Subjects, p. 410-421.

Knutson, K.K., 1962: The place of the fire behavior officer in the fire suppression organization. *Fire Control Notes*, 23(3), 81-82.

Lanoville, R.A., 1986: Development of a preparedness system for forest fire initial attack in the Northwest Territories. *Proc. Third Western Region Fire Weather Committee Sci. and Tech. Seminar* (Feb. 4, Edmonton, Alta.). Can. For. Serv., West. & North. Reg., North. For. Cent., Edmonton, Alta., Study NOR-5-05 (NOR-5-191) File Rep. No. 15, p. 8-19.

Lanoville, R.A., and R.E. Schmidt, 1985: Wildfire documentation in the Northwest Territories: a case study of Fort Simpson-40-1983. *Proc. Second Western Region Fire Weather Committee Sci. and Tech. Seminar* (Mar. 6, 1984, Edmonton, Alta.). Can. For. Serv., North. For. Res. Cent., Edmonton, Alta., Study NOR-5-191 File Rep. No. 9, p. 17-22.

Lawson, B.D., 1975: Forest fire spread and energy output determined from low altitude infrared imagery. *Proc. Symp. Remote Sensing and Photo Interpretation* (Oct. 7-11, 1974, Banff, Alta.), Vol. 1. Can. Instit. Survey., Ottawa, Ont.

Lawson, B.D., B.J. Stocks, M.E. Alexander and C.E. Van Wagner, 1985: A system for predicting fire behavior in Canadian forests. *Proc. Eighth Conf. Fire and Forest Meteorology* (Apr. 29-May 2, Detroit, Mich.). Soc. Am. For., Bethesda, Md., SAF Publ. 85-04, p. 6-16.

Luke, R.H., and A.G. McArthur, 1978: *Bushfires in Australia*. Aust. Govt. Publ. Serv., Canberra, A.C.T., 359 pp. [reprinted in 1986].

Lyons, P.R., 1978: *Techniques of fire photography.* 1st ed. Natl. Fire Prot. Assoc., Boston, Mass., NFPA No. SPP-39, 224 pp.

McAlpine, R.S., 1986: Forest fire growth calculator. Can. For. Serv., North. For. Cent., Edmonton, Alta., For. Manage. Note No. 35, 8 pp.

McArthur, A.G., 1965: Fire behaviour characteristics of the Longford Fire. Commonw. Aust., Dep. Natl. Develop., For. & Timber Bureau, Canberra, A.C.T., Leafl. No. 91, 19 pp.

McArthur, A.G., 1977: Fire danger rating systems. *Special paper prepared for FAO/UNESCO Consultation on Forest Fires in the Mediterranean Region* (May 8-19, Marseille, France). Food & Agric. Organ. United Nations, Rome, Italy, FAO Document FO:FFM/77/3-01, 15 pp.

McArthur, A.G., and N.P. Cheney, 1970: The fire behaviour characteristics of the Basin Creek Fire, 29th December 1967 - 1st January 1968. Commonw. Aust., Dep. Natl. Develop., For. & Timber Bureau, For. Res. Instit., Canberra, A.C.T., 33 pp.

Merrill, D.F., and M.E. Alexander (editors), 1987: Glossary of forest fire management terms. 4th ed. Natl. Res. Counc. Can., Can. Comm. For. Fire Manage., Ottawa, Ont., Publ. NRCC No. 26516 [*in press*].

Newstead, R.G., and M.W. Potter, 1982: An initial attack planning model. *Proc. Symp. Computer Modelling: It's Application in Fire Management* (Oct. 20-22, 1981, Salt Lake City, Utah). Intermt. Fire Counc., Missoula, Mont. & Utah State Univ., Logan, Utah.

Norum, R.A., 1982: Predicting wildfire behavior in black spruce forests in Alaska. USDA For. Serv., Pac. Northwest For. & Range Exp. Stn., Portland, Oreg., Res. Note PNW-401, 10 pp.

Rothermel, R.C., and R.W. Mutch, 1986: Behavior of the life-threatening Butte Fire, August 27-29, 1985. *Fire Manage. Notes*, 47(2), 14-24.

Rothermel, R.C., and G.C. Rinehart, 1983: Field procedures for verification and adjustment of fire behavior predictions. USDA For. Serv., Intermt. For. & Range Exp. Stn., Ogden, Utah, Gen. Tech. Rep. INT-142, 25 pp.

