Citation:

Alexander, M.E. 2006. Forest health: Fire behavior considerations. *in* Appendix – DVD, Proceedings of the Post-harvest Stand Development Conference, Edmonton, Alberta, 31 January – 1 February 2006. Sponsored by Foothills Model Forest, Foothills Growth and Yield Association, Alberta Forest Genetic Resources Council, and Forest Resources Improvement Association of Alberta. Foothills Model Forest, Hinton, Alberta. 56 p.

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FOREST HEALTH: Fire Behavior Considerations

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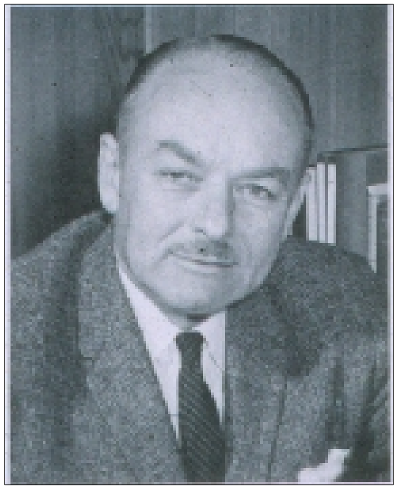
Natural Resources Canada | Ressources naturelles Canada

Canada

Fire Behavior and the Forest Manager

" The behavior of fires is an important factor in the growth, harvesting, and regeneration of forest crops. How often fires occur and how hot they burn affect … the … quantity of products harvested from the forest. The forest manager may influence fire behavior by the nature of his operations … it is important for forest managers to know fire behavior and to be able to evaluate the influence of forest management operations on it." – J.S. Barrows (1951)



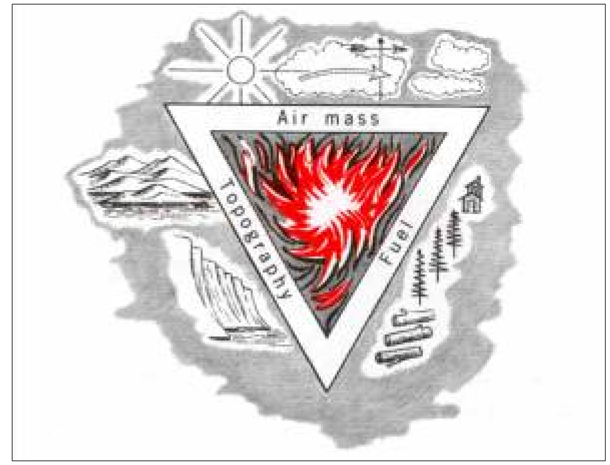
Purpose of Presentation:

Provide a overview (for the non-specialist) of relevant fire behavior terms and concepts, existing tools for predicting fire behavior at the stand level (with particular emphasis on crown fire), and finally, to offer some suggestions for future direction

Outline of Presentation:

I. Fire Behavior Fundamentals
II. Prediction of Fire Behavior
III. Conclusions and Suggestions on Future Direction

I. “FIRE BEHAVIOR 101”: The Fundamentals



Fire behavior is defined as the manner in which fuel ignites, flame develops, fire spreads and exhibits other related phenomena as determined by the interaction of fuels, weather, and topography (i.e., the fire environment).

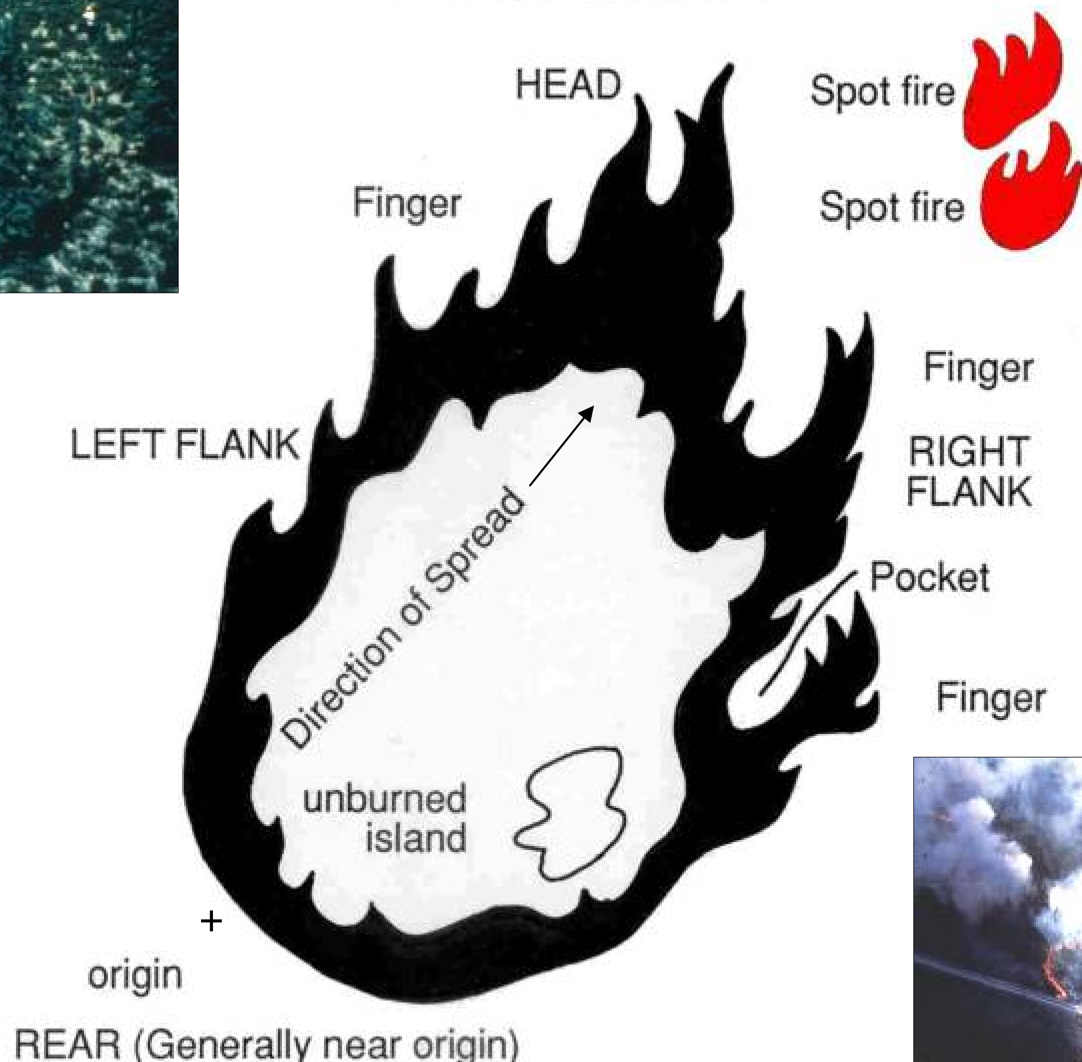
Fire Environment Factors

Fuel Characteristics:
- Quantity
- Moisture
- Size & Shape
- Depth/Height
- Arrangement

Weather Characteristics:
- Wind Speed & Direction
- Relative Humidity
- Air Temperature
- Rainfall Amounts & Duration
- Cloud Clover
- Atmospheric Instability

Topographic Characteristics:
- Slope Steepness & Aspect
- Elevation
- Configuration
- Barriers to Fire Spread

PARTS OF A FIRE



Nominal Spread Rates for Wildland Fires

Ground or Subsurface Fires: < 0.01 m/min

Surface Backfires in Forests: 0.1 – 1.0 m/min

Surface Head Fires in Forests: 1 - 10 m/min

Crown Fires in Forests: 15 - 200 m/min

Grass Fires: up to 250 - 350 m/min

Basic Features of a Forest Fire:

It spreads …

it
consumes
or
"eats" fuel
and …

it produces heat energy and light in …

… a visible flaming combustion reaction.

Fire Intensity

$$I \quad = \quad H \quad \times \quad W \quad \times \quad R$$

Fire Intensity (kW/m)	Heat of Combustion (18 000 kJ/kg)	Fuel Consumed (kg/m^2)	Rate of Fire Spread (m/sec)

<u>Fire Intensity Spectrum</u>

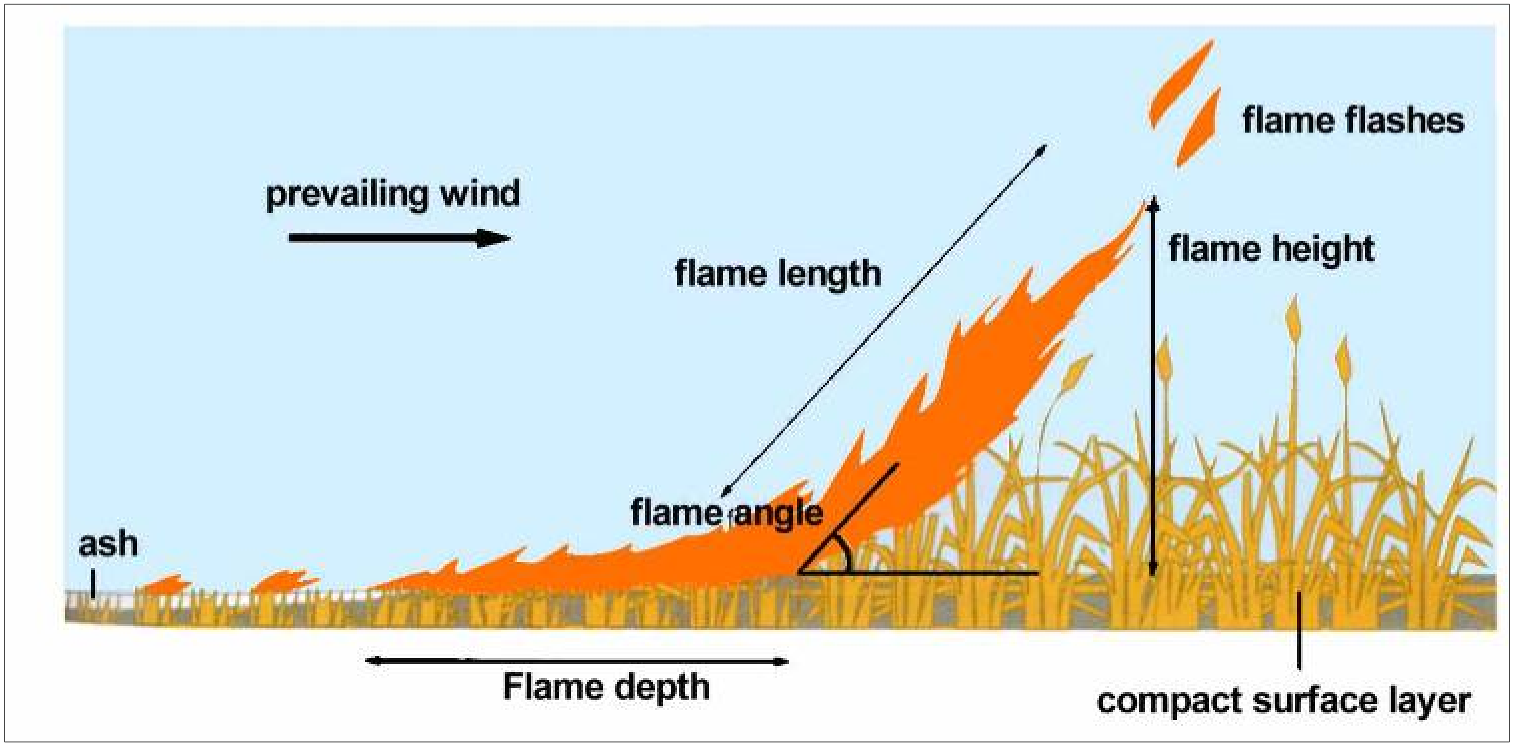
10 kW/m – Lower limit of surface fire spread

