A RÉSUMÉ OF CURRENT FIRE RESEARCH IN THE CANADIAN FORESTRY SERVICE

by

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FOREWORD

This report was originally presented at the Bureau of Land Management, Alaska State Fire Seminar in Anchorage, Alaska, October 16, 1975. Although the main purpose of the paper was to give an overview of the current fire research program of Canadian Forestry Service, we emphasized the fire behaviour and fire suppression methods programs conducted at the Northern Forest Research Centre. To reflect the current situation we included some previously unpublished data which will be covered more adequately in several reports to be published shortly. Similarly, the views and opinions expressed about the application of danger rating, fuel appraisal and fireline construction data are our own and do not necessarily reflect those of other fire researchers in the Canadian Forestry Service.

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A RÉSUMÉ OF CURRENT FIRE RESEARCH ACTIVITIES IN THE CANADIAN FORESTRY SERVICE

by

A.D. Kiil and D. Quintilio

INTRODUCTION

The forest fire research program of the Canadian Forestry Service[1] (CFS) involves about 25 researchers plus technical support staff and total funding approaching 1.5 million dollars annually. Fire research staff and funds are about equally divided between the Ottawa-based Forest Fire Research Institute (FFRI) and regional establishments at Victoria, B.C. (Pacific Forest Research Centre), Edmonton, Alberta (Northern Forest Research Centre), Sault Ste. Marie, Ontario (Great Lakes Forest Research Centre), Chalk River, Ontario (Petawawa Forest Experiment Station), and St. John's, Newfoundland (Newfoundland Forest Research Centre).

The primary goal of the CFS fire research program is to provide, through research, development and application activities on fire management problems, for the greatest reduction of forest fire losses and control costs consistent with the realities of economics and ecology. Within this framework, the FFRI has the primary role of developing and conducting a program of research and development which is Canada-wide in scope and application, as well as providing expertise in aid of regional programs.

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[1] The Canadian Forestry Service is an integral part of the Environmental Management Service (EMS) of the Department of the Environment (DOE). In addition to the CFS, EMS includes the Canadian Wildlife Service (CWS), and the Inland Waters and Lands Directorates.

In general, the Institute places greater emphasis on work which has the potential for significant longer-term payoffs, including computer applications and electronics. Regional programs are basically mission-oriented with emphasis on providing practical solutions to the "day-to-day" problems facing the fire management agency. Longer-term investigations of a definitive nature continue as an integral part of the program, albeit on a relatively limited scale.

Identification of research problems and the assignment of work priorities have been the responsibility of each establishment. A wide range of problems are being tackled, according to needs expressed by fire management agencies, the probability of CFS being able to do the work and our own assessment of present and anticipated future needs. Development of meaningful liaison and cooperative procedures with client agencies at local, regional and national levels has received high priority. Advice on the CFS fire research program is received from the Canadian Committee on Forest Fire Control (CCFFC), which serves as a forum for all provincial and federal fire control agencies in Canada. At the regional level, several advisory committees and groups contribute to problem identification and program balance. Internally, a CFS Fire Research Program Advisory Group (FRPAG) meets annually to review and to propose approaches for improving coordination and integration of the entire program.

While advisory committees and groups of various kinds serve an essential function, the cooperation and sometimes direct involvement of fire researchers in operational programs has proven to be a key element in the development of some fire-related work at the regional level.

Testing and evaluation of airtanker/retardant drop effectiveness, fire-line construction rates and detection studies are examples of research activities where considerable familiarity with operations is essential for problem solution.

AN OVERVIEW OF THE CFS FIRE RESEARCH PROGRAM

The CFS fire research program has four primary aims as follows:

1. To develop methods for predicting occurrence of wildfires, and behavior of wild and prescribed fire.
2. To improve existing and to develop new methods and techniques so as to enable fire management agencies to assess and optimize effectiveness of fire suppression operations.
3. To understand the natural role of fire and fire effects on the environment and to develop concepts and procedures whereby this information can be integrated into fire management plans and operations.
4. To monitor, develop and standardize new fire management concepts, systems, planning aids, information sources and related material so as to enable fire management agencies to maximize net social and economic benefits from fire management across Canada.

The relative emphasis placed on each of these four major activities is evident from a listing and brief review of projects active during the 1974-75 fiscal year (Kiil, 1975).

Forest Fire Research Institute (FFRI)

Statistics, Technical Information and Liaison
Forest Meteorology
Improvement of Forest Fire Control Systems
Development and Application of Complex Fire
Management Systems
Forest Fire Detection

The collection, compilation and publishing of national forest fire statistics and related information has been a continuing function of the FFRI for many years. In addition, the Institute acts as a clearing house for technical information on fire control. Several meteorological studies have provided a better understanding of the complex relationships between weather and forest fire. The Project entitled "Improvement of Forest Fire Control Systems" covers several studies concerned with fire weather forecasting, fire physics and chemistry, analysis of the use of aircraft, measurement of effectiveness of water and retardants, and testing of pumps.

The development and application of complex management systems to forest fire management utilizes the computational capabilities of computers and available expertise of fire research and management personnel. A prototype fire management centre has been demonstrated to officials of federal and provincial fire management agencies. A thunderstorm tracking instrument has been developed and field tested. Networks of lightning sensors have been established in several areas to predict the occurrence of lightning-caused fires.

Petawawa Forest Experiment Station (PFES)

Forest Fire Behavior
The Effects of Fire on the Forest Environment

A major contribution to improved fire contol in Canada is represented by the development of the new Canadian Forest Fire Danger Rating System. This System, originally developed as a joint project involving the FFRI, the PFRC and to a lesser extent, most other regional establishments, is now in use throughout Canada, and refinements are being incorporated to increase its reliability in different fuels. Fire effects on tree growth, biomass, tree regeneration, vegetation diversity and succession are also being studied.

Newfoundland Forest Research Centre (Nfld. FRC)

Public Awareness
Technical Services

An ongoing study attempts to develop and schedule a newspaper, radio and television fire protection publicity campaign for the Newfoundland Forest Protection Association. Another study provides for fire control technical services, including development and demonstration of training programs.

Maritimes Forest Research Centre (MFRC)

Liaison and Development
Forest Fire Research (contract)

Forecasting of the Fire Weather Index for the Atlantic Provinces is an ongoing cooperative operational program involving the CFS, the Atmospheric Environment Service (AES) and the Fire Science Centre at the

University of New Brunswick (UNB). In recent years, the CFS has provided contract funds to the Fire Science Centre at UNB in support of fire research of direct interest to the MFRC.

Great Lakes Forest Research Centre (GLFRC)

Forest Fire Research

Analysis of past fire and weather data has facilitated the establishment of correlations between indices of the Canadian Forest Fire Weather Index Tables (Anon., 1970) and fire behavior. A prescribed burning program continues to provide empirical data required for the development of reliable fire behavior guides (Fire Behavior Indices) in major Ontario fuel types. A fuel classification system has been developed and is being field-tested. A study of wind patterns associated with major fuel complexes in continuing.

Northern Forest Research Centre (NFRC)

Reduction of losses by improved fire suppression methods
Reduction of losses by improved fire danger forecasting

The fire suppression methods program attempts to determine drop patterns of various airtanker/retardant combinations, to provide accurate fireline construction rates, to assist fire control agencies in raising the performance level of detection systems, to devise operational models for use in aid of suppression and to provide guidelines for improving suppression strategies and tactics. These and similar studies are developed in close cooperation with user agencies and results are often implemented when available. Work is continuing on development of Fire Behavior Indices for major fuel types, appraisal of fuel, development of guidelines for prescribed burining, and assessment of fire effects on the environment.

Pacific Forest Research Centre (PFRC)

Improved use of prescribed fire in forestry
Improved fire danger assessment
Improved prediction of wildfire behavior

A major area of work involves the development of prescribed burning guidelines for hazard reduction and site preparation for planting. Field instrumentation and sampling techniques are being developed to obtain fire behavior data from wildfires and operational prescribed burns. The evaluation, interpretation and application of the Canadian Forest Fire Danger Rating System continue as important work areas.

Thus the entire CFS fire research program consists of some 17 Projects, each with one or more Studies. More detailed discussion of several selected programs follows.

OPERATIONAL ASSESSMENT OF THE CANADIAN FOREST FIRE DANGER RATING SYSTEM

The Canadian Forest Fire Weather Index Tables (CFFWIT) were first published in 1970, with a revised 2nd edition to appear in time for use during the 1976 fire season (Anon., 1970). The Fire Weather Index (FWI) represents the relative intensity of a fire in a standard fuel type, and is derived from three primary fuel moisture codes and two intermediate sub-indices representing rate of spread and amount of available fuel. The system is dependent on solar noon readings of temperature, relative humidity, wind speed and precipitation amount. The codes and indices thus provide a uniform scale for rating fire season severity across Canada.

The basic building blocks of the Canadian system are the three moisture codes - the Fine Fuel Moisture Code (FFMC, representing the litter layer weighing about 0.05 lb/sq ft or 0.24 kg/m^2), the Duff Moisture Code (DMC, duff layer weighing about 1 lb/sq ft or 4.86 kg/m^2) and the Drought Code (DC, compact organic layer weighing at least 5 lbs/ft^2 or 25 kg/m^2) when dry. The three moisture codes plus wind are linked to produce two sub-indices, the Initial Spread Index (ISI) and the Buildup Index (BUI), representing rate of spread and total fuel available to the spreading fire. The Fire Weather Index (FWI) combines the ISI and the BUI and represents line-fire intensity in Btu sec ft or kcal/sec-m of fire front.

While the System is based on actual fuel moisture and fire behavior data collected over the past several decades, it is sensitive to weather only and does not reflect the effect of fuel type on fire behavior. In addition, fire bevavior is affected by such factors as latitutde, slope, aspect, elevation, condition of lesser vegetation (green vs. cured), type and position of weather systems, time of year and the diurnal weather pattern. In fact, the list is almost endless and a definitive system of fire danger rating is not likely to appear on the horizon for some time.

A CFS Working Group is presently preparing a User's Interpretive Manual to enable fire management agencies to better understand, interpret and use the Tables as a decision-making aid in various planning and operational activities. By presenting the best available information on fire danger at the national level, we hope to extend and refine the fire manager's ability to adapt and apply danger rating principles and practices for local and regional use. Manual topics include Description of Codes and Indices, Interpretation of the Six Components, Calibration and Assessment of Codes and Indices, Effects of Topography, and Fire Behavior Indicies for major slash and standing timber fuel complexes. Some of these guides are based on approximations and generalizations, but we feel that the overriding purpose of the exercise is to recognize key factors not presently incorporated into the Tables and to synthesize this information in the form of immediately useable guides for regional and local applications.

If one accepts the premise that the current system satisfies national needs but is not sufficiently refined for effective use at the local level, then the material incorporated into the Manual should have a very salutory effect on the fire manager's ability to extend the system's applicability at the level of a forest district or region. While some fire management agencies utilize specific codes and indices to guide site-specific operational activities such as prescribed burning, the most widespread application of the danger rating system is in various prevention, detection and related pre-suppression planning activities. Development of absolute Fire Behavior Indices for major fuel types is considered to be a desirable goal, but it is recognized that full use of this type of information will be contingent on availability of up-to-date fuel type maps, denser weather station networks, improved fire weather forecasts and similar considerations. The remainder of this section will describe some recent and ongoing work to extend the applicability of the System, particularly in the boreal forest region.

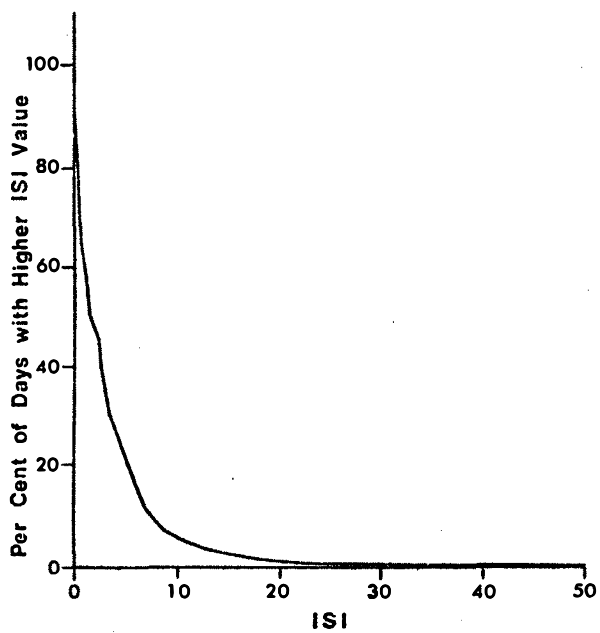
Calibration of Codes and Indices

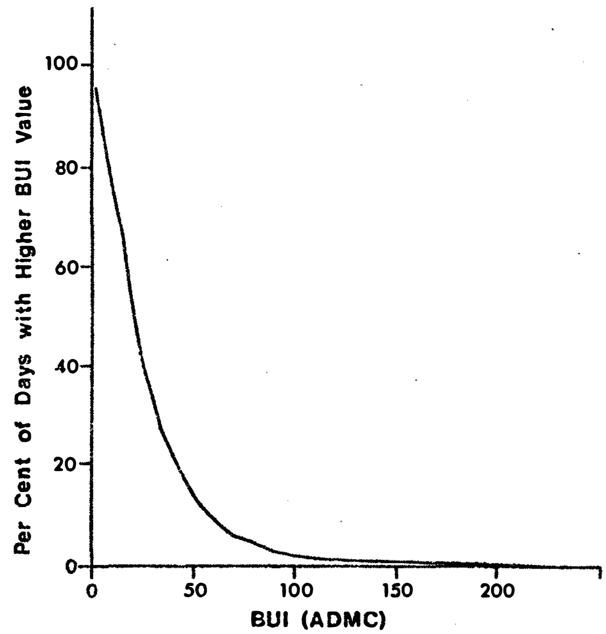
Since the Fire Weather Index refers primarily to a standard pine fuel type and is useful as a general index of fire danger across Canada, calibration of the FWI and component codes and indices is intended to extend the System's usefulness for predicting certain aspects of fire behavior. Commonly, historical codes and indices are compared with fire frequency, fire spread, area burned, and suppression costs. Knowledge of accumulative index frequencies and their correlation with aspects of fire behavior allows the fire planner to establish danger classes to serve as a basis for pre-suppression and suppression activities, including prevention, regulation of public use, logging restrictions, and detection and dispatch procedures.