Rowe, J.S., 1972: Forest regions of Canada. Can. For. Serv., Ottawa, Ont., Publ. No. 1300, 172 pp.

Sackett, S.S., and J.H. DeCoste, 1967: A new mobile fire laboratory. *Fire Control Notes*, 28(4), 7-9.

Schaefer, V.J., 1961: Better quantitative observations of atmospheric phenomena in going fires. *Proc. Soc. Am. For. 1960*, p. 120-124.

Silversides, R.H., 1974: An inexpensive and simple technique for measuring wind velocity in the lower 600m of the atmosphere. Can. For. Serv., Great Lakes For. Res. Cent., Sault Ste. Marie, Ont., Inf. Rep. O-X-200, 9 pp. + Appendix.

Stocks, B.J., 1975: The 1974 wildfire situation in northwestern Ontario. Can. For. Serv., Great Lakes For. Res. Cent., Sault Ste. Marie, Ont., Rep. O-X-232, 27 pp.

Stocks, B.J., 1986: The Canadian Forest Fire Danger Rating System -- recent developments. *Proc. Prescribed Burning in the Midwest: State of the Art Symp.* (Mar. 3-6, 1986, Stevens Point, Wisc.). Univ. Wisc., Stevens Point, Wisc., p. 14-19.

Stocks, B.J., 1987: Fire behavior in immature jack pine. *Can. J. For. Res.*, 17(1), 80-86.

Sutton, M.W., 1984: Extraordinary flame heights observed in pine tree fires on 16 February 1983. *Aust. For.*, 47(3), 199-200.

Turner, H.E., and J. Markes, 1974: A minisonde for atmospheric profiles. Environ. Can., Atmos. Environ. Serv., Downsview, Ont., Tech. Memor. TEC 811, 26 pp.

Turner, J.A., and B.D. Lawson, 1978: Weather in the Canadian Forest Fire Danger Rating System: a user guide to national standards and practices. Can. For. Serv., Pac. For. Res. Cent., Victoria, B.C., Inf. Rep. BC-X-177, 40 pp.

Van Wagner, C.E., 1977: A method of computing fine fuel moisture content throughout the diurnal cycle. Can. For. Serv., Petawawa For. Exp. Stn., Chalk River, Ont., Inf. Rep. PS-X-69, 15 pp.

Van Wagner, C.E., 1987: Development and structure of the Canadian Forest Fire Weather Index System. Can. For. Serv., Ottawa, Ont., For. Tech. Rep. 35.

Van Wagner, C.E., and T.L. Pickett, 1985: Equations and FORTRAN program for the Canadian Forest Fire Weather Index System. Can. For. Serv., Ottawa, Ont., For. Tech. Rep. 33, 18 pp.

Walker, J.D., and B.J. Stocks, 1972: An analysis of two 1971 wildfires in Ontario: Thackeray and Whistle Lake. Can. For. Serv., Great Lakes For. Res. Cent., Sault Ste. Marie, Ont., Inf. Rep., O-X-166, 13 pp.

Ward P.C., 1983: Evaluation of a remote recording weather station. Ont. Min. Nat. Resour., Aviation & Fire Manage. Cent., Sault Ste. Marie, Ont., Rep. No. 144, 14 pp.

Warren, J.R., and D.L. Vance, 1981: Remote automatic weather station for resource and fire management agencies. USDA For. Serv., Intermt. For. & Range Exp. Stn., Ogden, Utah, Gen. Tech. Rep. INT-116, 11 pp.

Warren, J., and R.A. Wilson, 1981: Airborne infrared forest fire surveillance -- a chronology of USDA Forest Service research and development. USDA For. Serv., Intermt. For. & Range Exp. Stn., Ogden, Utah, Gen. Tech. Rep. INT-115, 8 pp.

APRIL 21-24, 1987
SAN DIEGO, CALIFORNIA

Ninth Conference on Fire and Forest Meteorology

Sponsored by

AMERICAN METEOROLOGICAL SOCIETY

SOCIETY OF AMERICAN FORESTERS

with special participation from the

University of Wisconsin Fire Sciences Center at Stevens Point

COVER PHOTO: *Lightning storm in San Francisco Bay*
September 19, 1984
by Robert E. Martin

AMERICAN METEOROLOGICAL SOCIETY
45 Beacon St.
Boston, Mass. 02108