1000 kW/m – Limit of suppression capability by hand crews

10 000 kW/m – Active crown fires have developed

100 000 kW/m – Major conflagrations

Fire intensity is related to size of flames



Simple Formula for Field Use

(for surface fires & intermittent crown fires)

$$I = 300 \times (L)^2$$

***L* = Flame Length (metres)**

For active crown fires, flame height ~ 2X stand height

Extreme fire behavior represents a level of fire activity that often precludes any fire suppression action. It usually involves one or more of the following:

- High Rate of Spread & Intensity

- Crowning

- Prolific Spotting

- Large Fire Whirls

- Well-developed Convection Column

Comparison of Fire Behavior in a Pine Plantation under High Fire Danger Conditions

(adapted from McArthur 1965)

Fire Description and Characteristics	Stand A (pruned up to 5 m)	Stand B (unpruned)
Type of fire	Surface	Crown
Forward spread rate (m/min)	5	10
Fuel Consumed (t/ha)	18	28
Head fire intensity (kW/m)	2700	8400
Flame height (m)	2	12
Fire area @ 1 hour (ha)	4.86*	19.44*
Fire perimeter @ 1 hour (km)	0.83	165
Spotting distance (m)	<200	up to 2000

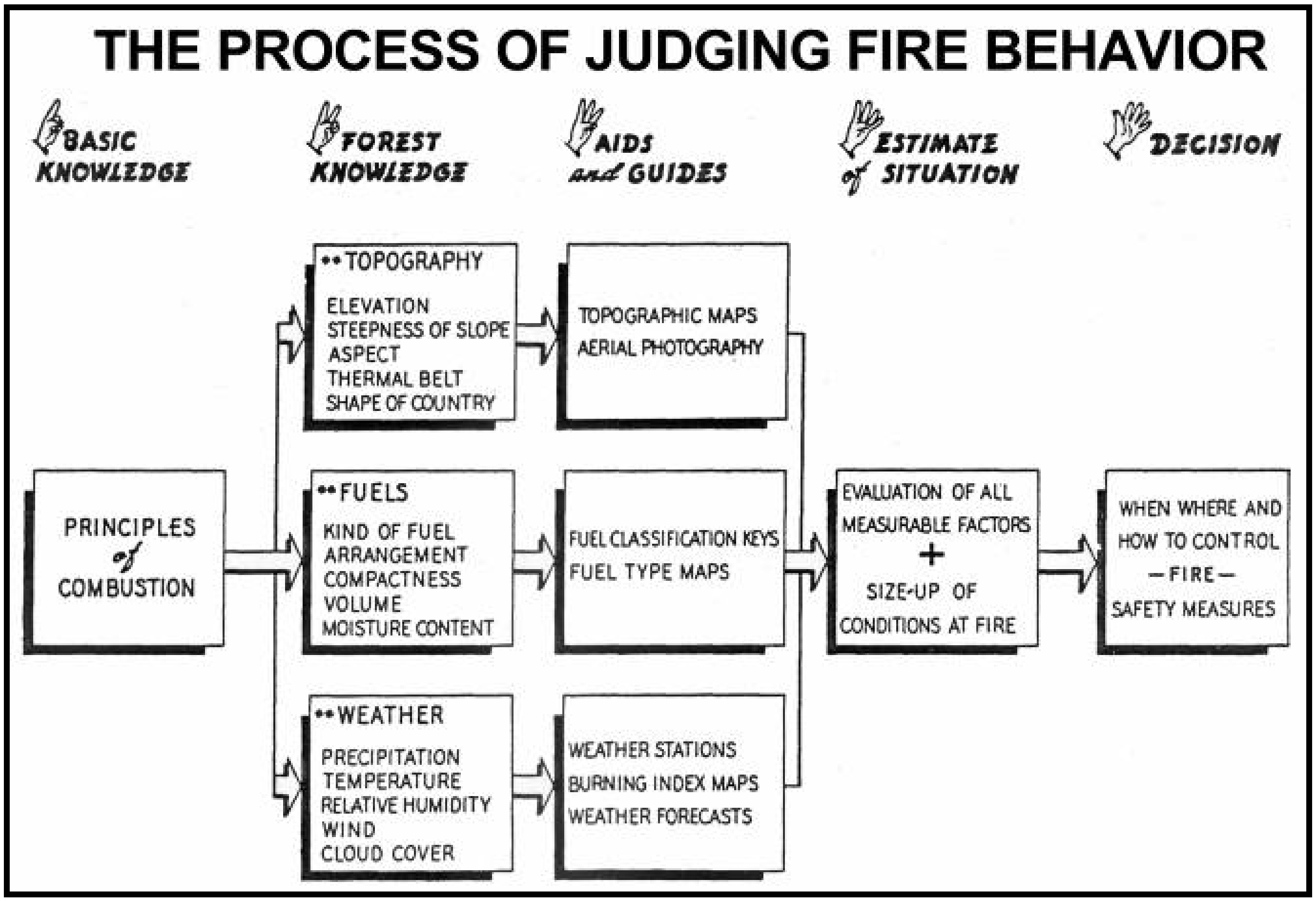
*Area enlargement = (Rate of Spread Increase)^2

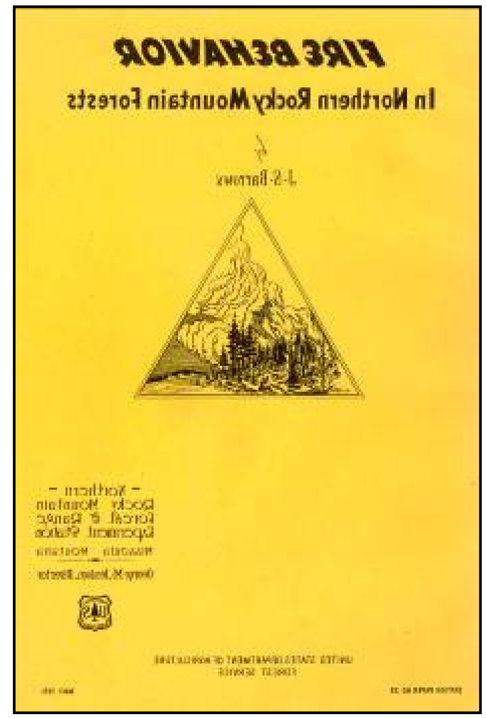
The more important fire behavior characteristics from the practical standpoint of fire suppression are:

- Forward Rate of Spread
- Fire Intensity
- Flame Front Dimensions
- Spotting Pattern (densities & distances)
- Fire Size and Shape
- Rate of Perimeter Increase
- Burn-out Time

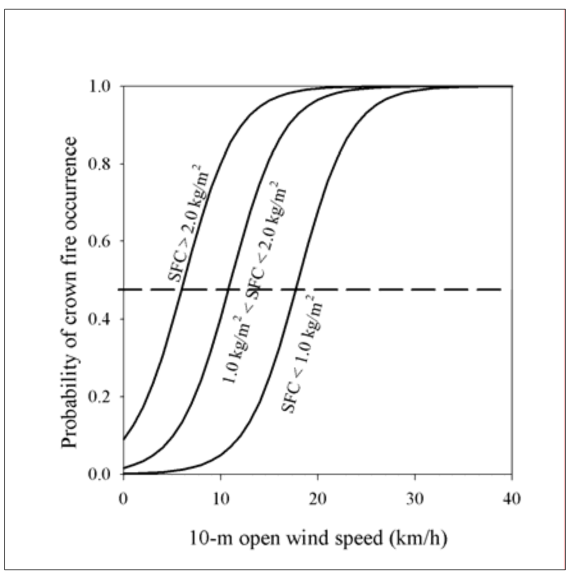
II. Predicting Fire Behavior

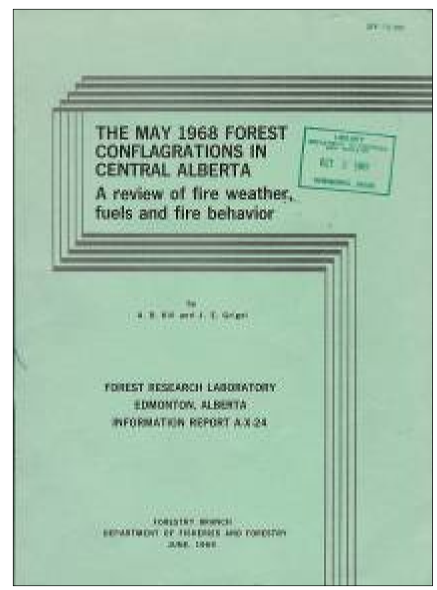
Systematic analysis that combines "art and science"