This approach to FWI calibration has proven useful but requires careful scrutiny and interpretation in relation to local conditions and changing fire management standards. For example, a ten-year period may be the minimum period of time required to reflect expected variation in fire climate, but fire control methods and techniques during that period may well have changed to such an extent that they obscure the important weather-related trends and effects. Nevertheless, calibration is an extremely important and useful exercise whereby the fire manager can gain considerable insight into fire business within and between years, seasons and administrative units.

A basic calibration procedure involves the calculation of accumulative frequency distributions for various codes and indices (Figure 1). These curves are useful to the fire manager in that they serve as a basis for establishment of descriptive danger classes (low, moderate, high, extreme, etc.) for various prevention and fire management planning activities. Figure 2 depicts seasonal trends of fire incidence and key indices in Alberta during the 5-year period 1965-69. As expected, average Buildup Index values increase steadily from spring to late summer, then decrease with the approach of cooler weather and shorter days. Based on the 1965-69 data, there is a tendency for fire incidence to decrease as the season progresses, with a peak period of man-caused fires in late spring and early summer, and a second peak of high lightning-fire incidence in mid-summer. In general, the fire manager needs to consider the presence of various seasonal ignition sources and fuel differences, and to adjust fire prevention, fire control and preparedness measures accordingly.

The associations between BUI and area burned, are shown in Figures 3 and 4. It is interesting to note that fire occurrence increases to a maximum at BUI 60 to 80, then falls off. The apparent decrease in fire business at high BUI levels is attributed to the relatively small proportion of days with high BUI, increased prevention and preparedness measures, and the possibility that lightning-fire incidence is lower





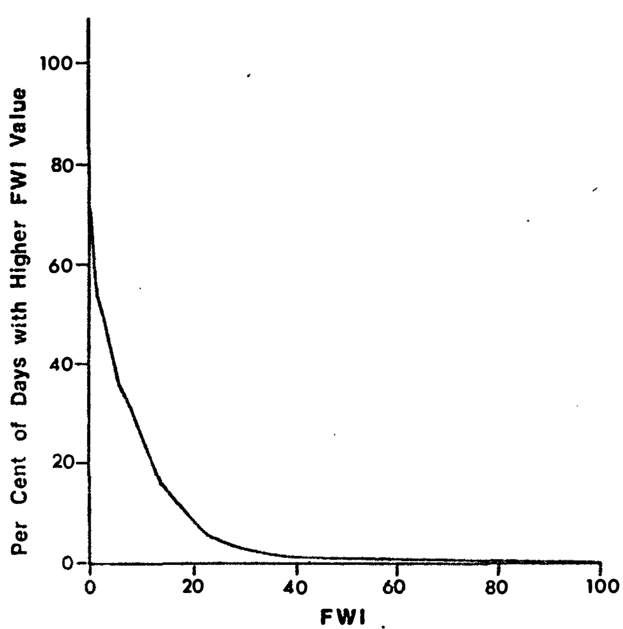


FIGURE 1 – Frequency distribution of ISI, BUI (ADMC) and FWI in Alberta, based on 30,124 observations during the five-year period 1965–69.

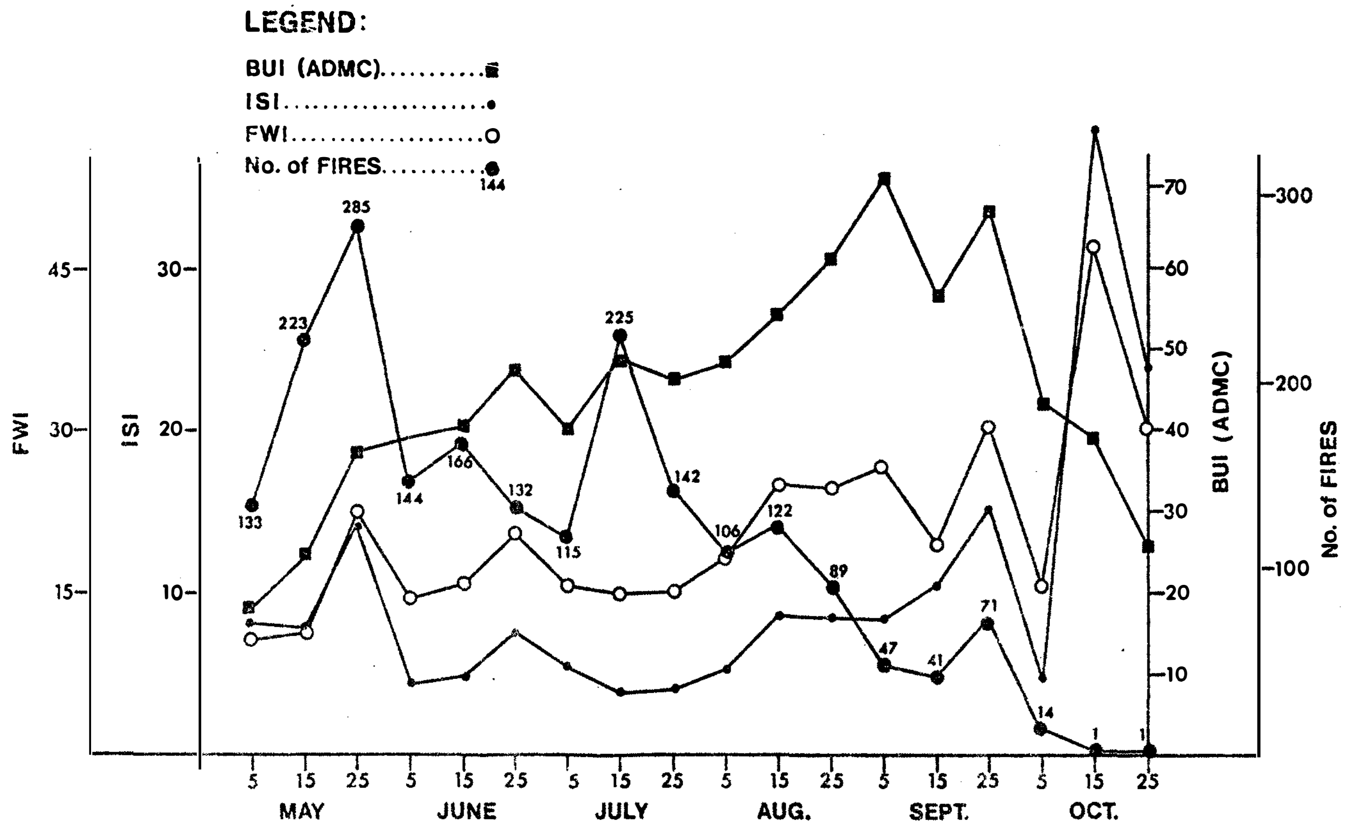


FIGURE 2 –Average values for ISI, BUI(ADMC), FWI and number of fires, on days with fires, by 10-day periods, 1965–1969.

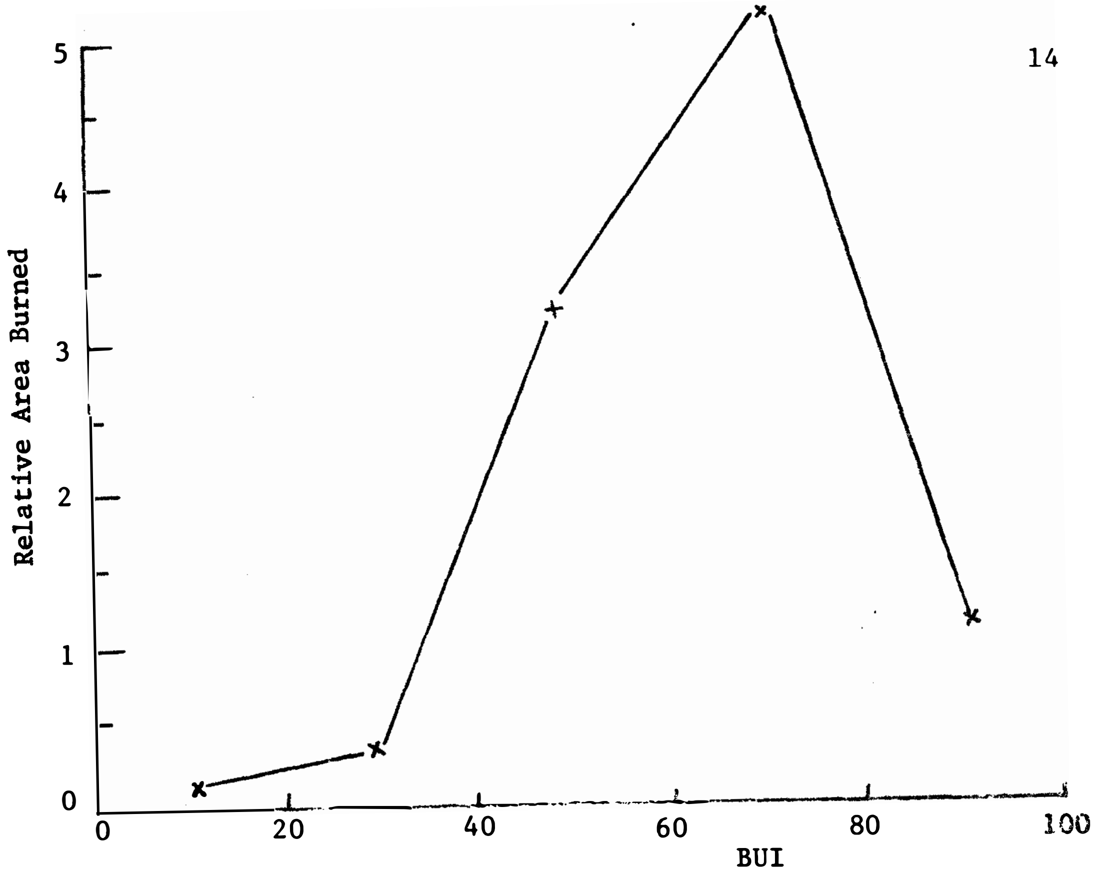


Figure 3. Relative number of Class E (500 acres+) fires in terms of area burned by BUI classes, Alberta, May 1-June 20, 1971-1974.

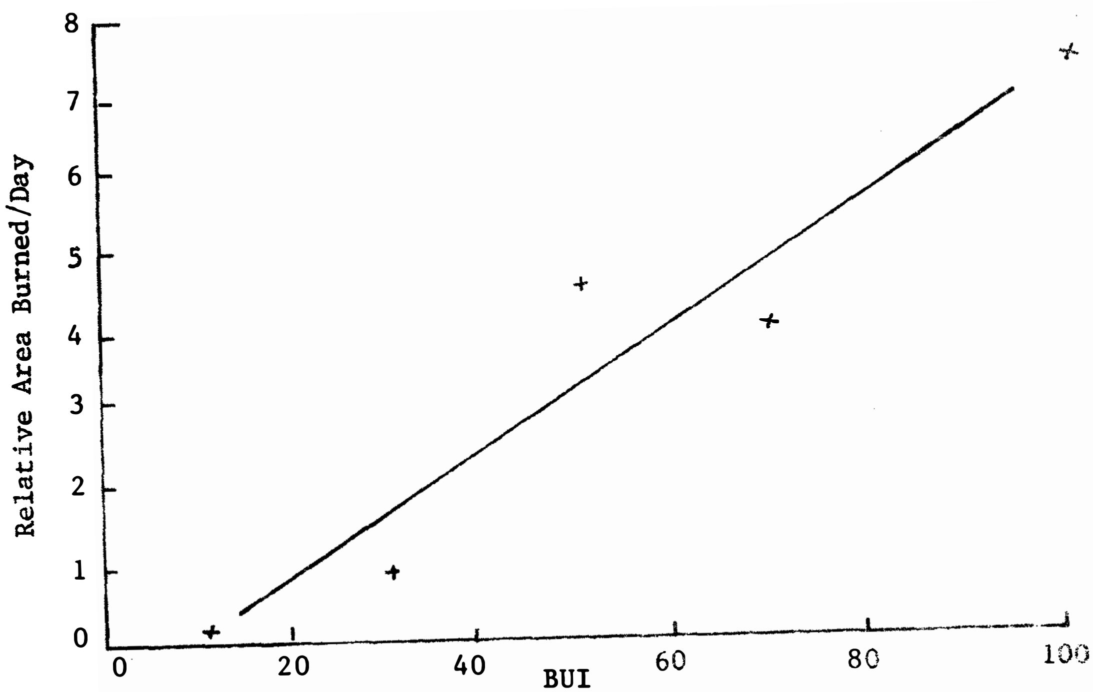


Figure 4. Class E fires. Area burned/day by Class E fires in Alberta, by BUI classes, May 1-June 20, 1971-1974

during long periods of settled weather. By contrast, area burned per day continues to increase over the full range of BUI. Table 1 illustrates the separate effects of ISI and BUI on fire incidence and enables the fire planner to better match the fire management organization to the problem. Preparation of such fire readiness plans should be accompanied by additional analyses relative to season, fire cause, area burned, fire size at initial attack and expected suppression expenditures. Table 2 illustrates the value of isolating the effects of fire cause and season on area burned and suppression costs.