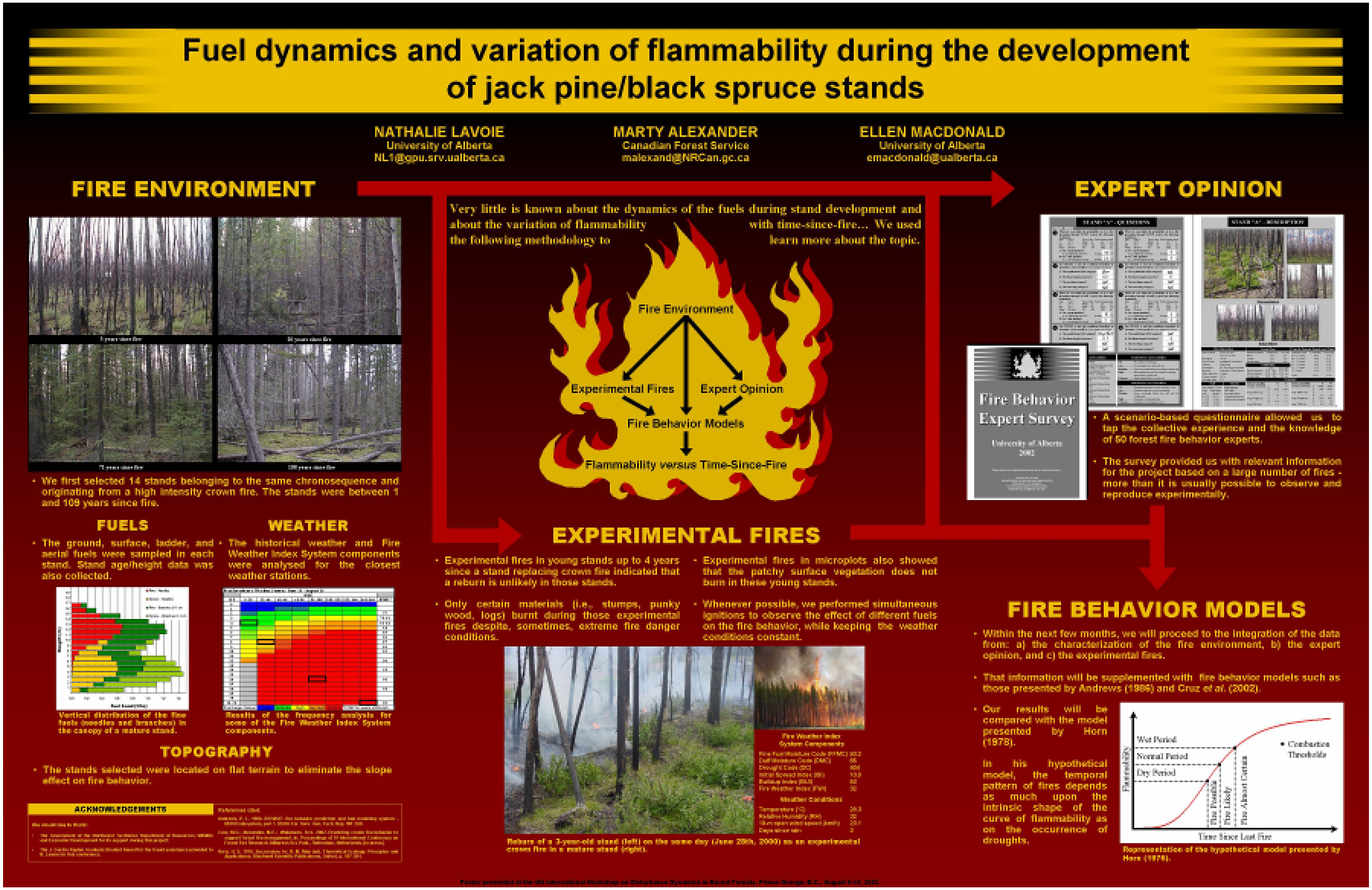




The most effective means of appraising or evaluating potential fire behavior is considered to be the coupling of <u>mathematical modelling</u> with <u>experienced judgement</u> (e.g., "expert opinion"), and published <u>case study knowledge</u> (e.g., experimental, wild and prescribed fires)

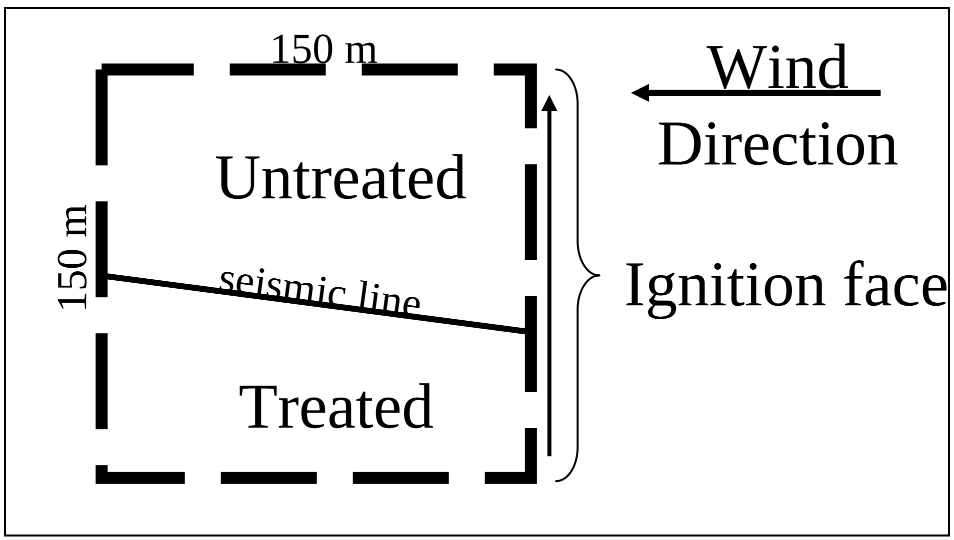






See **Lavoie, N. 2004. Variation in flammability of jack pine/black spruce forests with time since fire in the Northwest Territories, Canada. Ph.D. Thesis, University of Alberta. 332 p.**

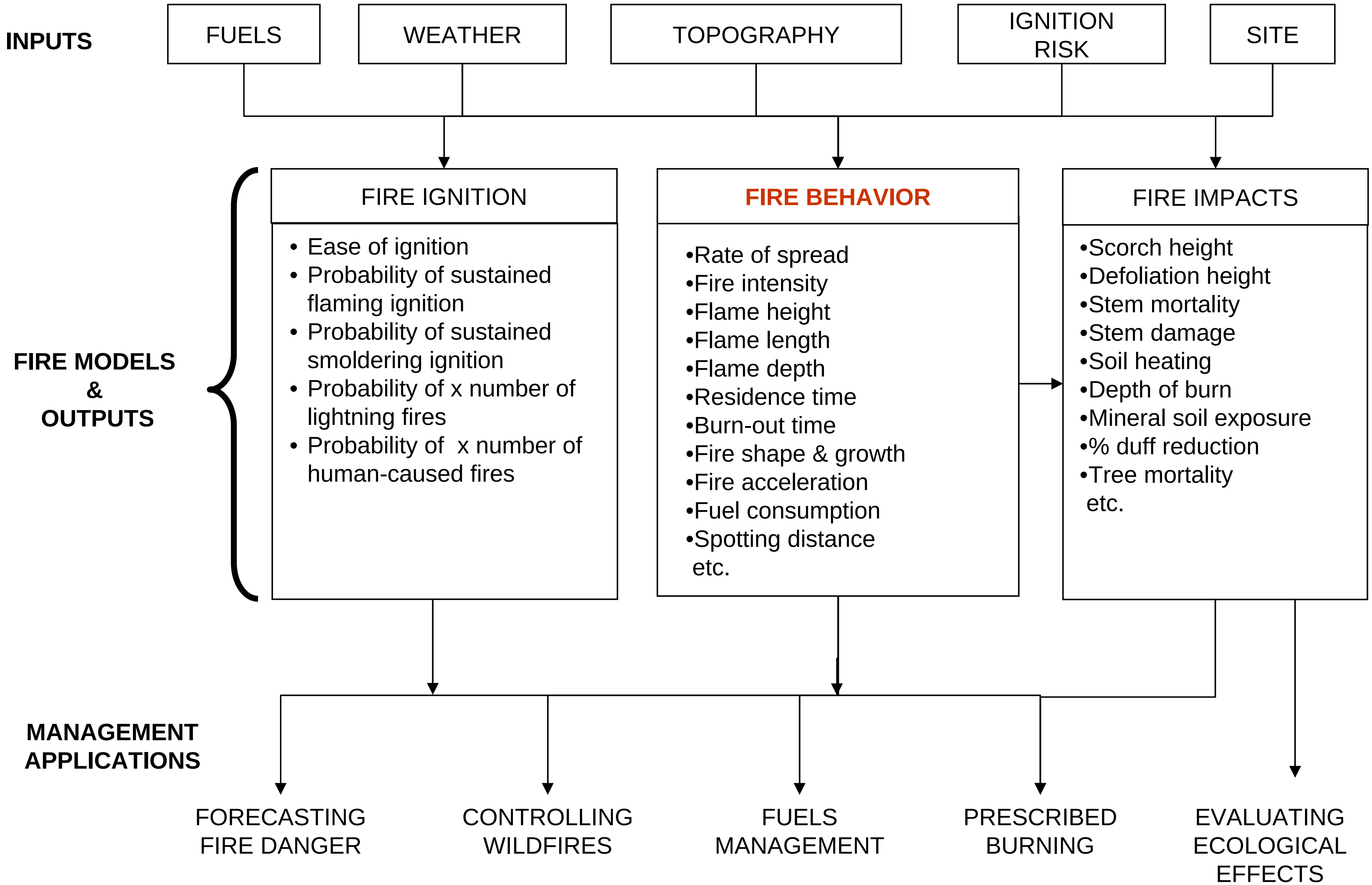
ICFME Treated/Untreated Plot, NWT – June 14, 2000



Note “prune line”

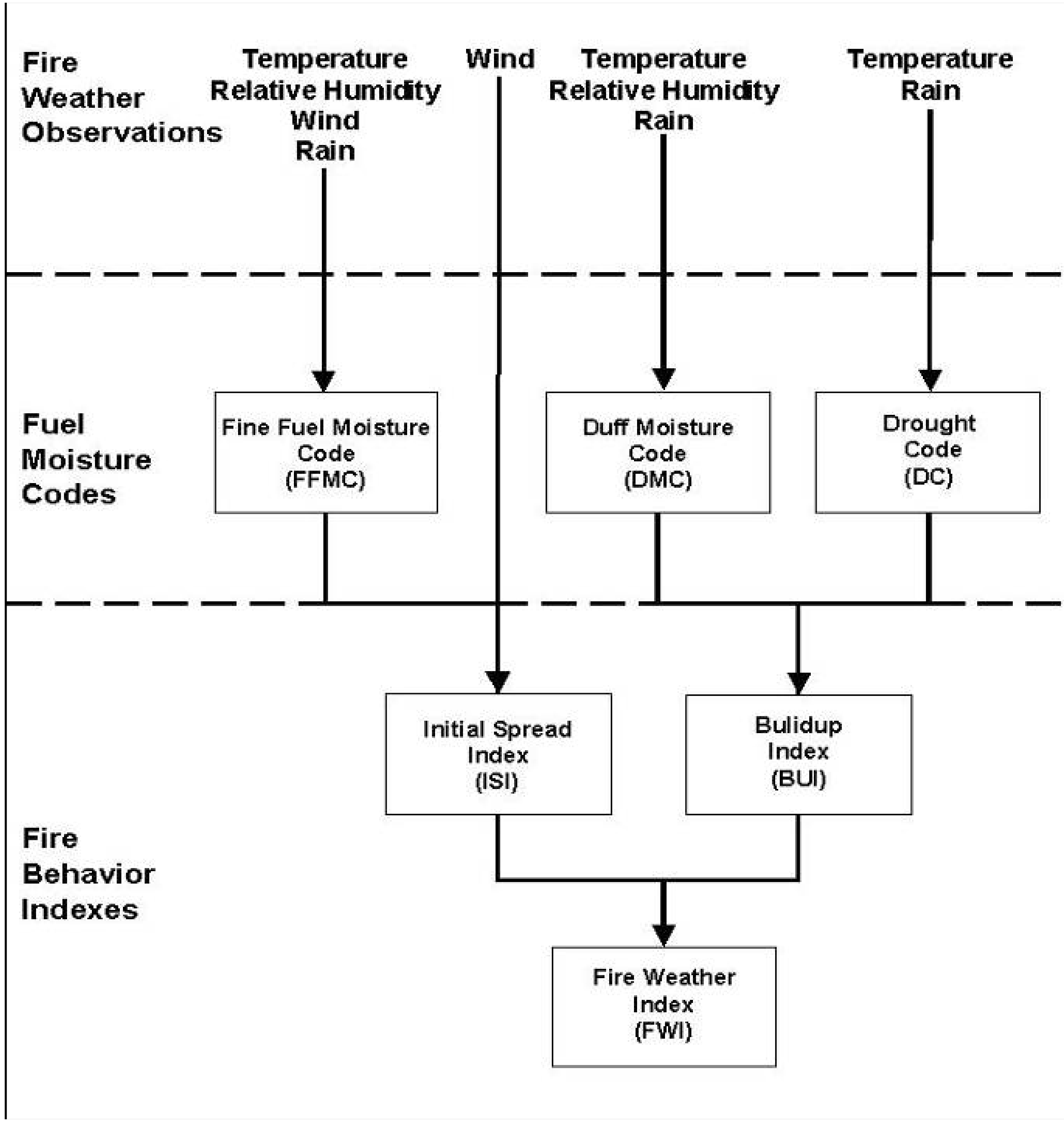
ICFME Treated/Untreated Plot, NWT – June 14, 2000

Conceptual Model of Scientifically-based Forest Fire Management

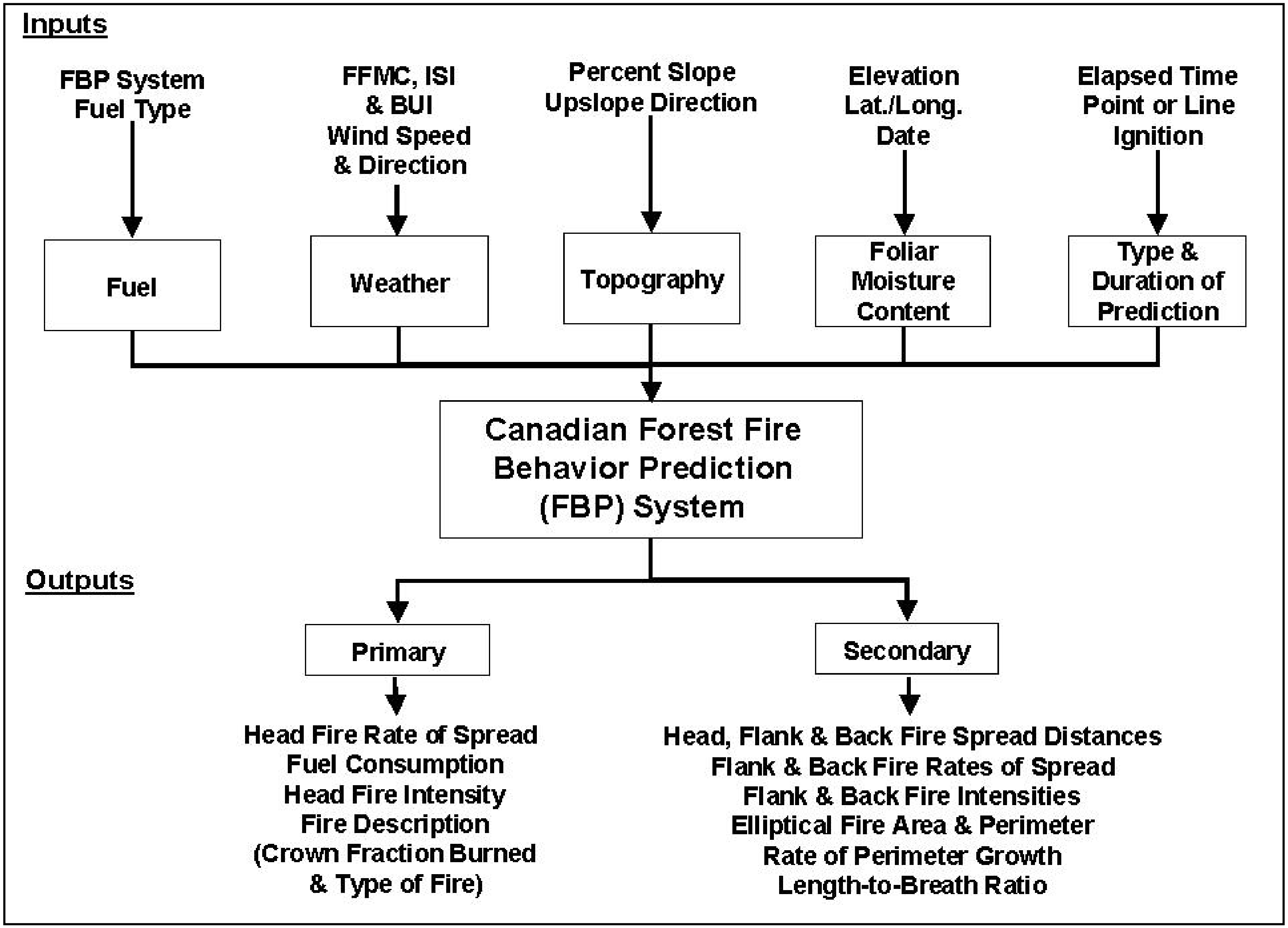


Structure of the Canadian Forest Fire Weather Index (FWI) System

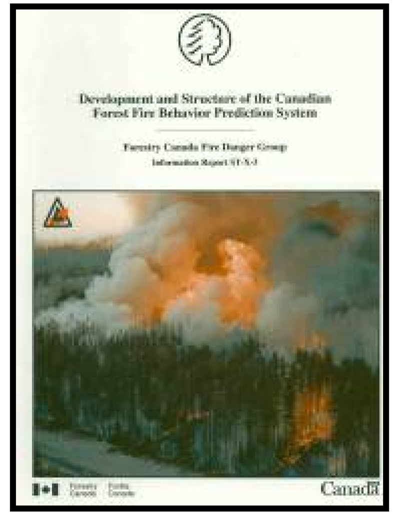
C F F D R S



Structure of the Canadian Forest Fire Behavior Prediction (FBP) System



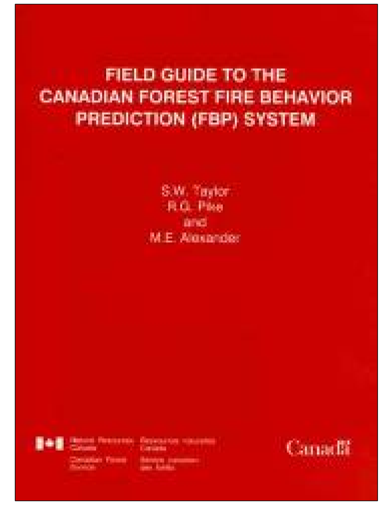
Basis of FBP System & Documentation


Development and Structure of the Canadian Forest Fire Behavior Prediction System

Forestry Canada Fire Danger Group

Information Report ST-X-3

Canada

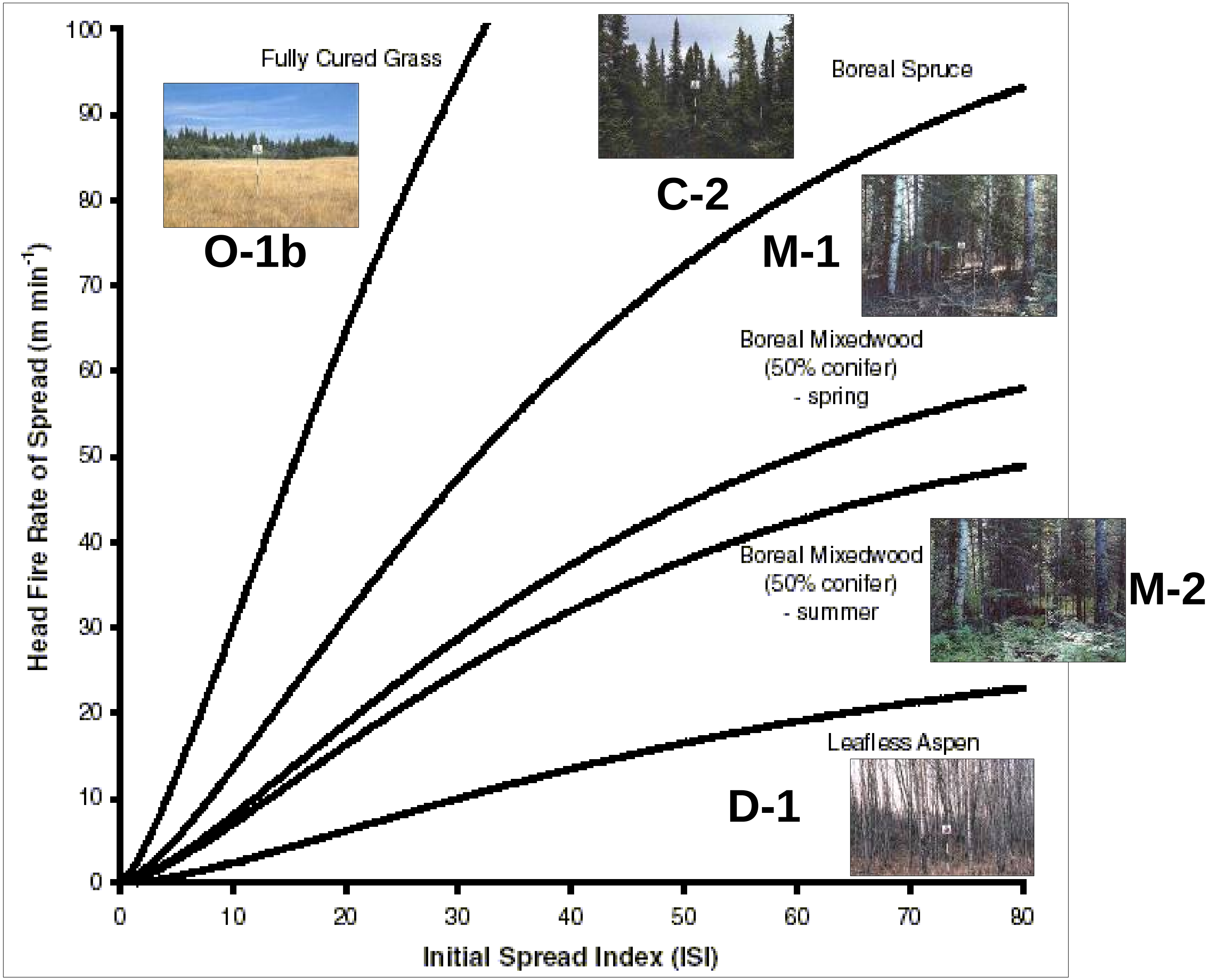

FIELD GUIDE TO THE CANADIAN FOREST FIRE BEHAVIOR PREDICTION (FBP) SYSTEM

S.W. Taylor
R.G. Pike
and
M.E. Alexander

Canada

List of FBP System Fuel Types

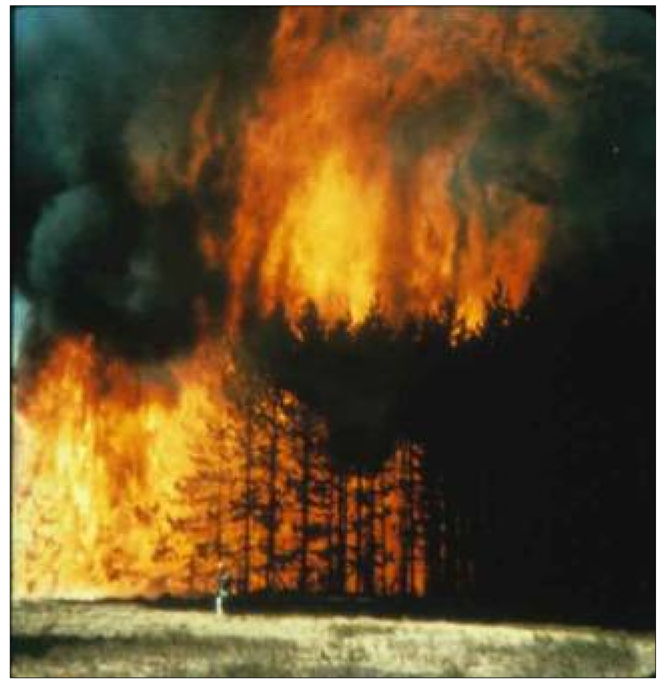
General Category	Fuel Type	Input Modifier
Coniferous	C-1 Spruce-Lichen Woodland	-
	C-2 Boreal Spruce	-
	C-3 Mature Jack or Lodgepole Pine	-
	C-4 Immature Jack or Lodgepole Pine	-
	C-5 Red and White Pine	-
	C-6 Conifer Plantation	Live Crown Base Height
	C-7 Ponderosa Pine/Douglas-fir	-
Deciduous	D-1 Leafless Aspen	-
Mixedwood	M-1 Boreal Mixedwood-Leafless	% Conifer/Hardwood
	M-2 Boreal Mixedwood-Green	% Conifer/Hardwood
	M-3 Dead Balsam Fir/Mixedwood-Leafless	% Dead Fir
	M-4 Dead Balsam Fir/Mixedwood-Green	% Dead Fir
Slash	S-1 Jack or Lodgepole Pine Slash	-
	S-2 Spruce/Balsam Slash	-
	S-3 Coastal Cedar/Hemlock/Douglas-fir Slash	-
Open	O-1a Matted Grass	% Degree of Curing
	O-1b Standing Grass	% Degree of Curing