The Alberta Forest Service (AFS) has a chronic spring fire problem that usually dominates the fire statistics. For example during the period 1971-74, 78% of the Class E (>500 ac or 202 ha) occurred between May 1 and June 20 (Miyagawa, 1975). Cured lesser vegetation, "blocking" high pressure systems and increased man-caused risk, all contribute to the seriousness of the spring fire period. To help the fire management agency cope more effectively with this problem manning tables, based on the FWI, lightning risk, and a crown foliar index (Stashko and McQueen, 1974) were issued for the spring of 1975 following a winter analysis by CFS and AFS. The tables provide for increasing manpower and equipment in six forest districts with increasing fire hazard and risk. Tables 3-5 describe the manning table matrix and associated expenditures (McQueen, 1975).

Additional manning up to Level 1 costs $171,000 for a five-day period in the six districts. However, the elimination of a single Class E fire should result in savings of $400,000. Owing to low fire

TABLE 1. FIRE INCIDENCE BY INITIAL SPREAD INDEX (ISI) AND BUILDUP INDEX (BUI) CLASSES IN ALBERTA, 1965-69

	BUI CLASSES							
ISI Classes	0-25	26-50	51-75	76-100	101+	Total	No. of Fires %	No. of Days %
				Lightning-Caused				
0.0-1.0	124	56	33	2	1	216	28.6	38
1.1-3.0	42	105	35	4	0	186	24.6	23
3.1-8.0	32	86	74	28	2	222	29.4	27
8.1-16.0	8	46	33	9	6	102	13.6	9
16.1	0	7	13	1	8	29	3.8	3
Total	206	300	188	44	17	755	100.0	
No. of fires (%)	27.3	39.8	24.9	5.8	2.2	100.0		100
				Man-Caused				
0.0-1.0	79	34	6	0	0	119	9.8	38
1.1-3.0	80	73	34	5	1	193	14.8	23
3.1-8.0	131	178	97	30	9	445	34.0	27
8.1-16.0	88	146	37	28	23	322	24.6	9
16.1	22	123	31	23	27	226	17.3	3
Total	400	554	205	86	60	1,305	100.0	
No. of fires (%)	30.6	42.5	15.7	6.7	4.0	100.0		100
				All Combined				
0.0-1.0	203	90	39	2	1	335	16	38
1.1-3.0	122	178	69	9	1	379	18	23
3.1-8.0	163	264	171	58	11	667	32	27
8.1-16.0	96	192	70	37	29	424	21	9
16.1	22	130	44	24	35	255	13	3
Total	606	854	393	130	77	2,060	100	100
No. of Fires (%)	29.4	41.5	19.0	6.3	3.7	100.0		
No. of Days (%)	59	27	9	3	2	100.0		

TABLE 2. FIRE SIZE AT INITIAL ATTACK, FINAL FIRE PERIMETER AND SUPPRESSION COSTS PER FIRE IN ALBERTA, 1965-69

Season	Fire Cause	Average Fire Size at Initial Action in Acres	Average Final Fire Perimeter in Chains	Average Suppression Costs/Fire in Dollars
Spring	Lightning	1	33	2,800
	Man	126	272	7,030
	All	118	254	6,750
Summer	Lightning	28	35	4,880
	Man	8	22	1,460
	All	19	29	3,350
Fall	Lightning	0.3	4	770
	Man	7	28	2,520
	All	7	27	2,450
All Seasons	Lightning	26	35	4,730
	Man	63	138	4,150
	All	50	100	4,350

TABLE 3. MANNING AND EQUIPMENT LEVELS - SPRING

FOLIAR BUILDUP INDEX	FIRE WEATHER INDEX	WEATHER FORECAST	LEVEL OF PRE-SUPPRESSION READINESS
High and Climbing or Extreme	High or Extreme	Lightning Predicted	I
High and Climbing or Extreme	High or Extreme	No Lightning Predicted	II
Low, Moderate or High and Falling	High or Extreme	Lightning Predicted	II
Low, Moderate or High and Falling	High or Extreme	No Lightning Predicted	*III
Any Foliar Buildup Index	Low or Moderate	Any Forecast	*III

*Normal manning level used by Forests.

TABLE 4. EQUIPMENT AND MANPOWER REQUIREMENTS FOR IMPLEMENTING MANNING TABLES

Level I

- suppression and minimum security crews as normally used by the Forest.
- three 25 man fire crews.
- three helicopters (206B minimum capacity) complete with bucket and sling stationed with the crews.
- one bomber group within 30 minutes flying time of the geographical centre of the problem hazard area.

Level II

- suppression and minimum security crews as normally used by the Forest.
- one 25 man fire crew.
- one helicopter (206B minimum capacity) complete with bucket and sling stationed with the crew.
- one bomber group within one hour flying time of the geographical centre of the problem hazard area.

* Level III

- suppression crews and minimum security crews as normally used by the Forest.

TABLE 5. COSTS AND SAVINGS OF ADDITIONAL MANNING

Level I

It is possible for all six northern Forests to have high or extreme hazards and a lightning forecast during the spring period. This type of condition could last for as long as 5 days.

Resource	Cost/Day	Cost/5 days
3 Helicopters	$ 2,700	$ 13,500
3 Crews	$ 3,000	$ 15,000
Total Per Forest		$ 28,500
Cost for 6 Forests		$171,000

Level II

It is possible that all six Forests would be at this level for 10 days during the spring period. The difference between Manning Levels I and II is in the lightning prediction. The cost of additional men and equipment requirements for 10 days is as follows:

Resource	Cost/Day	Cost/10 Days
1 Helicopter	$ 900	$ 9,000
1 Crew	$ 1,000	$ 10,000
Cost Per Forest		$ 19,000
Cost for 6 Forests		$114,000

Level III

This is the present manning level used by the Forests for the entire fire season. No additional saving or additional costs result from this manning level.

activity in spring of 1975, there has been no opportunity to assess the merits of the new tables.

The above section outlines some common approaches and procedures related to calibration of various codes and indices.

Table 6 summarizes actual and potential applications of various codes and indices in support of fire management planning and operational activities.

Effect of Latitude on Fire Weather

The forested regions in Canada lie between latitudes of 45° and 65°; a north-south distance of about 1,000 mi or 1,609 km. Within these latitude extremes exist important climatic differences which must be considered if the FWI is to be truly national in scope. The purpose of this section is to define the variation of insolation, temperature and relative humidity.

Moisture regimes in forest fuels are significantly affected by solar radiation (insolation) on a seasonal basis. The total undepleted radiation depends on day length and solar altitude, while the net radiation at the earth's surface is a function of the atmosphere and cloud cover. Assuming the same atmosphere and cloud cover on June 21, net solar radiation at 50° latitude and 67° latitude is about equal. On all other days of the year latitude 67° receives less radiation than latitude 50°. Table 7 attempts to adjust the FFMC to compensate for the seasonal radiation differences at various latitudes. The main purpose of the table is to recognize season and latitude as important determinants of fuel drying rates; additional information will be incorporated into the "User's Manual".

TABLE 6. APPLICATION OF CODES AND INDICES IN VARIOUS FIRE PLANNING AND OPERATIONAL ACTIVITIES

	Fine Fuel Moisture Code (FFMC)	Duff Moisture Code (DMC)	Drought Code (DC)	Initial Spread Index (ISI)	Buildup Index (BUI)	Fire Weather Index (FWI)
Yearly Seasonal Weekly	-frequency distributions useful in establishing guidelines for various applications, i.e. regulation of industrial use, forest closure prescribed burning fire prevention	-establishment of guidelines for various planning activities, i.e., prescribed burning, fire-fighting preparedness -integrates weather effects for past several weeks	-potential for integrating drought effects over several years -long-term drought effects	-comparison between years	-comparison of trends and relationships between years and seasons	-facilitates comparison of fire season severity -provides scale for rating critical fire hazard periods -integrates many short, medium and long-term effects into one index number
Daily	-interprets weather effects of past several days -useful in prescribed burning	-reflects duff removal by fire -indicates lightning fire probability	-smouldering potential	-indicates head-fire spread potential including crowning	-fuel consumption -mop-up difficulty	-daily dispatch decisions
Hourly	-diurnal changes in weather and fuel moisture -ignition predictor			-ISI and BUI, in combination should be useful indicators of fire business, including fire occurrence, area burned, etc.		

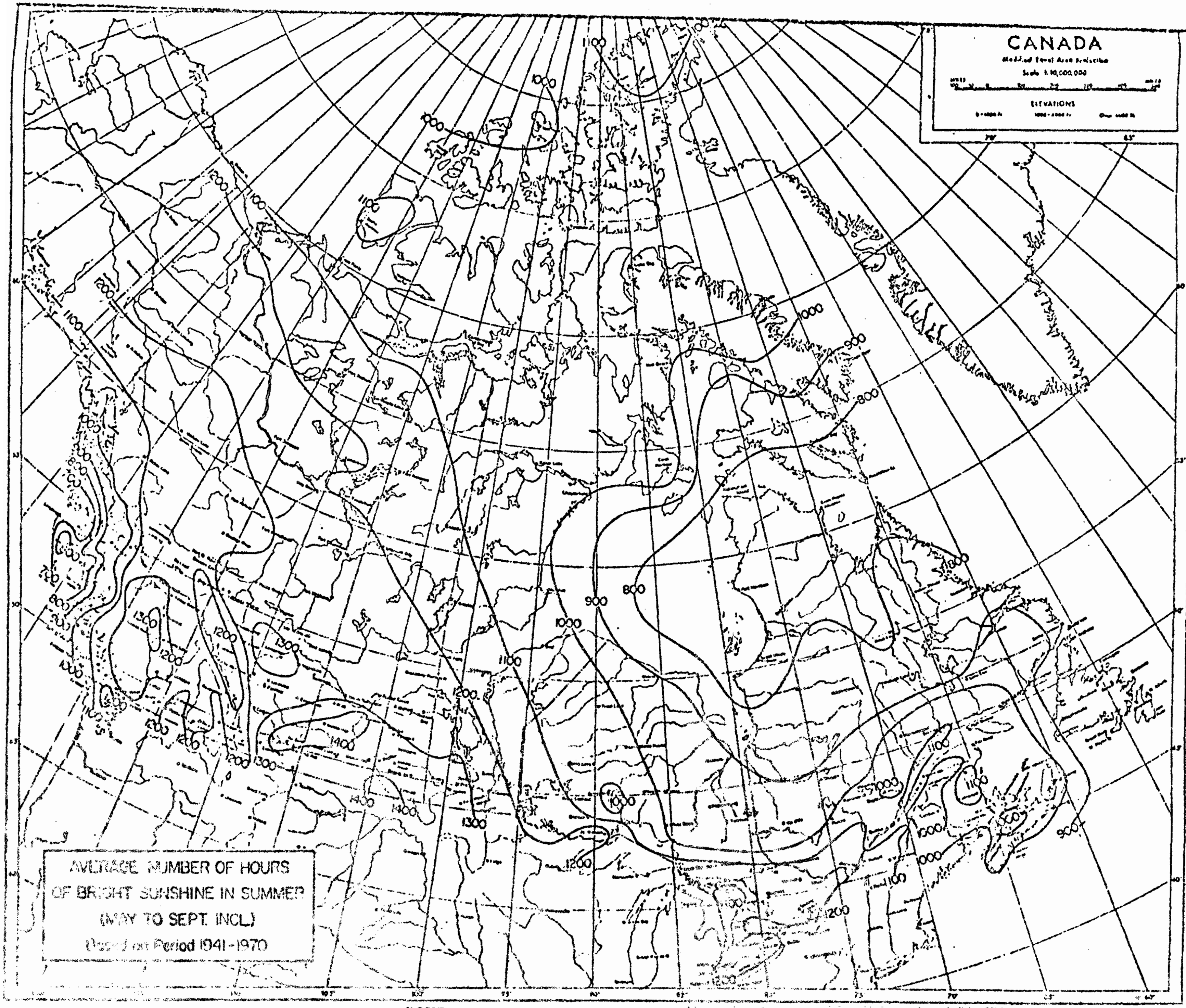
TABLE 7. FINE FUEL MOISTURE CODE (FFMC) MODIFIERS FOR LATITUDE AND SEASON (based on undepleted solar radiation values)

Latitude	Month						
	April 15	May 15	June 15	July 15	Aug. 15	Sept. 15	Oct. 15
45°	-2	-1	0	-1	-2	-4	-7
50°	-3	-1	0	-1	-2	-4	-8
55°	-3	-1	0	-1	-1	-5	-9
60°	-4	-2	0	-1	-3	-5	-10
65°	-4	-2	0	-1	-3	-6	-10
70°	-5	-2	0	-1	-4	-7	-11

Atmospheric conditions and cloud incidence are as important as solar energy since the former can severely limit the latter. Figure 5 illustrates the range of average bright sunshine hours that can be expected throughout Canada during the fire season at any given latitude. Interior British Columbia, the Prairie Provinces, Yukon Territory and the Northwest Territories have a greater number of potential "drying days" than the remainder of Canada.