Fully Cured Grass
O-1b
C-2
Boreal Spruce
M-1
Boreal Mixedwood
(50% conifer)
- spring
Boreal Mixedwood
(50% conifer)
- summer
M-2
Leafless Aspen
D-1
Head Fire Rate of Spread (m min^{-1})
Initial Spread Index (ISI)
0
10
20
30
40
50
60
70
80
90
100

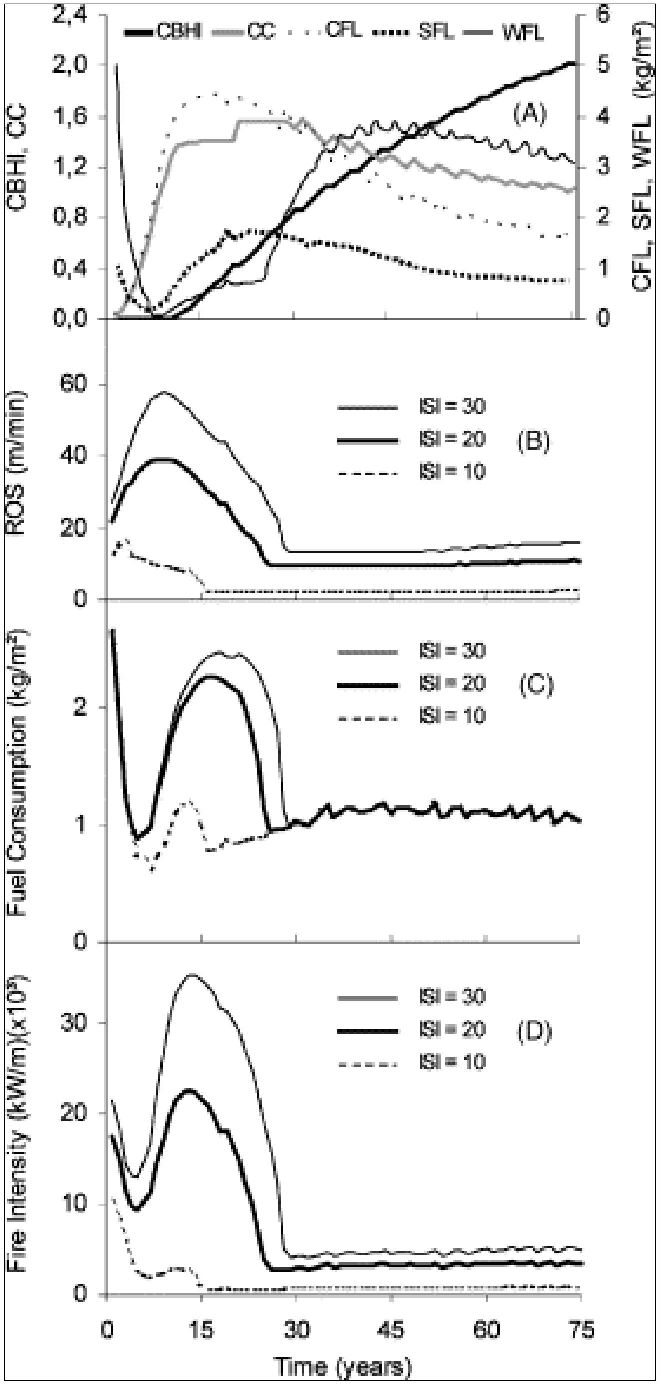
C-6 Fuel Type - Conifer Plantation

(Allowance for variable crown base height)



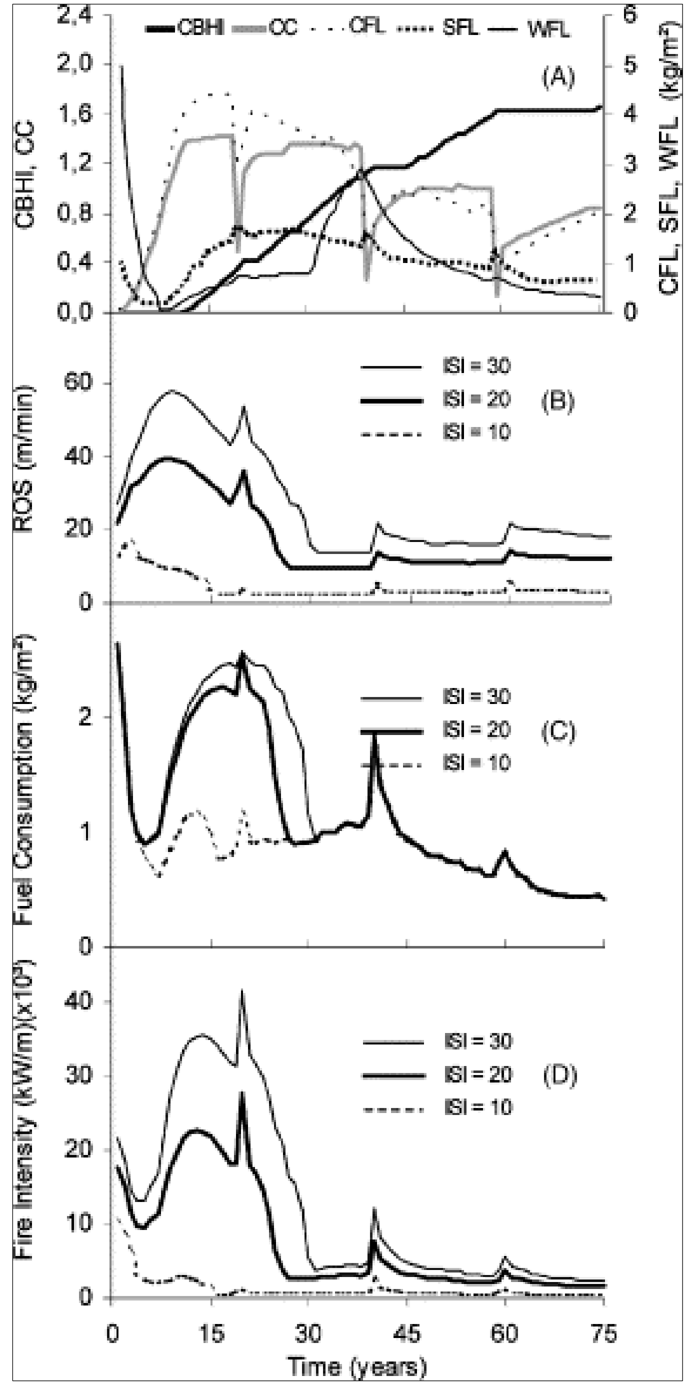
Experimental Fires in Red Pine Plantation, Petawawa Forest Experiment Station, Ontario

Bilgilli (2003)



← **No treatment (2 x 2 spacing)**

Treatment: → **thinnings at 20, 40 & 60 yrs – 30, 50 & 50% of trees removed**



CBH – Crown Base Height

CC – Crown Closure

CFL – Crown Fuel Load

SFL – Surface Fuel Load

WFL – Woody Fuel Load

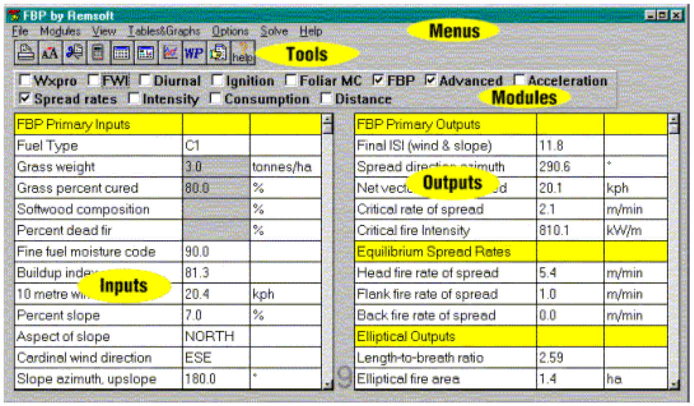
Limitations of FBP System Fuel Types

- Some allowance for seasonal changes in flammability and stand composition
- Fuel types are static and not “dynamic” in nature (i.e., no variation in fuel complex structure and fire behavior with stand age *per se*)
- Except for C-6, the emphasis todate has been on natural fire-origin forest stands
- There is at present no capacity to alter any crown fuel characteristics, other than crown base height in C-6
- Slash fuel types reflect logging methods and utilization standards of the 1960s

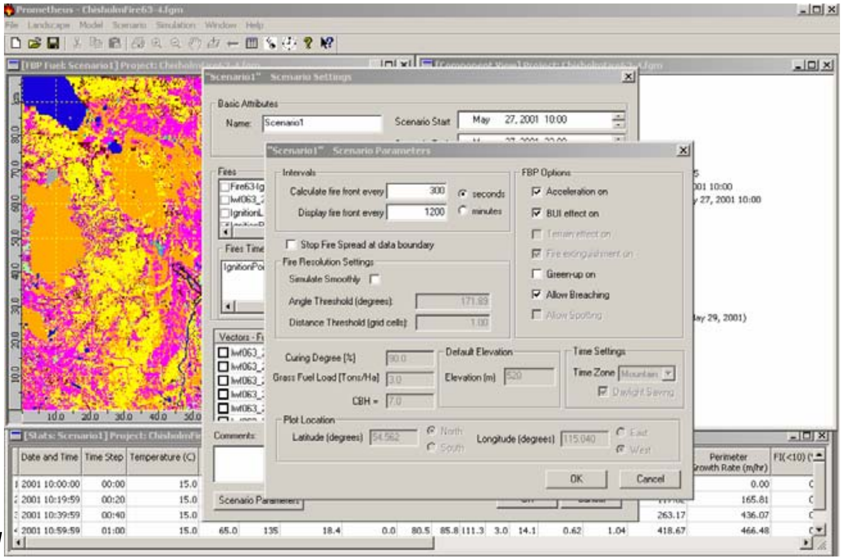
FBP System Software

Behave by Remsoft®

http://www.remsoft.com/



PROMETHEUS – Canadian Wildland Fire Growth Model



http://www.firegrowthmodel.com/

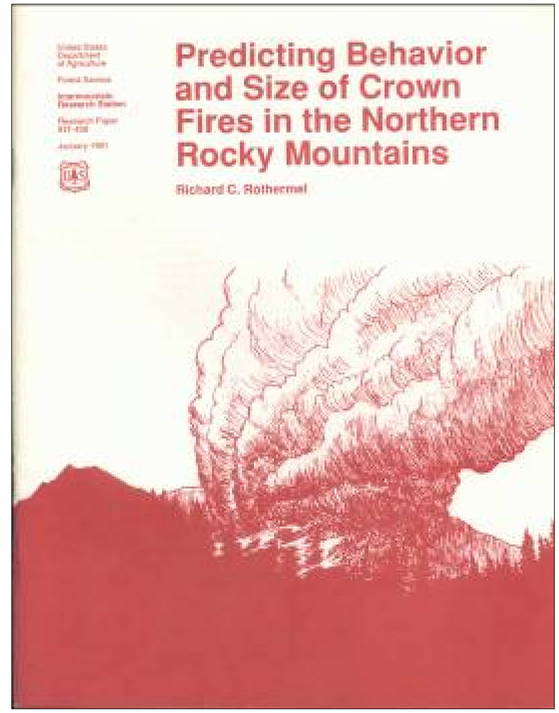
U.S. Fire Behavior Predicition System

http://www.fire.org

- **Based largely on Rothermel's (1972) surface fire rate of spread model involving laboratory test fires and physical theory (some empiricalism)**

- **Limited validation**
- **Does not consider duff layer**

BehavePlus System now includes Rothermel's (1991) crown fire rate of spread model which is based on an empirically derived multiplier (3.34) between the predicted surface fire rate of spread and a limited number of wildfire observations (8).



Nearly all simulations undertaken in the U.S. regarding the impacts or effectiveness of fuel treatments on fire behavior involve the BehavePlus System (or its derivatives – NEXUS, FARSITE, Fuel Management Analyst), and the Rothermel (1991) model.

New Models for Assessing Crown Fire Hazard

Re-analysis of the experimental data used in the development of the Canadian FBP System undertaken by M.G. Cruz (Univ. MT/ADAI Portugal), M.E. Alexander & Ron Wakimoto (Univ. MT) in 1999-2005 has lead to the development of more generic-based models for predicting crown fire initiation and spread in conifer forest stands


Definition of a Fire Behavior Model Evaluation Protocol: A Case Study Application to Crown Fire Behavior Models

Miguel G. Cruz, Martin E. Alexander, and Ronald H. Wakimoto


Assessing the probability of crown fire initiation based on fire danger indices

by Miguel G. Cruz, Martin E. Alexander and Ronald H. Wakimoto


Modeling the Likelihood of Crown Fire Occurrence in Conifer Forest Stands

Miguel G. Cruz, Martin E. Alexander, and Ronald H. Wakimoto


Development and testing of models for predicting crown fire rate of spread in conifer forest stands

Miguel G. Cruz, Martin E. Alexander, and Ronald H. Wakimoto

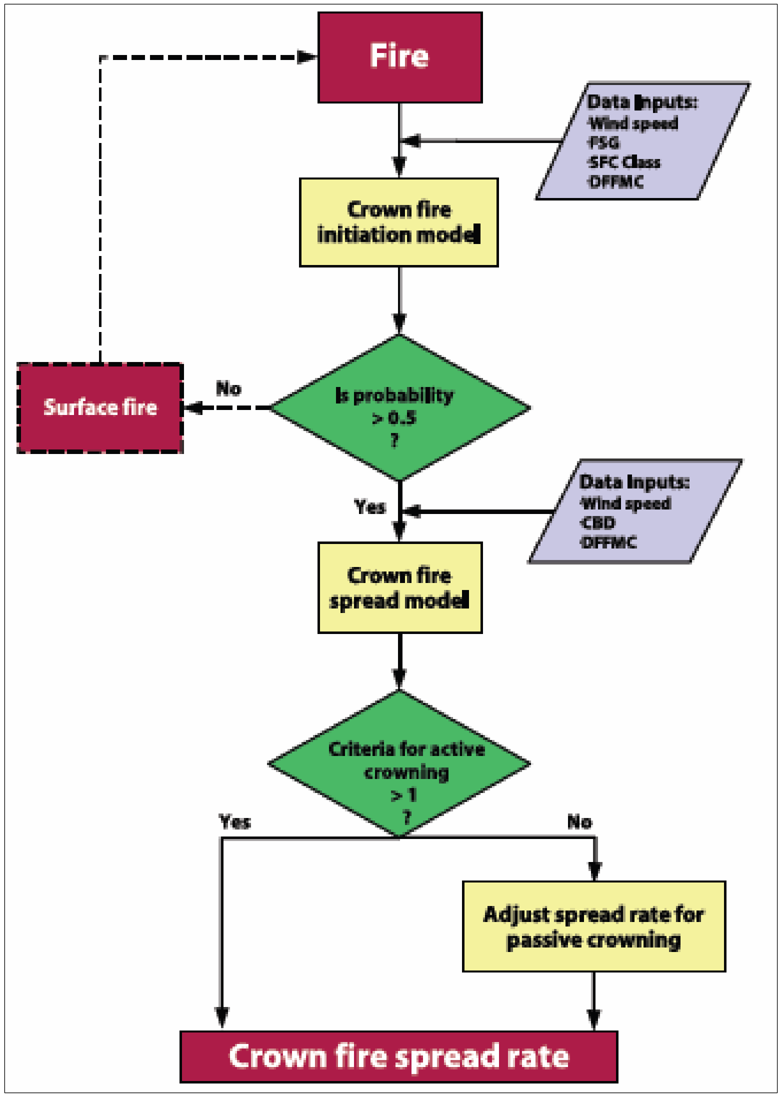


Diagram of information flow for predicting crown fire initiation* and spread potential based on the models developed by Cruz, Alexander and Wakimoto (2004, 2005).

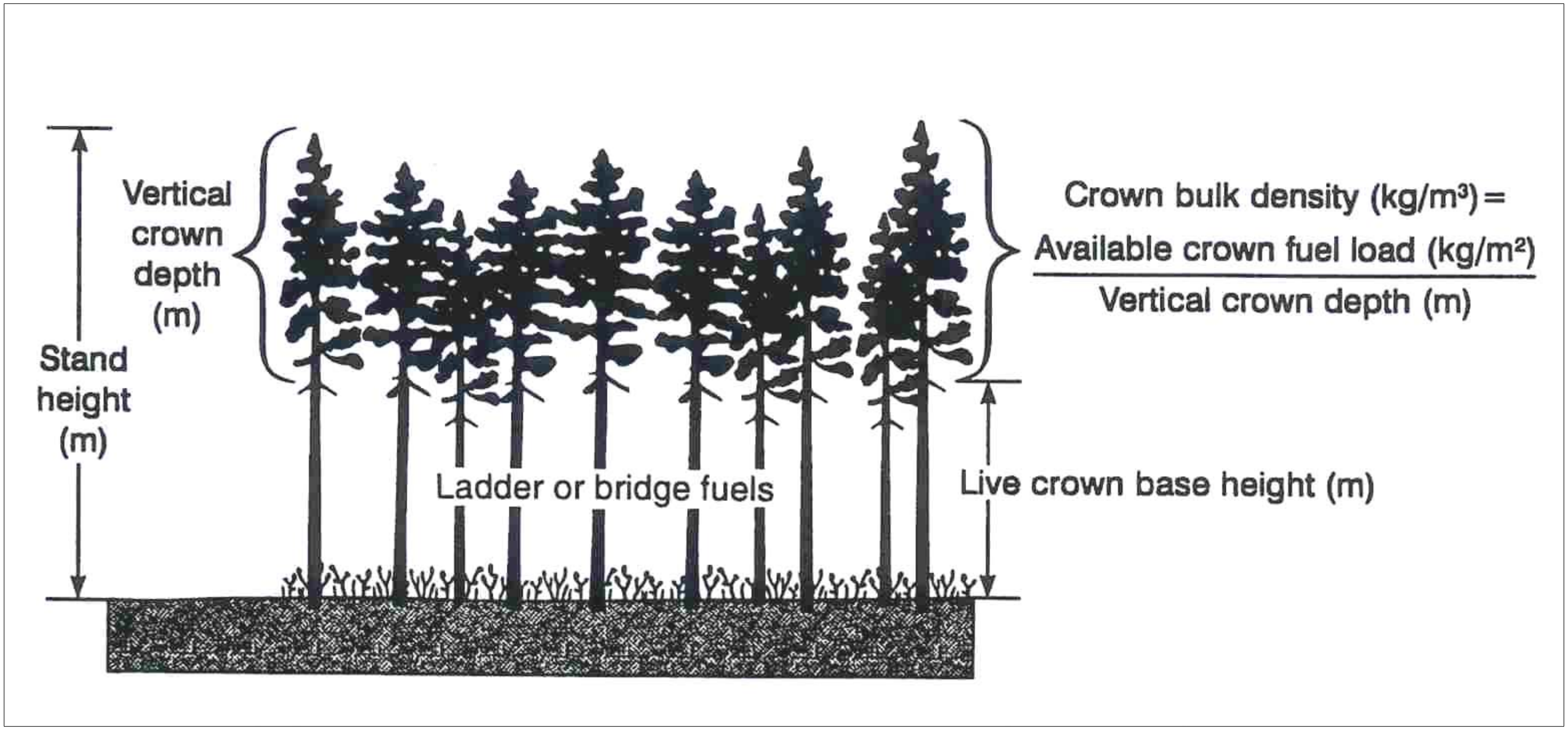
***Alternatively, crown fire initiation can be predicting using crown base height, 10-m open wind speed, and FWI System components (Cruz, Alexander and Wakimoto 2003)**