While forest fuels at 50° and 67° receive equal amounts of insolation on June 21st, the corresponding daylength periods are 16 and 24 hours, respectively. Owing to the low angle of incidence traversed by the sun little radiation is received on the ground surface during these extra daylight hours at northern latitudes. However diurnal temperature and relative humidity cycles are affected,with the result that relatively severe fire behavior conditions sometimes prevail for several days and nights.

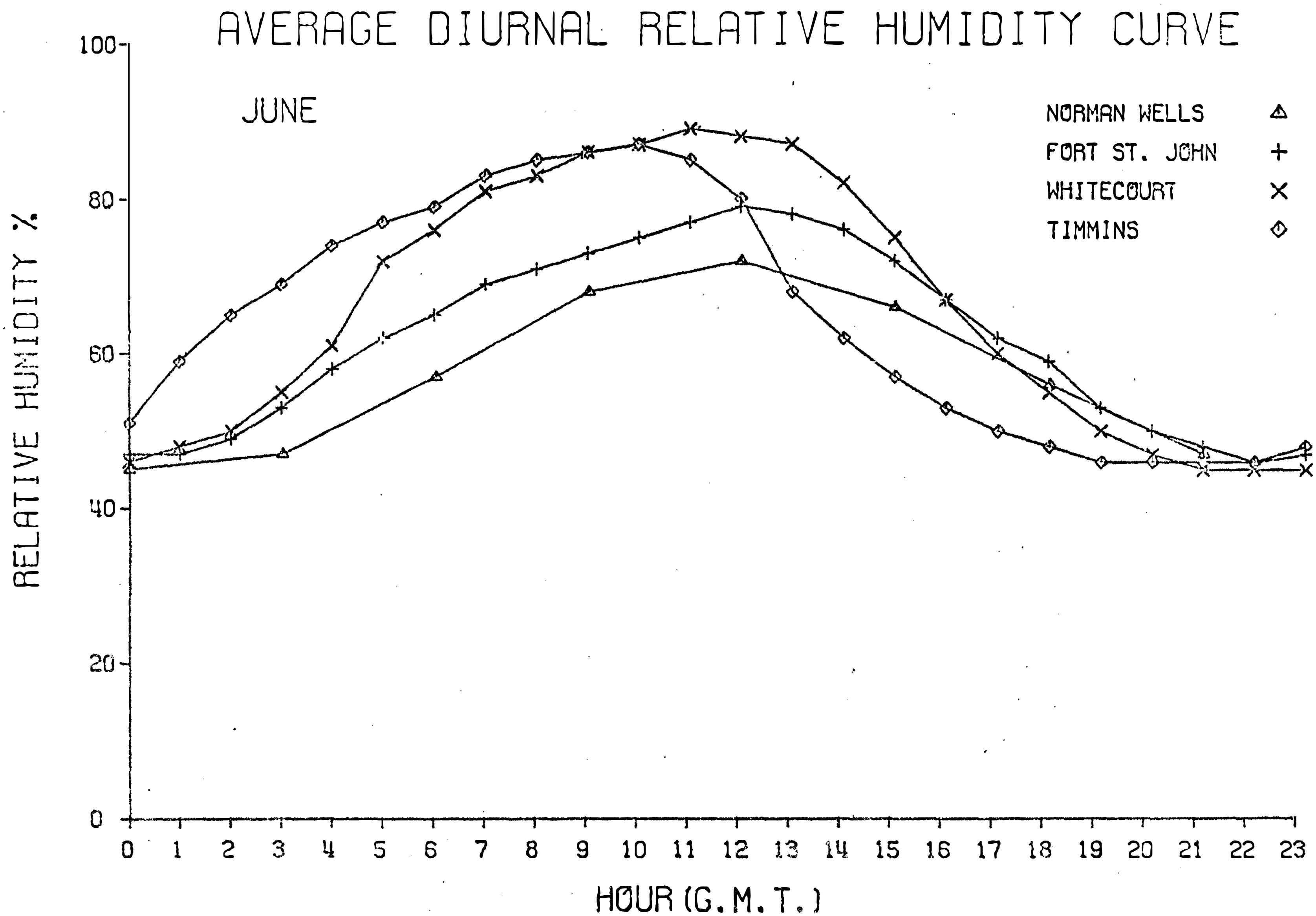
Comparison of diurnal relative humidity cycles for a ten-year period show that maximum overnight humidities are significantly lower in the N.W.T. than at lower latitudes (Figure 6). As would be expected, maximum overnight temperatures are higher at northern latitudes, reflecting the absence of extended cool, moist nights common in the south. Northern fires are known to burn "round-the-clock" with high intensity, presumably due to the combined effects of lack of recovery of moisture in fuels and prevalence of ambient weather conditions conducive to rapid fire spread.



SOURCE: ATMOSPHERIC ENVIRONMENT SERVICE

FIGURE 5

FIGURE 6


AVERAGE DIURNAL RELATIVE HUMIDITY CURVE
JUNE
NORMAN WELLS
FORT ST. JOHN
WHITECOURT
TIMMINS
RELATIVE HUMIDITY %
0
20
40
60
80
100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
HOUR (G.M.T.)

Fuel Evaluation

The problem of fuel description and classification has been with us for some time and will no doubt continue to defy easy solution. Studies of biomass in different forest stands have quantified the amount, size and distribution of organic matter on the forest floor and in tree crowns, but our ability to predict rate of spread and other fire behavior characteristics has generally not kept pace with fuel inventories. Part of the problem can be attributed to a lack of consensus as to what the fire manager needs to carry out his seasonal and daily planning and operational activities. Even if he has reliable information on fire behavior in a large number of fuel complexes, can he put all this knowledge to effective use unless commensurate improvements can be made in the weather station network, fire weather forecasting, detection and suppression activities, and the provision of real-time intelligence on the fire situation generally? Thus, while we have the high-speed data processing capability of the electronic computer, that by itself is not a very compelling reason for producing an abundance of outputs unless these are likely to contribute to a saving in fire management costs and fire damages. In practice, the needs of most fire management agencies appear to be met by provision of fire behavior information for a handful of key fuel complexes.

Several years ago, we looked at the area of fire behavior prediction and decided that a broad-scale fuel inventory would be a basic building block for predicting fire behavior. Four major Alberta forest cover types - aspen, black spruce, white spruce and lodgepole pine - were sampled and an attempt was made to develop equations for predicting weight of the fuel complex from selected stand parameters such as height, density and basal area. The results of this and other fuel studies enables us to predict the weight of the slash fuel complex following harvesting, or of the aerial fuels in undisturbed forests. These findings and predictive procedures can be refined but present-day operational requirements are not sufficiently pressing for this to be done. Figure 7 shows crown fuel weight curves by dbh for four common Alberta species. The weight and depth of forest floor fuels; litter (L), fermentation (F) and humus (H) layers can be predicted from one or more stand descriptors such as basal area, stand height and stand age. With the aid of these and other correlations, forest stand descriptors can be used to quantify key forest (fuel) types which in turn can be useful in predicting fire behavior. This approach to fuel typing and mapping has several limitations, but it appears to correspond reasonably well with present-day planning and operational requirements of fire management agencies in Canada. Development and effective use of more sophisticated fuel appraisal procedures dictate improved weather data collection and weather forecasting procedures, an increased data-handling capability by the operational agency, and some indication that the fire manager's ability to predict changes in fire behavior over short time spans and on small areas is of real practical importance in relation to suppression activities.

Fire Behavior Indices

Much of the fire behavior research of the 1960's related to the slash fuel complex; hence, Canadian and American guidelines are available

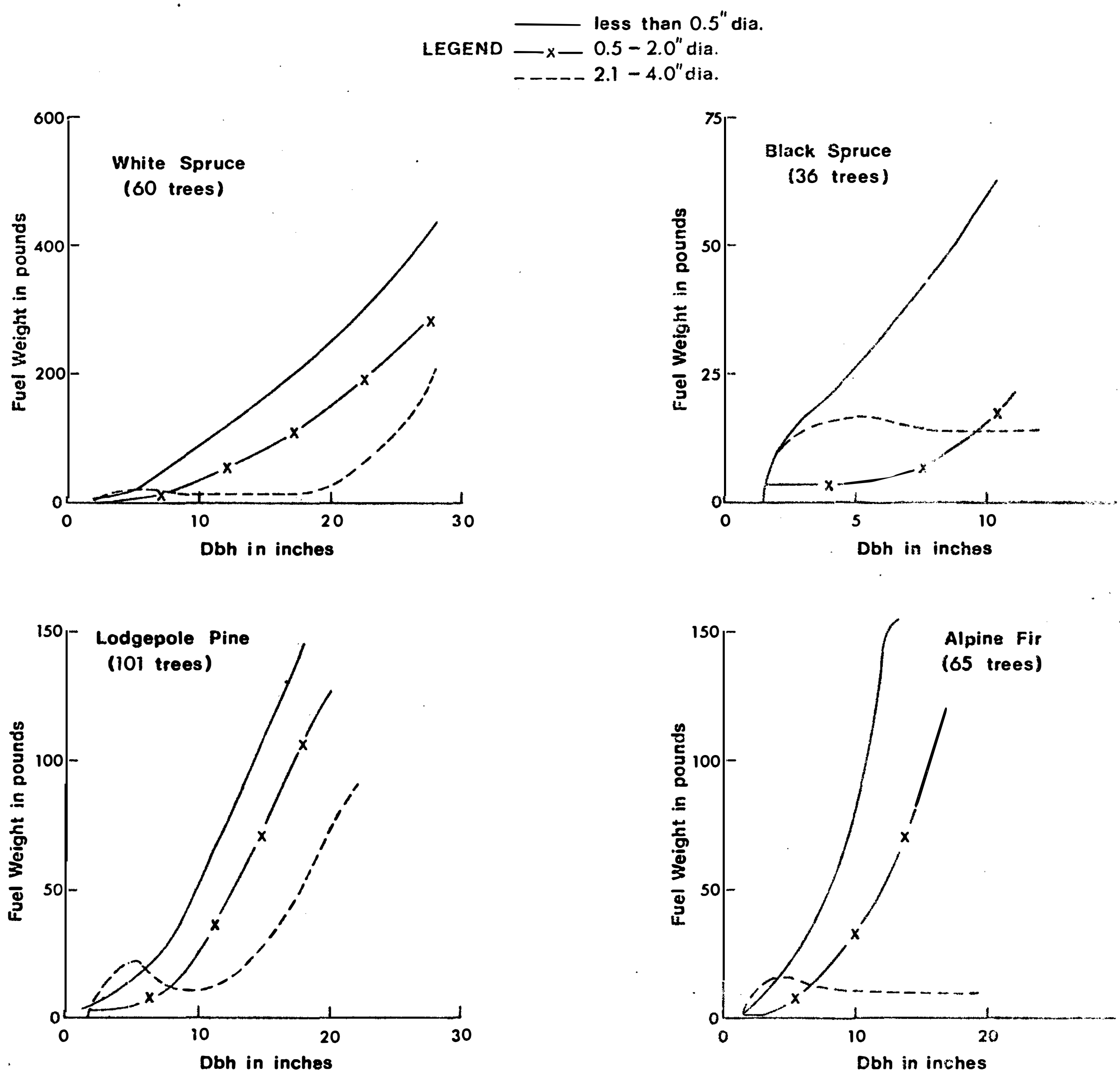


FIGURE 7 – Slash weight of fuel components by three size classes and four tree species.

for assessing slash-fuel hazard and for conducting burns in terms of the respective National Danger Rating Systems. In the Boreal Forest Region however, the major suppression problems are in natural fuels and an immediate requirement is Fire Behavior Indices (FBI) for the major forest (fuel) types. Therefore, much of the current Canadian work on fire behavior prediction is concerned with the preparation of FBI's for standing timber fuel types. It is the role of a FBI to account for as much of the fuel-related variation in fire rate of spread, fuel consumption and fire intensity, as possible or practicable and to express these values in absolute units such as feet per minute (metres/min), lbs/ft^2 (kg/m^2) or Btu/sec/ft (kcal/sec-m) of fire front. Owing to the infinite variety of fuel types, the basic approach has been to correlate fire behavior in a selected fuel type with one or more of the existing indices of the danger rating system. When the fuel in question is not well represented by any fuel moisture code, a new moisture code might have to be designed.

In recent years, a number of correlations have been established between fuel types and various moisture codes and indices of the danger rating system. For various slash fuel complexes, actual depth of burn in organic matter, percentage of total slash fuel consumed and absolute linear rate of spread can be predicted with considerable confidence (Quintilio, 1970; Stocks, 1971, Tables 8 and 9). A Daily Prescribed Fire Predictor is now available and enables the fire manager to use the FFMC, the DMC and the DC to predict ignition probability, rate of spread,

TABLE 8. PREDICTION OF HEADFIRE RATE OF SPREAD FROM INITIAL SPREAD INDEX (ISI) FOR LODGEPOLE PINE SLASH

Initial Spread Index (ISI)	Rate of Spread		Initial Spread Index (ISI)	Rate of Spread	
	ft/min	m/min		ft/min	m/min
0	0	0	11-12	51	15.6
1	5	1.5	13-14	60	18.3
2	9	2.7	15-16	68	20.7
3	14	4.3	17-18	77	23.5
4	18	5.5	19-20	86	26.2
5-6	25	7.6	21-24	99	30.2
7-8	33	10.1	25-28	116	35.4
9-10	42	12.8	29+	117+	35.7+

TABLE 9. ASSOCIATION BETWEEN BUILDUP INDEX (BUI) AND DEPTH OF BURN AND SLASH REDUCTION FOR LODGEPOLE PINE SLASH

Average depth of burn		Buildup Index (BUI)	Slash reduction in %
in.	cm		
0.5	1.3	0-10	20
		11-19	25
.51 to .75	1.31 to 1.91	20-26	30
		27-35	35
.76 to 1.00	1.92 to 2.54	36-43	40
		44-51	45
1.01 to 1.50	2.55 to 3.81	52-59	50
		60-67	55
1.51 to 1.75	3.82 to 4.44	68-83	60
		76-83	65
1.76 to 2.00	4.45 to 5.08	84-91	70
		92-100	75
2.01+	5.09+	101+	76+

difficulty of control and percent reduction of duff depths and slash fuels (Muraro, 1975). This slide-rule procedure can be used to either predict the behavior and impact of a prescribed burn under today's conditions or to estimate the moisture codes required to achieve specific prescribed fire objectives.

Several approaches, all of them empirical in nature, are being pursued to document fire behavior in the major standing timber fuel types of concern to fire management agencies in Canada. These include prescribed burns in selected stands, observation and measurement of going wildfires and use of infra-red scanners to map fire perimeters at specified time intervals. Van Wagner (1973) has prepared rough prediction equations of fire spread rates by fuel type (Table 10). We have also synthesized additional observations and measurements to produce preliminary (rate of) spread rates for black spruce by ISI classes. These are admittedly based on fragmentary evidence from various sources, but even that is better than no estimate at all.

Darwin Lake Fire Project - An example of the CFS approach to fire behavior studies is given by the Darwin Lake Project when, during the summer of 1974, fire researchers converged on the Canadian Shield in northeastern Alberta to observe and measure fire behavior in the jack pine (*Pinus banksiana* Lamb.) fuel complex. Nineteen researchers, five Alberta Forest Service district personnel, two Atmospheric Environment Service meteorologists, and two squads of fire fighters participated in the study, with the assistance of Northwest Lands and Forest Service and Parks Canada.

TABLE 10. PREDICTED RATE OF SPREAD FOR SIX FUEL TYPES

Initial Spread Index	Grass (McArthur 1962)	Aspen (leafless)	Red-white pine stand	Red pine planta-tion	Jack pine stand	Black spruce (open, lowland)
			feet per minute			
1	15	0.5	0.0	0.0	0.0	0.3
2	24	1.5	0.1	0.1	0.1	0.8
3	30	2.5	0.5	0.8	0.7	1.0
4	37	3.5	1.0	1.6	1.3	2.0
5	43	4.5	1.3	2.6	2.0	5.0
7	53	6.0	2.5	5.7	3.7	9.0
10	65	8.5	4.8	13.0	7.0	15.0
12	75	10.0	6.7	19.0	10.0	20.0
15	86	13.0	10.0	31.0	15.0	25.0
20	100	17.0	17.0	60.0	25.0	35.0
25	115	22.0	25.0	100.0	40.0	45.0
30	135	25.0	-	150.0	56.0	60.0
40	160	35.0	-	295.0	95.0	80.0
50	180	44.0	-	480.0	145.0	100.0

Shaded area: figures reflect extrapolation beyond actual fire behavior data.

Crowning threshold varies with stand type but becomes highly probably and widespread in range of ISI from 15 to 30. Estimated crowning thresholds for black spruce are ISI 10-15; for jack pine, ISI 20-25 and for white spruce, ISI 30+.

Rate of spread values for aspen, red pine plantations, jack pine and red-white pine stands interpretated from Van Wagner, 1973.

Area reconnaissance, plot layout, weather instrumentation and camp establishment was completed in June via float plane and helicopter. A VHF communication system provided for weather information and operating messages.

Thirteen plots were burned between July 24 and August 9 over a range of weather and fuel moisture conditions. Fire vigor increased with increasing FWI, reaching full crown involvement at FWI 28. Post-burn inventories were completed by mid-August and all participants returned to their respective headquarters shortly thereafter. Total operational expenditures were about $20,000. A detailed summary of the complete project is available through the NFRC.

Cladonia Fire Behavior Index - Cladonia, often in association with Labrador Tea and open-growing black spruce on permafrost soils, is a major surface fuel throughout the boreal and subarctic regions. It is also found on sandy soils supporting stands of jack pine. Owing to its prevalence in the Far North and its uniqueness in terms of fire behavior and impact, a special Cladonia Fire Hazard Table - Alberta was prepared several years ago. The Cladonia Hazard Index is determined from noon readings of relative humidity in per cent and the amount of rain by time intervals of a day or less. A revised Cladonia Hazard Index is being prepared for inclusion in the User's Manual (Van Wagner, Personal Communication). The main difference between it and the original Alberta Cladonia Tables relates to a modified FFMC using rainfall up to 0.03 inches only and the inclusion of a wind effect absent from the first version.

The Cladonia Index gives relative rate of spread of fires in forest types where Cladonia is a major forest floor fuel. Absolute rate of spread values are almost completely non-existent in this important fuel type. Results of a prescribed burning study in this fuel type in northern Alberta suggest that incipient fire spread can be extremely rapid within about five days of a saturating rainfall (Kiil, 1975). Within 15 minutes from a point-ignition, the headfire had reached a point about 180 feet away and was rapidly assuming the characteristics of a crown-fire with spotting several chains ahead of the fire front. Fire perimeter increased from a point-source at ignition to something in excess of 500 feet 15 minutes later. Fuel consumption was about 0.4 lbs/sq ft (2.02 kg/m^2), based on an average depth of burn of 3.1 in (8.1 cm) and variable crowning.

An exploratory study of Cladonia fuel moisture content during three distinct diurnal weather patterns revealed that moisture content of the 2-3 in (5-8 cm) Cladonia fuel layer can range from about 20% to 110% within a single 24-hour cycle (Figure 8). Of particular interest is the rapid drying between 1600 and 2200 hrs on July 8-9.

Crown-Fire Spread - Extensive crown fires in spring and early summer are a common phenomenon in many parts of Canada. Their occurrence is attributed to a number of factors, including the prevalence of weather patterns conducive to rapid fire spread, continuity and amount of cured minor vegetation on the forest floor, the relatively rapid drying of dead fuels in well-aerated open boreal forest stands, carry-over moisture deficit from previous year, and the relatively low moisture content of

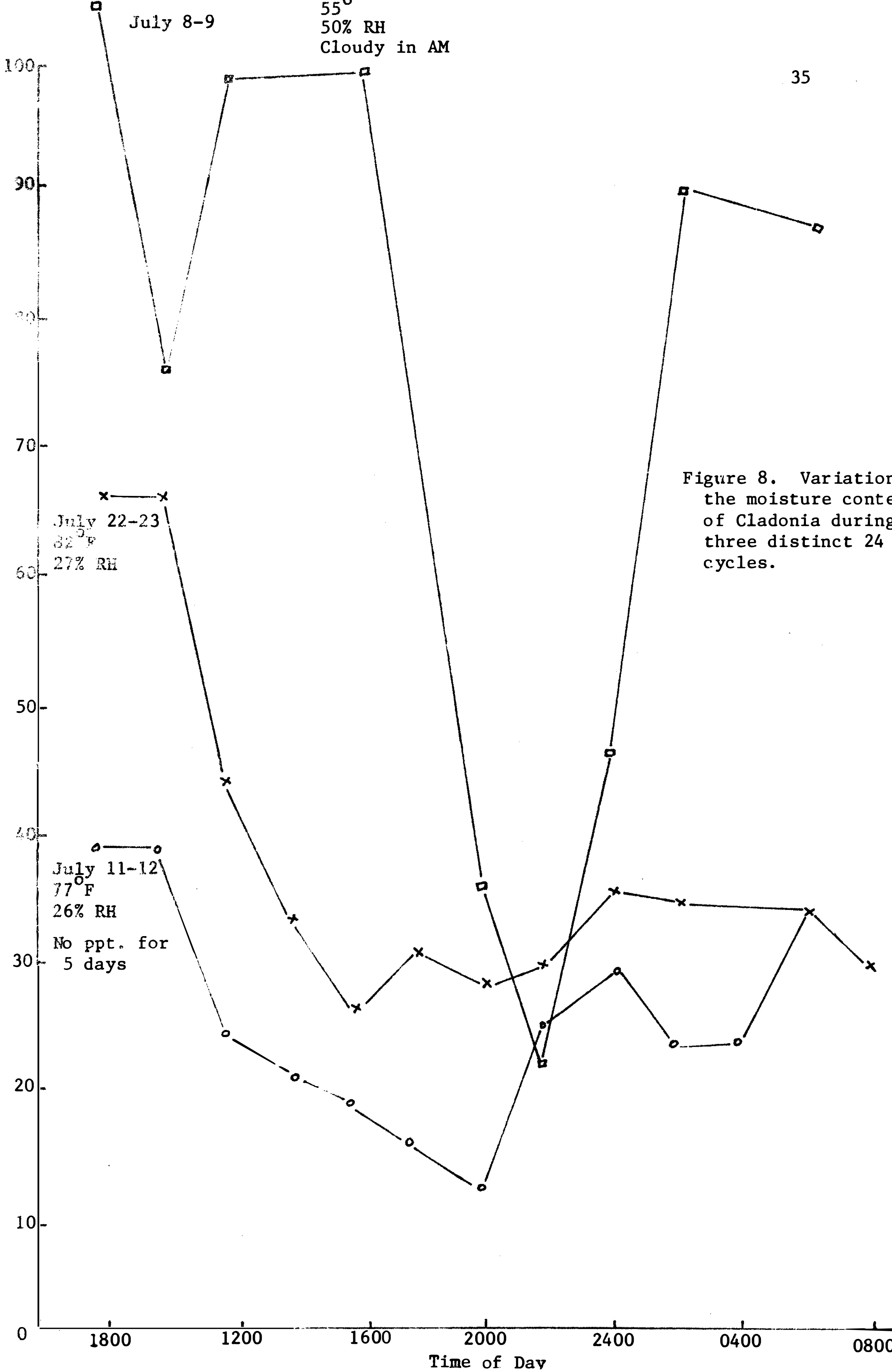


Figure 8. Variation in the moisture content of Cladonia during three distinct 24 hr cycles.

conifer foliage during this period. Van Wagner (1974) has developed a crown spread index based on foliage moisture content variation during the spring foliage moisture content dip. Van Wagner's Crown Spread Index (CSI) is obtained by multiplying the Initial Spread Index by the Crown Spread Factor as determined from foliar moisture content and the foliar weight ratio.

Fire behavior studies in jack pine and red pine suggest that Initial Spread Index of 20 to 30 indicates the onset of crowning. Significant torching of groups of black spruce trees can be expected at ISI of 10 to 15. Thus the crowning threshold appears to lie in the range of Initial Spread Index from 10 to 30, depending on the horizontal and vertical distribution of dead and live fuel components, and wind speed within the stand.