Model Inputs

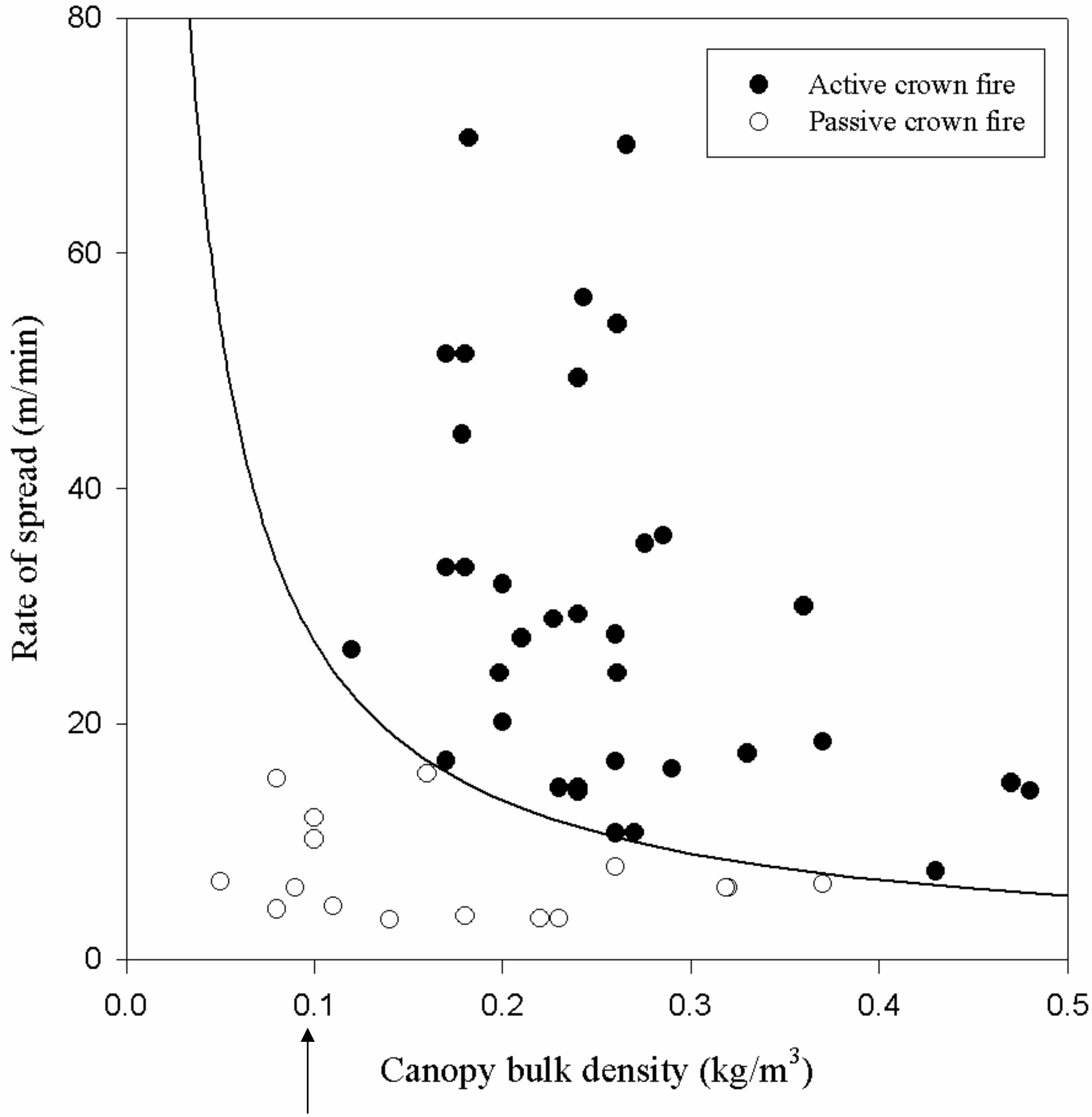
- Estimated Fine Fuel Moisture (determined from air temperature, relative humidity, time of year & day, and degree of shading)
- Surface Fuel Consumption (<1, 1-2 or > 2 kg/m^2)*
- Fuel Strata Gap or Canopy Base Height*
- 10-m Open Wind Speed
- Canopy or Crown Bulk Density*

*These three characteristics of a forest stand or fuel complex are subject to manipulation by silvicultural and other vegetation management techniques

Canopy or Crown Bulk Density Concept



Available crown fuel load determined from stand data (i.e., number of stems per hectare by DBH size class) and foliage/twig vs. DBH relationships

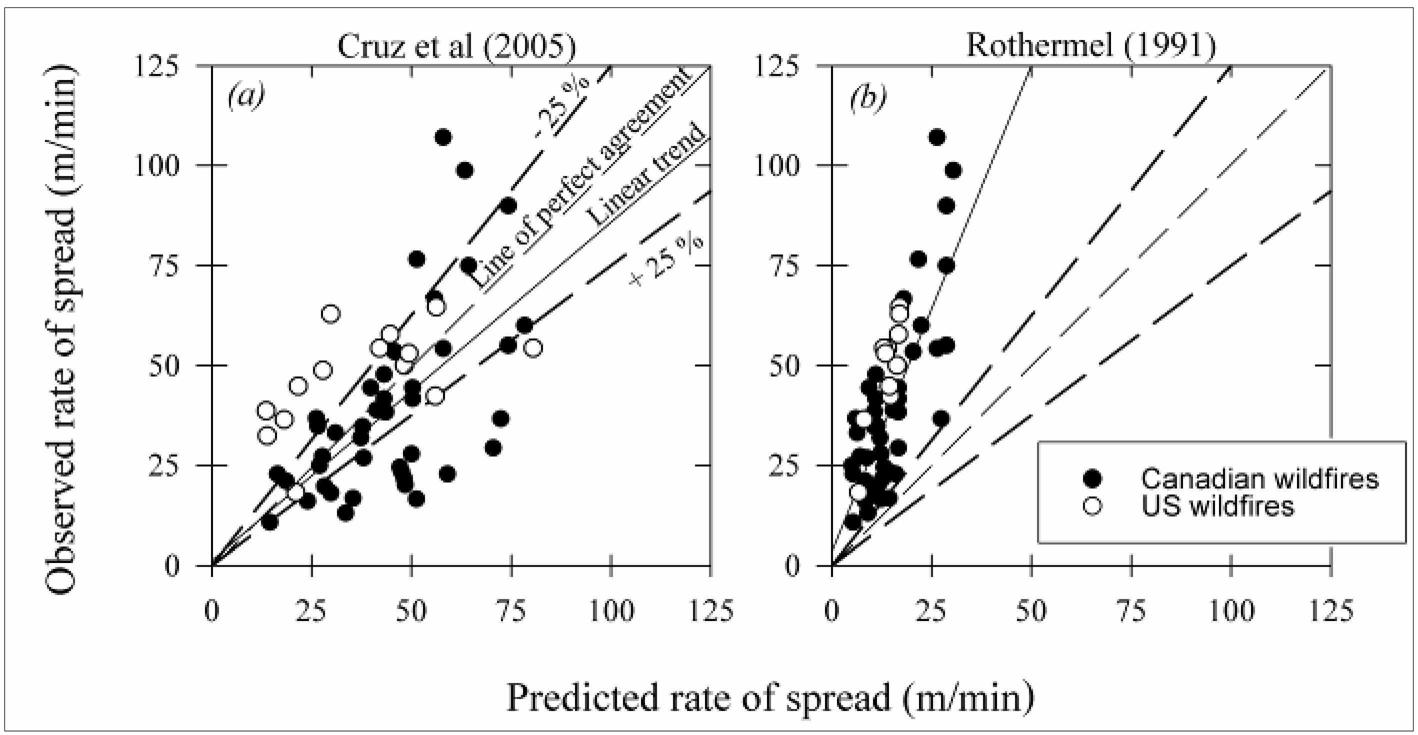


Critical threshold

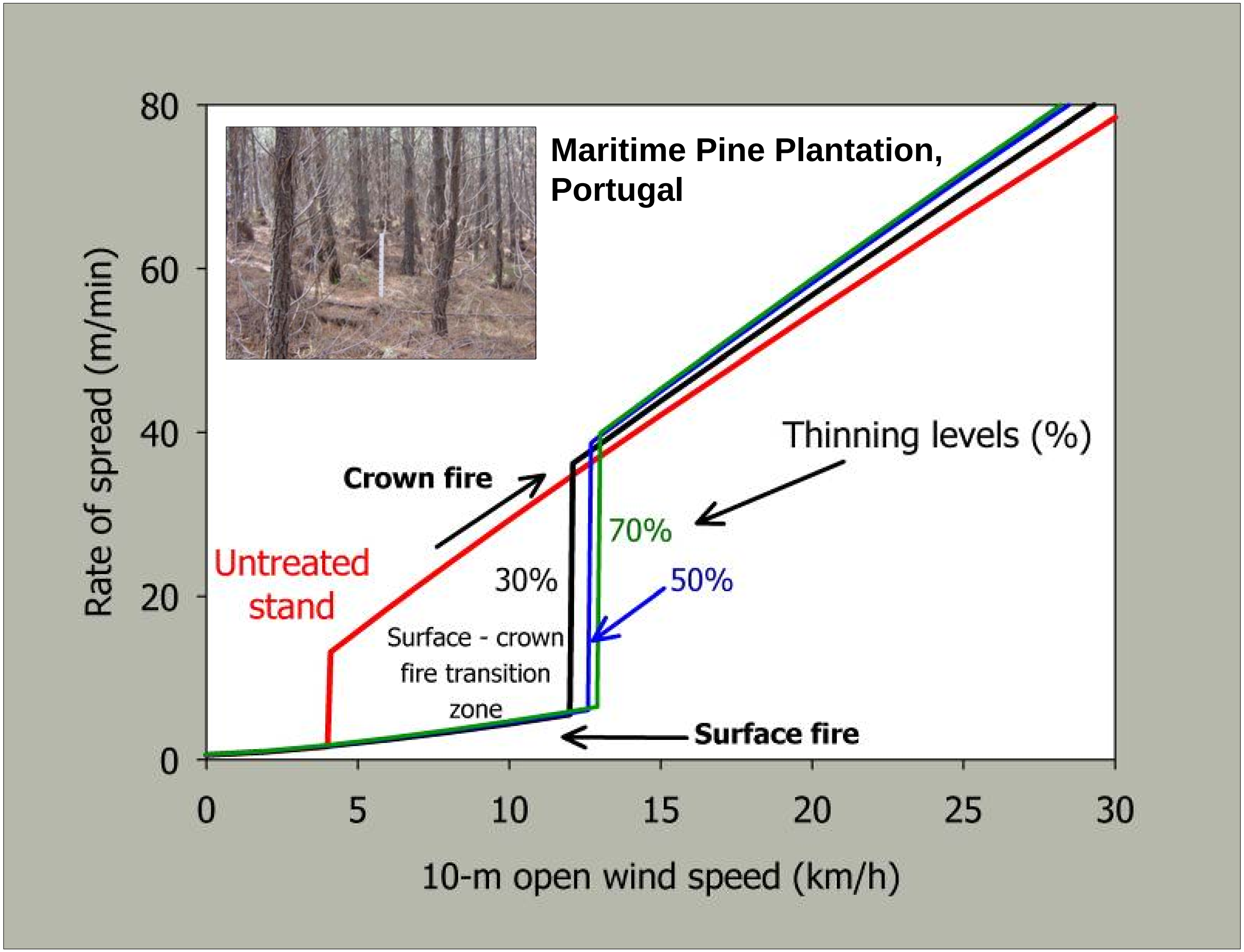
Van Wagner's (1977) critical minimum spread rate criterion for active or continuous crowning as related to canopy bulk density (curve) in relation to experimental crown fire data

Model Evaluation

The Cruz, Alexander and Wakimoto (2003, 2004, and 2005) model outputs have been compared to two independent experimental datasets (ICFME & Porter Lake) as well as 57 wildfire observations (43 Canadian & 14 U.S.) obtained from case studies. The results have been quite favourable.