The seasonal pattern of foliage moisture content in conifer needles is well-documented and appears to be dependent more on the internal metabolism of a tree rather than on daily or seasonal weather patterns (Figures 9 and 10). There is a pronounced spring dip in foliar moisture, and part of this may be due to a concurrent temporary increase in the dry weight per needle. For most northern conifers, the moisture content of foliage covers a range of between 25 to 40% from spring to late summer or winter (Chrosciewicz, Personal Communication). Minimum values of 70% occur; however, absolute moisture content fluctuates from about 70 to 130%, depending on year, age of foliage and species. Moisture content differences between lodgepole pine and white spruce in Alberta approach 20% during the early part of the growing season, with lodgepole pine

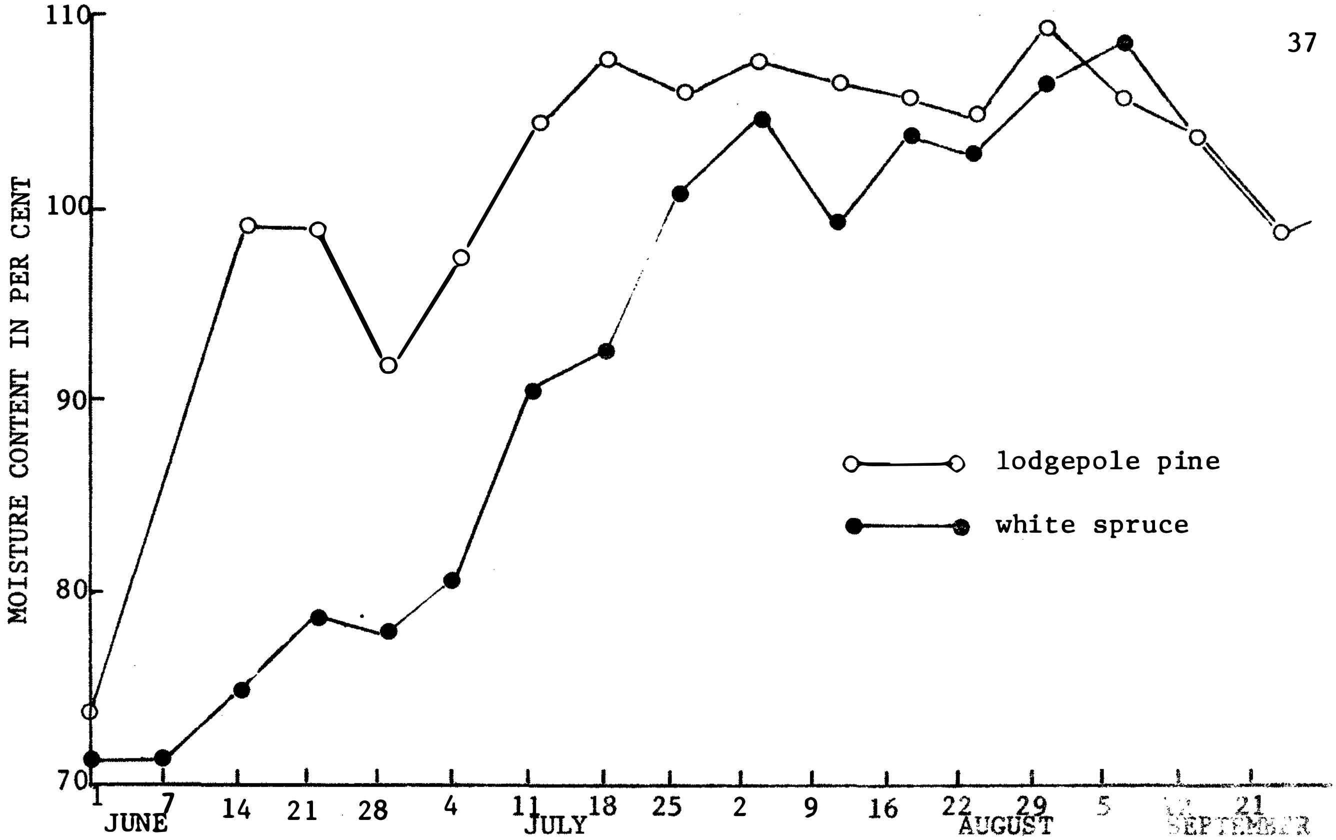


Figure 9. Moisture content of lodgepole pine and white spruce needles during 1964.

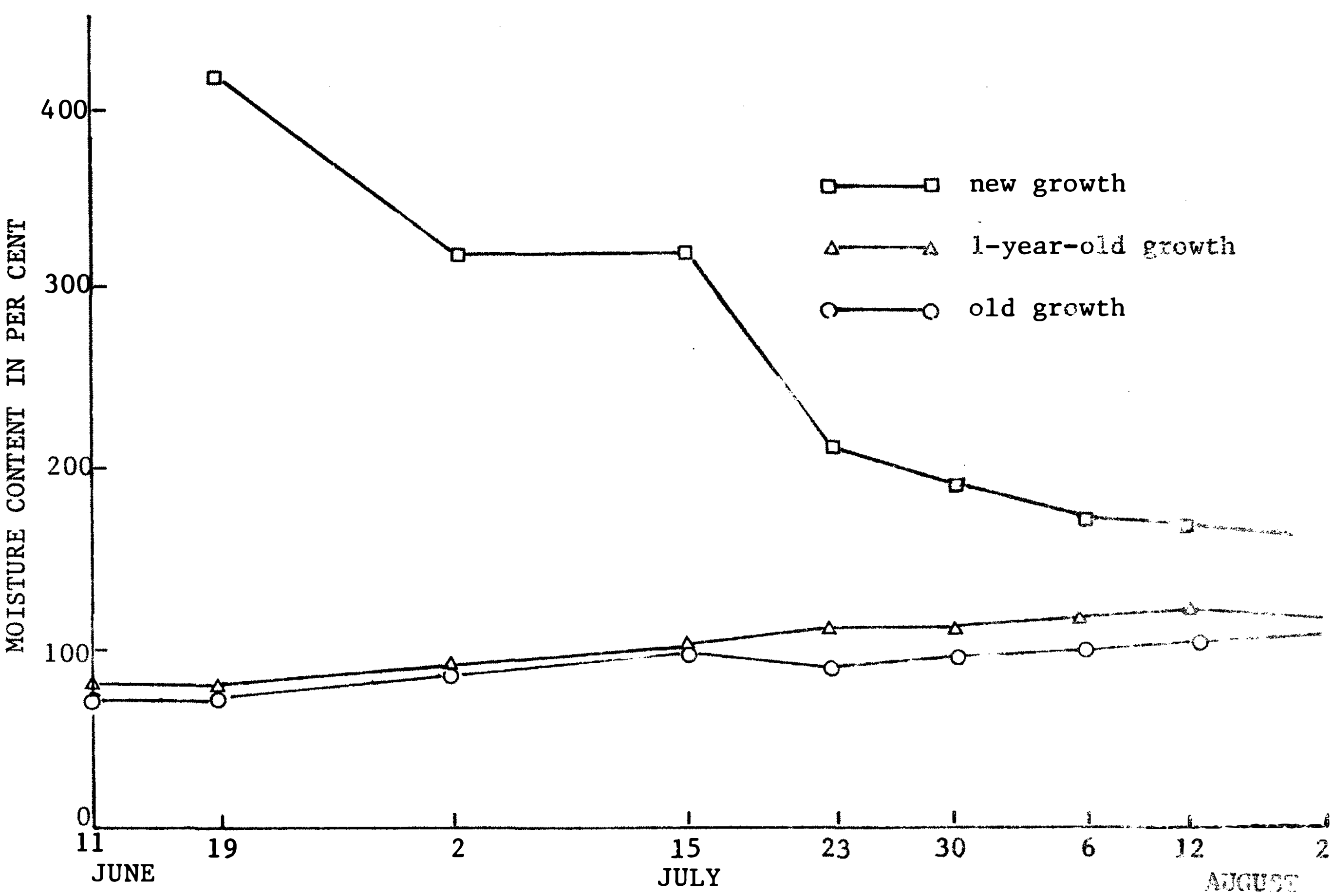


Figure 10. Moisture content of white spruce needles during 1965.

having the highest values. Similarly, differences in foliage moisture content due to age of needles range from 15 to 20%. Since more than two-thirds of the needles on most northern conifers exceed three years in age, the moisture content of these older needles and bark near the stem of the tree could have an over-riding effect on candling and subsequent crowning.

Comparison of American and Canadian Systems

At this point, perhaps a quick look at some of the similarities and differences between the American and Canadian danger rating systems will serve a useful purpose. Each system recognizes three classes of forest fuels of different drying rates. Similarly, various indices reflect the linear rate of fire spread, available fuel energy for combustion and finally, a measure of line-fire intensity. The FWI in the Canadian system provides a means of comparing fire weather at different locations across Canada, whereas the Burning Index (BI) in the American system relates to fire behavior in nine different fuel types. The Canadian system is founded on literally thousands of sets of weather, fuel and fire behavior measurements in the field, whereas the American system is "purely analytical, being based on the physics of moisture exchange, heat transfer, and other known aspects of the problem" (Deeming *et al*, 1974). Temperature, relative humidity, wind speed, rain amount and month are the required weather data for the Canadian system. The American system operates on temperature, relative humidity, wind speed, rain duration, daily maximum and minimum relative humidity, cloud cover, herbaceous and woody vegetation condition, slope, and fuel model. Differences between the two sets of fuel moisture schemes are depicted in Table 11 (Van Wagner, Personal Communication).

An example of how key indices respond to rainfall is shown in Table 12. Rainfall amounts have a rather strong effect on the ISI and FWI whereas the SC of the American system does not respond to rainfall duration. Also, the Energy Release Component (ERC) and the Burning Index of the American system (Fuel Model D) recover at a faster rate than do the Buildup Index and the Fire Weather Index (BUI) of the Canadian system.

FIRE SUPPRESSION METHODS

Fireline Construction Rates

Handcrew and bulldozer production rates are available for several U.S. Forest Service regions (Steele, 1961); however, published results are highly variable and not applicable under conditions found in the Boreal Forest. The Northern Forest Research Centre thus instituted time and motion studies on going wildfires in 1972 to provide local production figures for these two common suppression methods.

The bulldozer is an efficient dirt moving machine, but its efficiency decreases once it is transported to the fireline where footing, servicing, and operating conditions are less than ideal. Although the dozer is a proven fire control tool, unfavourable boreal forest conditions and concern about environmental damage dictate that it not be used indiscriminately.

In Alberta, dozers are teamed to assist each other through the inevitable muskeg areas encountered during fireline construction. It is

TABLE 11. THE AMERICAN AND CANADIAN FUEL MOISTURE SCHEMES

Factor	American			Canadian		
	1-hr TL[1]	10-hr TL	100-hr TL	FFMC	DMC	DC
Moisture content range in %	1-25	1-25	0-200	2-101	20-300	400
Timelag days at 70°F	0	0	2.0	0.7	12	52
Rain effect?	No	Yes	Yes	Yes	Yes	Yes
Rain effect depends						
on amount	-	-	-	X	X	X
duration	-	X	X			
Rain capacity	-	-	-	0.3 mm	15 mm	200 mm
Fuel						
-litter, duff weight	-	-	-	0.25 kg/m²	4.86 kg/m²	>25 kg/m²
-litter, duff depth	surface	<19 mm	<100 mm	10 mm	80 mm	250 mm
- roundwood diameter	6 mm	6 to 25 mm	26 to 76 mm	-	-	-

[1]TL is timelag. Timelag in the Canadian system is measured in daily cycles, based on field data and fluctuations in weather data. The American system considers timelag as a property of the fuel and constant with changing weather conditions.

TABLE 12. RAINFALL EFFECT ON COMPONENTS OF AMERICAN AND CANADIAN SYSTEMS

	Ppt.	Canadian			American		
		ISI	BUI	FWI	SC	ERC	BI
Day 1	0	11	42	21	3	4	8
2	0.2	2.5	34	6	3	3	8
3	0	7	38	15	3	8	10
4	0	9	41	17	3	11	12
5	0	11	43	23	3	13	13
Day 1	0	11	42	21	3	4	8
2	1.0"	1.5	21	2	3	1	5
3	0	7	25	12	3	5	9
4	0	9	27	15	3	9	11
5	0	11	32	19	3	13	13
6	0				3	15	14

	Canadian	American (Model D)
Assumed starting values:	T 70° RH 35%	T 70° RH 35% (Sunny)
	FFMC: EMC (90)	1-hr TL MC EMC
	DMC: 30	10-hr TL MC EMC
	DC: 150	100-hr TL MC 35
	Month: June	% Green herbs: 25%
	Wind: 10 mph	Wind: 10 mph
		Rain duration: 0.25" = 6 hrs: Aug. RH 75%
		1.0" - 24 hrs: Aug. RH 90%

not uncommon to find six machines of different models and sizes building line and helipads in a combined unit. Rates given in this paper reflect average production/dozer-hour based on the range of machines present in the team. The most common units observed were D-7's and wide-pad D-6's.

Data from this study represent 561 hours of observation on wildfires and a total of about 100 miles of fireline construction. Production rates ranged from 1 ch/dozer-hr to 40 ch/dozer-hr and averaged 14.3 ch/dozer-hr for all situations. An approximation of rates for three resistance-to-construction categories is as follows:

Extreme	1 ch/dozer-hr
High	4 ch/dozer-hr
Moderate	30 ch/dozer-hr

Of the 561 working hours observed, 336 hrs (60%) were classified as production time while the remaining 40% was "down" time as a result of mechanical difficulty or complete loss of footing requiring a rescue pull.

Within the sampling area (Alberta, Northwest Territories and Yukon Territory), a continuous operation of textbook fireline construction by handcrews was rarely observed. The majority of our data is based on trained crews working under simulated fire conditions in district fuel types, and as such represent optimum production based on a 60-minute hour (Murphy, 1975):

	Fuel type resistance-to-construction			
	Low	Moderate	High	Extreme
Const. rate in ch/man-hr	2.23	0.50	0.37	No data

Murphy measured handcrew rates as a function of stand component resistance, i.e., overstory, understory, debris, and organic layer (Table 13). Crews performed the operations independently and total time was used to compute a rate for the complete stand. An index was subsequently produced from this data for operational prediction of handcrew rates (Figure 11).

An index example is given below:

	Index Component
Stand density - 31-70% Height Class - 31-45 ft	2
Brush density - A Height Class - <8'	1
Debris - 1-10 tons/acre	1
Trenching depth - 4"	8
FINAL INDEX	12

Reading from Figure 11, an index of 12 corresponds to a fireline construction rate of .54 ch/man-hr.

Initial Attack Simulation Model

In addition to the basic collection of fireline productivity rates, current computer technology and simulation modelling expertise was utilized to examine the performance of suppression techniques over a range of fire situations. A comparatively simple study was designed to simulate the capabilities of three initial attack methods used in the Whitecourt Forest District of Alberta and to evaluate their impact relative to ten years of actual fire data. A data base was created from (1) weather and fire reports for the years 1961-1969, (2) fireline

TABLE 13. FUEL RESISTANCE-TO-CONSTRUCTION (HANDTOOLS) INDEX TABLE[1]

1. TREES

STAND DENSITY - crown closure -	HEIGHT CLASS - feet (30' and under treat as brush) 31 - 45	46 - 60	61 - 80	81 over
A up to 30%	-	(-)*	(-)	(-)
B 31 - 70%	2	(2)	-	-
C 71 - 100%	5	5	5	5

2. BRUSH

DENSITY	HEIGHT 8' & UNDER	HEIGHT 9 - 30'
A	1	-
B	2	(3)
C	3	4 powersaw 5 axe

3. SLASH & BLOWDOWN

QUANTITY - tons/ac	
1 - 10	1
11 - 20	2
21 - 40	4
41 - 60	6
61 - 80	7
81 - 100	9

4. TRENCHING

DEPTH - inches	
up to 1	2
2	4
4	8
6	14
8	18
10	22
12	25
14	28
16	29

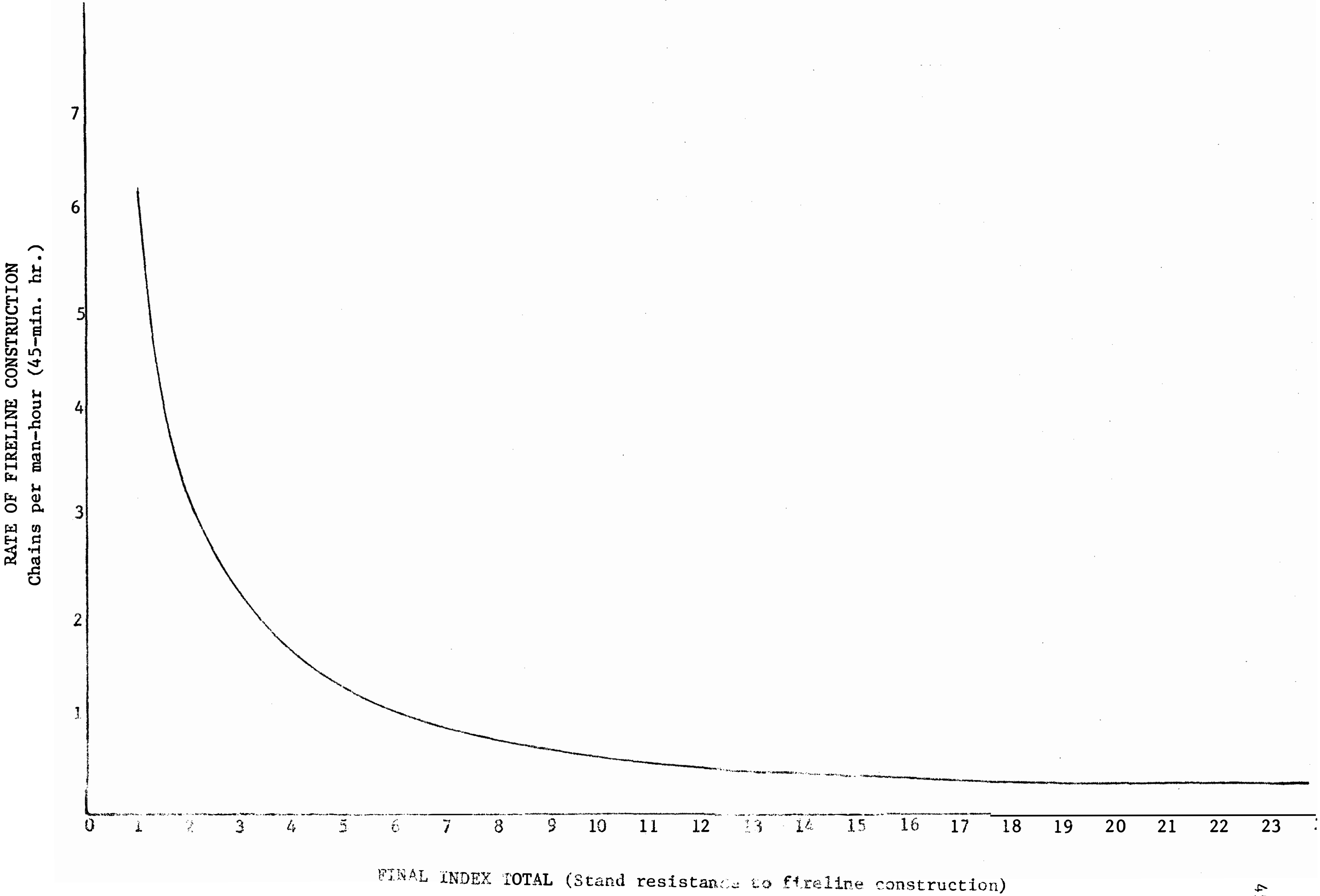
Heavy roots (2"+) add

Rock resistance (50%+) add

*numbers in brackets estimated

[1] Index components are additive and the sum total represents an estimate of resistance-to-fireline-construction for the particular stand.

FIGURE 11. RATE OF HANDLINE CONSTRUCTION



productivity rates for helitankers, airtankers, and handcrews and (3) resource and dispatch capabilities of the Whitecourt Forest.

Implementation began with the assignment of a study team consisting of three Alberta Forest Service headquarters personnel, two Alberta Forest Service field personnel, two Canadian Forestry Service research personnel, and Prairie Agri-Management Consultants Ltd. The team collectively designed the approach, extracted and summarized raw data, and analyzed results during group working sessions.

Simulation modelling is often used to duplicate a "real world" system which is either too complex or unwieldly to feasibly study by the more traditional means. The performance of initial attack forces is one such case. Fire control staff cannot afford to over-manipulate involved attack strategies while fires potentially threaten resources within their districts. The simulation technique is therefore a means of testing and refining resource performance without associated risk; however, there are acknowledged constraints. Simulation exercises are both time consuming and expensive, particularly at the programming and validation stage. There are inherently many opportunities to deviate from the real world and over-simplify; hence, results must be considered in light of the philosophy and input of the particular model.

Results of the study are summarized in Table 14. Handcrews were most successful in controlling fires and cost less than all other methods, reflecting their ability to work through the night. The 204B helicopter (w/235 gal. bucket) dropping water from nearest source, was more successful than airtankers working from three bases with long-term retardant as a result of short turn-around time.

TABLE 14. SUCCESS AND ASSOCIATED COST OF SEVEN SUPPRESSION METHODS USED FOR INITIAL ATTACK ON FIRES IN THE WHITECOURT DISTRICT, 1961-1969

Suppression Method	Total # of fires	# of fires attacked	# of fires controlled	Success		Expenditures			
				Fires controlled/ Fire totals	Fires controlled/ Fires attacked	Total Cost	Cost/Total # of fires	Cost/# of fires attacked	Cost/Fir controll
Handcrew[1]	485	447	287	59%	64%	$2,735,873	$5,641	$ 6,121	$ 9,533
204B[2]	485	362	213	44%	59%	3,931,022	8,105	10,859	18,456
B-26[3]	485	323	148	31%	46%	4,385,630	9,043	13,578	29,633
Thrush Commander[4]	485	345	125	26%	36%	3,645,423	7,516	10,566	29,163
PBY5A Canso[5]	485	354	106	22%	30%	4,008,941	8,266	11,325	37,820
206B[6]	485	317	56	12%	18%	2,136,131	4,404	6,739	38,145

1 Thirteen 4-man crews available night and day. Ground transportation used.

2 One 206B w/235 Imp. gal. bucket dropping water from nearest source to fire.

3 One B-26 dropping long-term retardant from one of three airtanker bases.

4 A group of 4 Thrushes dropping long-term retardant from one of three airtanker bases.

5 One PBY5A Canso dropping long-term retardant from one of three airtanker bases.

6 One 206B w/90 Imp. gal. bucket dropping water from nearest source to fire.

Total cost for 485 fires was approximately equal for airtankers and the 204B helicopter, but considerably less for handcrews. The 206B helicopter w/90 gal bucket performed poorly as a result of its low capacity, since the equivalent of .07" of water to .04" of long term retardant resulted in an effective open drop length of 12'.

The simulation exercise was beneficial for: (1) consolidating field, headquarters, and research opinions and facts, (2) sorting out agency data files and labeling the useful and non-relevant material, and (3) defining the areas which require additional data and research.

Results are useful in other areas, however care must be taken to consider local variables. For example, turbo fuel is trucked to all helicopter dispatch points in the Whitecourt Forest District and cost and supply is reasonable. In the North many fuel caches do not support helicopters for lengthy periods and price of fuel at the fire is considerably inflated. The performance and associated costs of the 204B in the Northwest Territories or Alaska would not be comparable to the Whitecourt Forest.

Airtanker/Retardant Evaluation

The origins of the currently heavy emphasis placed on suppression methods research at the Northern Forest Research Centre can be traced back to the mid-sixties. The initial effort in this work area was directed at drop pattern determinations for the Snow Commander, a small-capacity airtanker then in use in Alberta. Within a few years, similar airdrop tests were carried out with other airtankers such as the B-26, the TBM, the PBY5A Canso, the DC-6B, the Bell 204B and 206B, and the Sikorsky S58T

(Table 15). A number of suppressants and retardants, including water, Gelgard, Tenogum, Phos-Chek XA and 259, and Fire-Trol 100 and 931, have been evaluated under field conditions (Grigel, 1970). This program has been well received and the results largely implemented by client agencies.

The current program at the Northern Forest Research Centre involves testing of airdrop accuracy, field evaluation of airtanker/retardant effectiveness during actual fire-fighting situations, and static testing (motionless) of selected airtankers to determine effect of tank and gating systems on drop patterns. The static tests utilize the procedures developed at the Northern Forest Fire Laboratory in Missoula, Montana, with the Honeywell simulation model being used to assess airtanker performance characteristics.

A new retardant, Phos-Check XB (11-55-0) is now marketed in Canada. Phos-Chek XB retails for about $100/ton less than Phos-Chek XA and has better color separation against forest vegetation. However, it contains more impurities and requires re-circulation for longer periods of time following mixing. Mixing trials are in progress.

Similar work at the Forest Fire Research Institute is concerned with airtanker productivity in fire suppression operations. The modelling aspects of that program have been discussed at a previous Alaska State Fall Fire Seminar; this paper is concerned primarily with the field-oriented studies to test and evaluate the effectiveness of water and various fire retardants. Small-scale field tests have served to quantify the amount of water and retardant required to extinguish fires of known intensities burning in slash and needle fuelbeds (Stechishen and Little,

TABLE 15. SUMMARY OF AIRTANKER AND HELICOPTER DROP TESTS, NORTHERN FOREST RESEATCH CENTRE

Airtanker	Retardant	Drop Site			
		Open	Lodgepole Pine	White Spruce	White Spruce-Aspen
Snow Commander	Gelgard F,	X	X		
	H_2O,	X	X		
	Phos-Chek XA	X	X		
Thrush Commander	Fire-Trol 100	X	X		X
	Phos-Chek XA	X	X		X
B-26	Fire-Trol 100	X	X		
	Fire-Trol 931	X	X		
	Phos-Chek XA	X			
T.B.M.	Phos-Chek XA	X			
DC-6B	Phos-Chek XA	X			
PBY5A	H_2O	X		X	X
	Gelgard	X		X	X
Bell 206B (Sims Bucket)	H_2O	X	X		
	Fire-Trol 931	X	X		
	Phos-Chek XA,	X	X		
	259	X	X		
Bell 204B (Monsoon, Griffiths Buckets)	H_2O	X	X		
	Fire-Trol 100	X	X		
	Phos-Chek XA	X	X		
Sikorsky S58T (Chadwick Bucket)	H_2O	X			
	Phos-Chek XA	X			
	259	X			

1971). Results suggest that 0.04" to 0.07" of water will be required to extinguish a fire releasing about 100 Btu/sec/ft (83 kcal/sec-m) of energy at the fire front, depending on fuel type and burning conditions. Current work is aimed at clarifying effectiveness of various retardants, including cost/effectiveness considerations and impact of logistics. Related work at the Forest Fire Research Institute is concerned with the use of explosives for fireguard construction, testing of pump performance (Higgins, *et al*, 1974) and use of foam in fire suppression.

The Canadian CL-215 Airtanker continues to be used in Quebec. During the past two years, a new probe system has been field-tested and it appears to have increased the aircraft's handling stability. The Forest Fire Research Institute has been involved in determining mixing and dropping characteristics of Tenogum water thickener. Tests have also been carried out to assess the effect of the Fire-Trac system on retardant distribution patterns within airdrops from the CL-215.

FIRE ECOLOGY

A current study, entitled "Role of fire in the forest and intermingled vegetation in the Prairie Provinces, Rocky Mountains and the Far North" has the primary objective to undertake and complete a problem analysis relating to short- and long-term ecological influence of forest fire in managed and unmanaged areas. Particular emphasis is being placed on fire management in National Parks. To date a review of pertinent literature and field reconnaissance of Wood Buffalo National Park in the Northwest Territories, Riding Mountain National Park in Manitoba, and Jasper National Park in Alberta have been completed. A cooperative study, involving the Canadian Wildlife and Forestry Services, and personnel of Prince Albert National Park is aimed at using spring and fall burns to reduce the encroachment of aspen along the southern boundary so as to maintain areas of open grassland. In the Athabasca River Valley around Jasper townsite in Jasper National Park, detailed fire history studies and fuel inventories are being carried out to clarify the role of fire in the Park and to establish a basis for fuel and fire management.

In addition to the above, the Canadian Forestry and Wildlife Services have sponsored several contractual studies concerning fire in the boreal forest, including a problem analysis of fire in the western subarctic with particular reference to the Caribou Range, Northwest Territories. Other studies by Rowe and several associates at the University of Saskatchewan relate to vegetation and fire in the wintering ground of the Beverly caribou herd, buried seed populations, and the reproductive strategies of prevalent boreal species. M.L. Heinselman of the University of Minnesota has just completed a preliminary assessment under contract to Northern Forest Research Centre of the history and natural role of forest fires in the lower Athabasca Valley, Jasper National Park, Alberta, based partly on a detailed study of fire history just being completed by G.F. Tande, University of Alberta.

A multi-disciplinary study is continuing on the site of the Vermilion Pass Fire in Banff and Kootenay National Parks to elucidate post-fire conditions and changes in vegetation, soils and fauna. One aspect of this study deals with immediate post-fire revegetation of the different microsites.

In April, 1975, the Northern Forest Research Centre sponsored a meeting on fire ecology research in the North. Participants reported on the present status of research by the respective agencies such as Parks Canada, the Canadian Wildlife Service, the Canadian Forestry Service, Universities of Saskatchewan and Alberta, Department of Indian and Northern Affairs, and R.M. Hardy and Associates. The discussion was far-ranging but rather inconclusive as to research needs and priorities, although study of fire effects on total resource systems - landforms, hydrology, soils, vegetation and habitat, permafrost - appear to require top priority. Furthermore, approximate and preliminary information may prove adequate to satisfy management applications, although too much management orientation is to be avoided. Finally, more attention is needed to social, political and economic considerations because they ultimately decide how land will be managed.

During the past several years, a number of fire ecology related projects have been completed. These include fire hazard classifications for Prince Albert and Waterton Lakes National Parks, and prescribed fire effects in subalpine spruce-fir slash. "Forest fire effects on the Environment in Canada" was presented at a International Union of Forest Research Organizations Division 3 Symposium in Ottawa in late 1974 (Kiil, 1975).

Progress of tree regeneration, plant succession, and fuel-moisture related effects have been followed on prescribed burns in Manitoba, Saskatchewan and Alberta. Burning and seeding were successful in regenerating jack pine in central Ontario. In general, jack pine frequency distribution and heights of dominant trees were strongly affected by the depth of residual humus, with humus depths of up to 1/2 in. (1.2 cm) supporting optimum stocking and growth (Chrosciewicz, 1974). In Manitoba, stocking of black spruce seedlings increased with burn intensity, and various seedbed, regeneration and plant-succession characteristics indicated beneficial effects of controlled burning (Chrosciewicz, 1975). The number of seedlings associated with moderate and light burning, and a control amounted to 16,129, 3,075 and 1,898/acre (39,856, 7,598 and 4,690/ha). The light and moderate burns corresponded to Fire Weather Index and Buildup Index of 15 and 21, and 21 and 45, respectively. Assessment of fire effects on clearcut jack pine sites in Saskatchewan suggest that site moisture regime and depth of residual duff are key factors controlling stocking.

In eastern Canada, prescribed fire in association with shelterwood cutting is being evaluated in relation to survival of regeneration and perpetuation of red and white pine. Another study at the Petawawa Forest Experiment Station is concerned with fire effects on the vegetative productivity and nutrient capital in a red and white pine stand. Fire effects on plant succession and diversity are also being studied in several other forest types.

DEVELOPMENT OF FIRE CONTROL TECHNOLOGY

Helicopter Incendiary Launcher

Since 1972 the Northern Forest Research Centre has studied the potential for remotely igniting backfires via a helicopter incendiary device (Lait and Taylor, 1972). A manually operated machine was designed and built at Edmonton and field tested in the Yukon and the Northwest

Territories. The concept of aerial ignition looked promising and in 1974, the Alberta Forest Service equipment artisan, Roy Kruger, started development of a helicopter mounted incendiary machine to satisfy the following specifications.

1. Incendiary ejection rate, four units per second minimum.
2. Incendiary ground contact distance not less than sixteen feet (4.88 meters) at 45 mph (72.41 kph).
3. Must meet Ministry of Transport certification standards.
4. Convenient to mount in a 206B helicopter.

The prototype unit was field tested successfully in the spring of 1975 and production of operational units is proceeding.

Electronic Fire Marker

Relocating lightning strikes for initial attack is difficult if smoke is intermittent. Occasionally these "smokes" are not found until severe burning conditions exist and a major fire develops. In 1972 the Alberta Forest Service requested the Northern Forest Research Centre to develop an improved method to mark lightning "smokes" from the detection aircraft if necessary. A thorough literature review indicated that the visual standard of rolled flagging is commonly used but not recommended. Sophisticated audio and electronic equipment was too expensive. During tests with various electronic devices the high frequency transmitters similar to those used for wildlife tracking situations showed promise. Prototype models were developed for (1) compactness, (2) durability, (3) signal strength, and (4) low bush attenuation and a final model (Ponto and Lynch, 1973) built with the following specifications:

Frequency	29,920 mHz
Output power	100 mW, pulsed
Pulse width	100-500 ms
Pulse rep rate	40-300 per min
Antenna type	33 inch steel whip
Battery type	9v DC

Cloud Seeding

Effective methods of suppressing large forest fires are almost non-existent. Results of past research in cloud seeding is rather inconclusive, but the potential of seeding cumulus clouds to induce them to rain on forest fires remains. A cooperative study, involving the Forest Fire Research Institute, the Atmospheric Environment Service and the National Aeronautical Establishment, was initiated in 1974 to obtain more precise statistics on the occurrence of cumulus clouds during wildfires and to determine the effectiveness of seeding to trigger rain sooner or in greater amounts than would be the case without seeding (Isaac, *et al*, 1975). Ice nucleus concentrations, cloud droplet distributions and in-cloud and out-of-cloud turbulence parameters were measured.

Cloud observations were made around fires in northwestern Ontario and Manitoba in 1974. The findings from this reconnaissance-type effort were encouraging and the study was continued in 1975, with field work carried out from Yellowknife in the Northwest Territories.

Thermal Infrared Vidicons for Detection of "Sleepers" and in Forest Fire Mapping

Several units have been tested during the past several years. At the Forest Fire Research Institute, performance of characteristics of the Phillips infra-red vidicon system show promise for fire mapping through dense smoke and may provide a suitable alternative to expensive line scanners.

For years the forests in Alberta have been the site of major winter debris disposal burns as a result of bush road or power line right-of-way clearings or other exploration work, and almost every spring, despite extensive precautions and inspections, somewhere enough hot coals survive ready to become active with the onset of hot weather.

This year the mop-up crews were assisted by an infra-red scanner leased jointly from Sweden by the Northern Forest Research Centre and the Alberta Forest Service. The AGA Thermovision 750 is a light-weight hand-held camera unit and display unit. The latter contains a real time TV screen and controls for temperature measurement and photo recording. The nitrogen cooled Indium Antimonde sensor of the thermo-vision scans the 2.0 to 5.6-micron spectral range with a thermal resolution of 0.2°C and a spatial resolution of 1.1 milliradian (7° lens) and 3.4 milliradian (20° lens). One charge of nitrogen lasts approximately two hours.

A helicopter appears to be the best platform for airborne inspection. The scanner operator holds the camera so that it points at an angle of approximately 45° forward and downward through the open door window. The pilot "crabs" the helicopter enough off centre from the target to bring it into full view of the scanner and circles slowly to get a good look from all directions. The viewing screen can be and should be observed by the scanner operator and a second person. This assures that no hot-spot passes by unobserved while the operator observes the target visually.

Some 13 fuel piles had been treated at the time of inspection. There was no indication that there should be any hot live coals, the crews had done a thorough job yet the scanner detected hot-spots in the remnants of nine treated piles. A check on the ground proved that all of them were capable of providing that critical kindling spark under the right conditions. As it was, the weather began to change to light precipitation and considerable cooling occurred so it was decided to mark the found hot-spots and keep them under "scanner surveillance" from the air. Twenty-four hours later the scanner registered five spots, with one persistent spot still hot after one week. It was then dug out and drowned, to eliminate the need for further inspections.

A total of 45 subsequent missions produced similar results, including a 40-mile fire boundary inspection in Newfoundland, demonstrating the potential of the AGA for:

1. detection of persistent hold-over fires associated with debris burning,
2. expediting wildfire mop-up operations by utilizing crews only where hot-spots exist,
3. adding safety to summer prescribed burning operations.

More complete reporting is underway on this system (Niederleitner, Forestry Report, Vol. 4 (4), 1975).

Automated Fuel Type Mapping

ERTS data are being used as a basis for developing a set of suitable computer programs that will produce fuel type maps for use by fire management agencies (Kourtz, Personal Communication). A preliminary fuel type map on an acre basis has been produced for a 400 square mile test area in Quebec. The data analysis package appears capable of classifying up to 10 vegetation types. Ongoing work involves assessment of the discrimination power within fuel categories, i.e. age of slash, degree of budworm kill and stand density. ERTS photographs are also being used to map perimeters of wildfires, particularly in remote areas.

Fire Danger and Fire Weather Forecasting

A new Federal Department of the Environment Policy on Meteorological Services for Forest Fire Control is now being implemented across Canada. The Policy outlines the cooperative responsiblity of the Canadian Forestry Service and the Atmospheric Environment Service relative to the provision of research and operational fire weather-related forecasting services to satisfy the needs of provincial and other forest fire management agencies. The Canadian Forestry Service will continue the development of improved forest fire danger rating indices whereas the Atmospheric Environment Service will be responsible for meteorological data, weather forecasting and weather instruments and facilities. Three levels of committees - 1) National Steering and 2) Development, and 3) Regional - have been or are being established to guide the development, implementation and operation of the program. The AES, the CFS and user agencies, i.e. provincial and federal fire management agencies, are represented on each Committee.

Metric Conversion

The investigation and planning phases of the National Metric Conversion Program have been underway for several years. The peak period for implementation is expected to be 1977-78, although considerable activity is taking place even today. In the forestry sector, a national working group has completed a "Metric Practise Guide for Canadian Forestry Research", giving a comprehensive list of metric units to be used in specific disciplines including fire. Public weather forecasts now give temperature and precipitation in metric units, with wind speed to follow in 1976 or 1977. Thus all danger rating calculations and fire weather forecasts will utilize metric units. Since it is expected that Canada will complete the metric conversion program by 1980, all fire management agencies in Canada associated with the Canadian Committee on Forest Fire Control (CCFFC) have agreed that present legislation and statistics will be converted to the metric system by January 1, 1979. A Sub-committee on Metric Conversion within the CCFFC is active in identifying problems and contributing to coordination relative to metric conversion in fire control. The Sub-committee is concentrating on the following four areas of concern:

1. Power water delivery systems
2. Retardant loading systems in aircraft
3. Fire behavior rating
4. Ground fire-fighting equipment.

Forest Fire Research and Control Literature

The Forest Fire Research Institute file on publications, records and data, covering much of the forest fire research undertaken in Canada since 1909, is intended to serve as a reference centre for fire research information. Bibliography lists are mailed to interested individuals and agencies on an annual basis. Included in the total Information Centre package is "An Author Bibliography of CFS Publications" (Bruce, 1973) covering fire research literature since the inception of federal fire research in Canada. All of the reference material kept at the Information Centre is available upon request. Recent publications and reports not yet acquired by the Information Centre at the Forest Fire Research Institute in Ottawa are usually available from the author or the appropriate regional research centre.

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