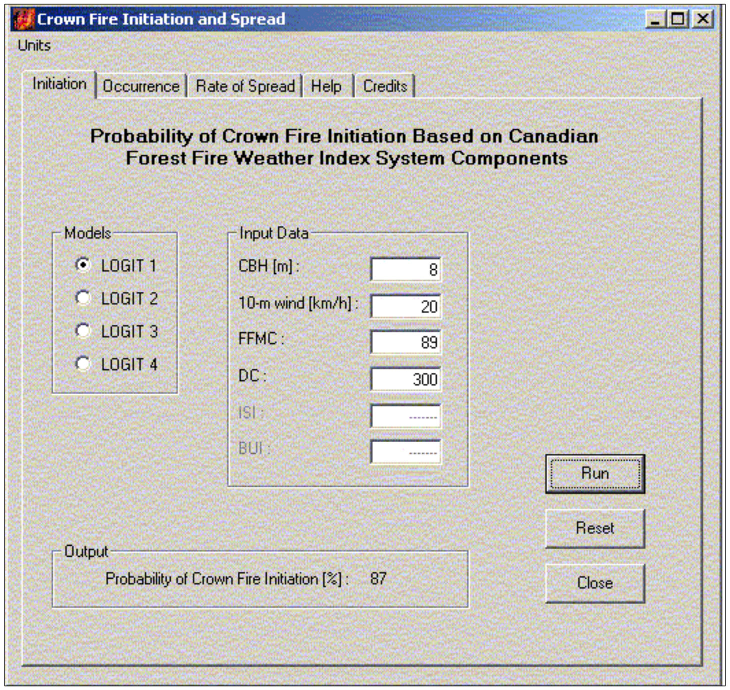
Simulation Using the Models Contained in CFIS

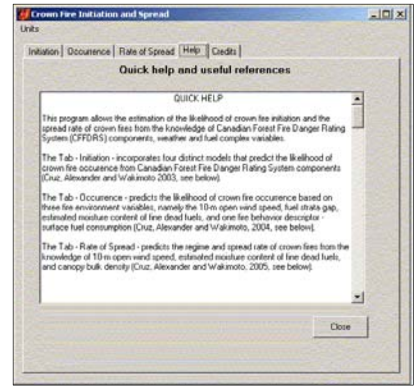


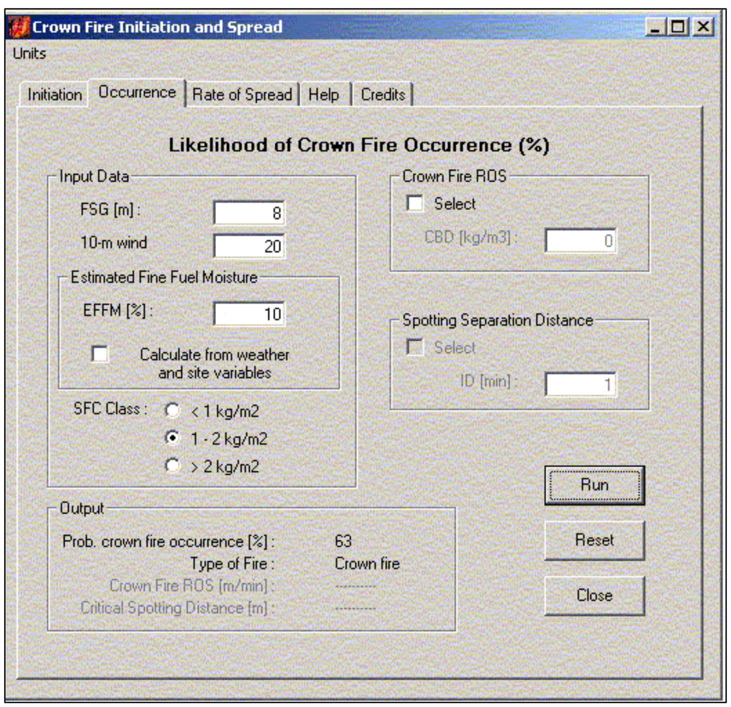
Cruz, Alexander and Wakimoto (2003, 2004, 2005) crown fire behavior models have now been incorporated into a software package

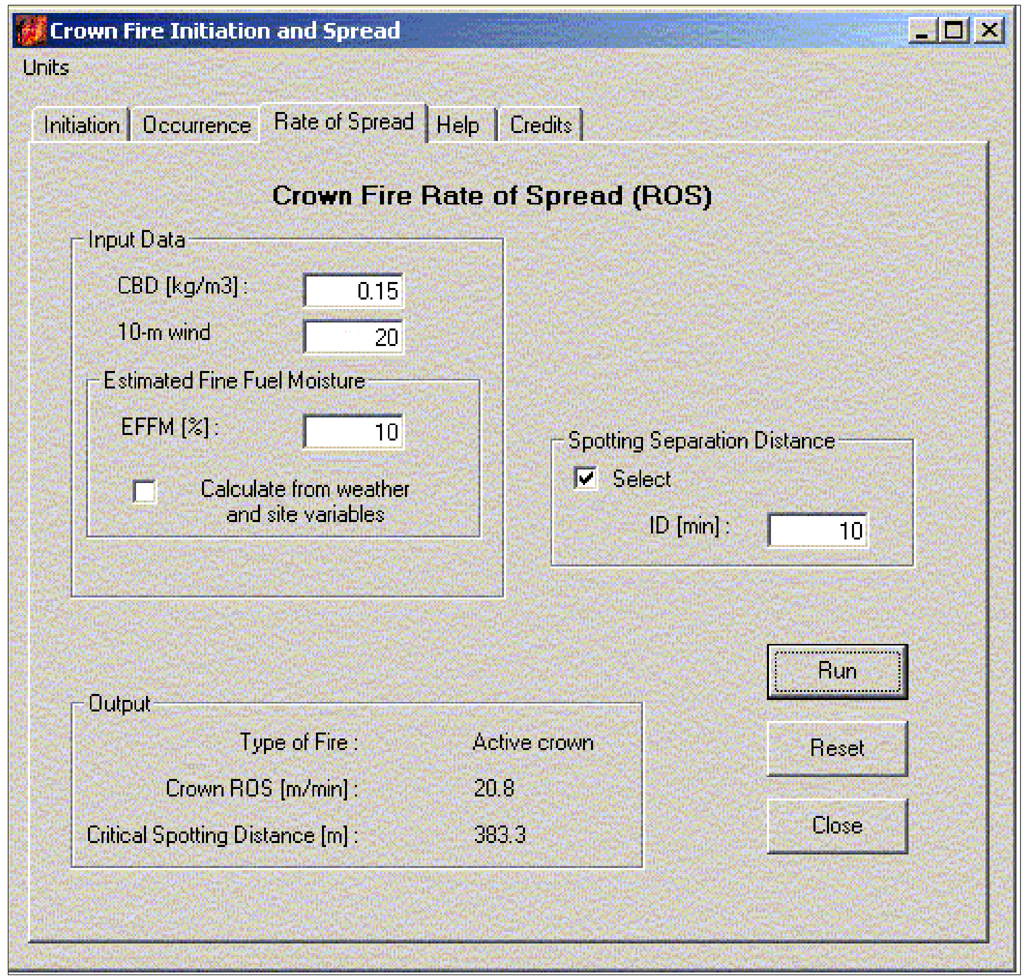
http://www2.dem.uc.pt/antonio.gameiro/ficheiros/CFIS.exe

Screen captures from CFIS

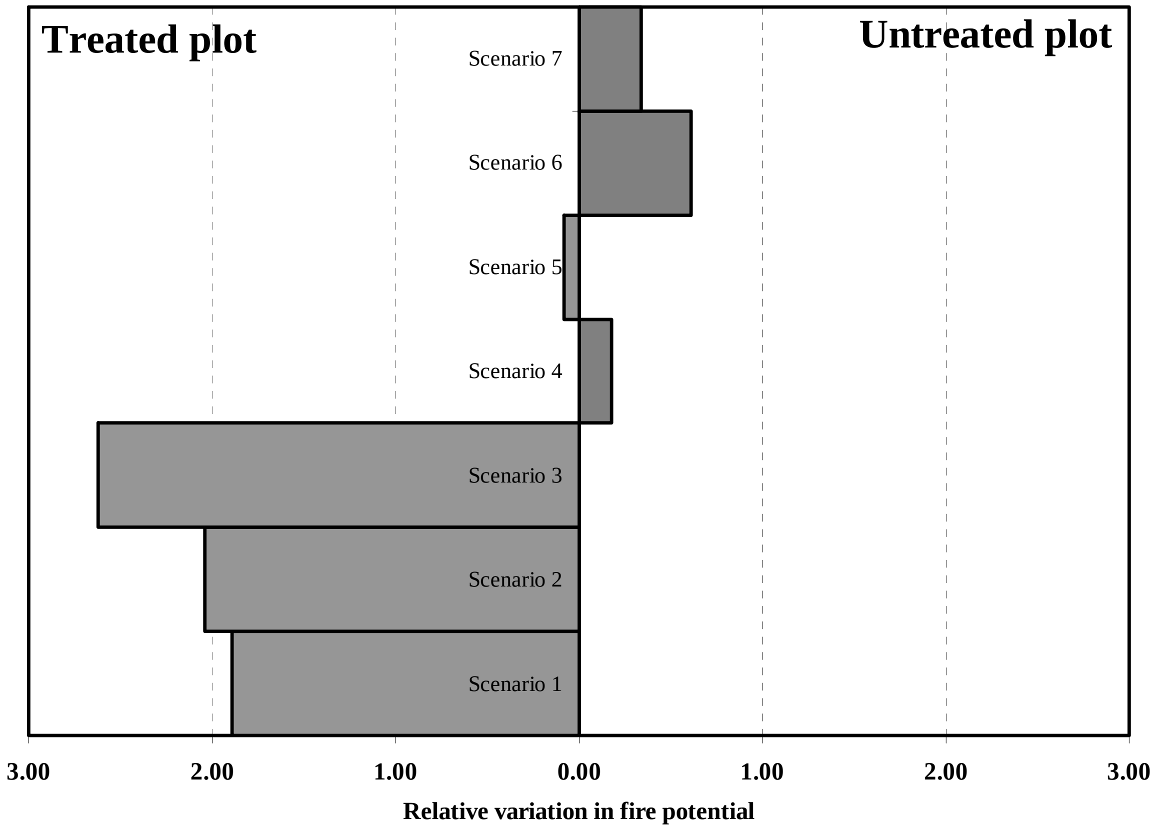








Relative Increases in Fire Intensity and Crowning Potential due to fuel manipulation in a Lodgepole Pine Stand* near Whitecourt, AB (as described by Dam 2000) based on various fire behavior models



*Dam, J. 2000. Effects of thinning in fire behavior: a case study in lodgepole pine in Canada. M.Sc. Thesis, Wageningen University, Holland. 60 p.

III. Conclusions & Some Suggestions for the Future

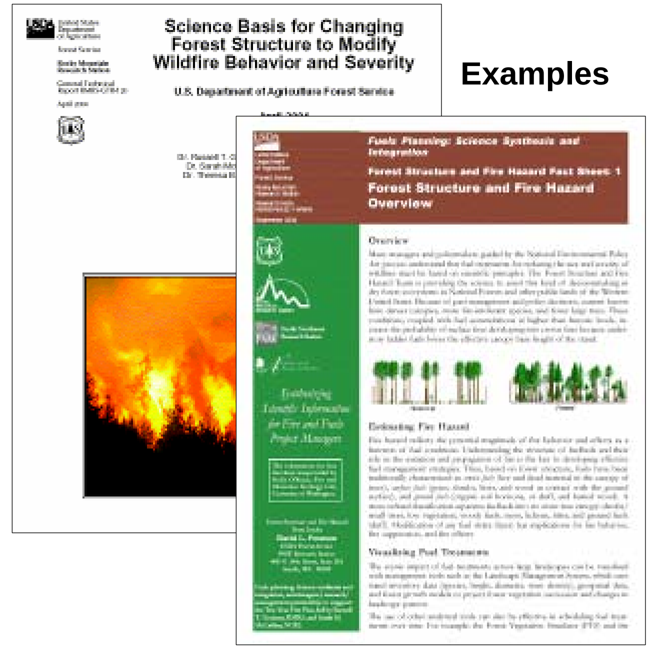
- Fire behavior is a multi-faceted subject area
- While acknowledging that the processes involved are complex with numerous controlling factors, qualitatively we know a great deal about fire behavior
- Fire behavior research and associated model development has matured greatly in recent years
- Rudimentary modelling of fire behavior potential in relation to post-harvest stand development is now possible; such efforts will no doubt identify critical knowledge gaps and research needs

continued …

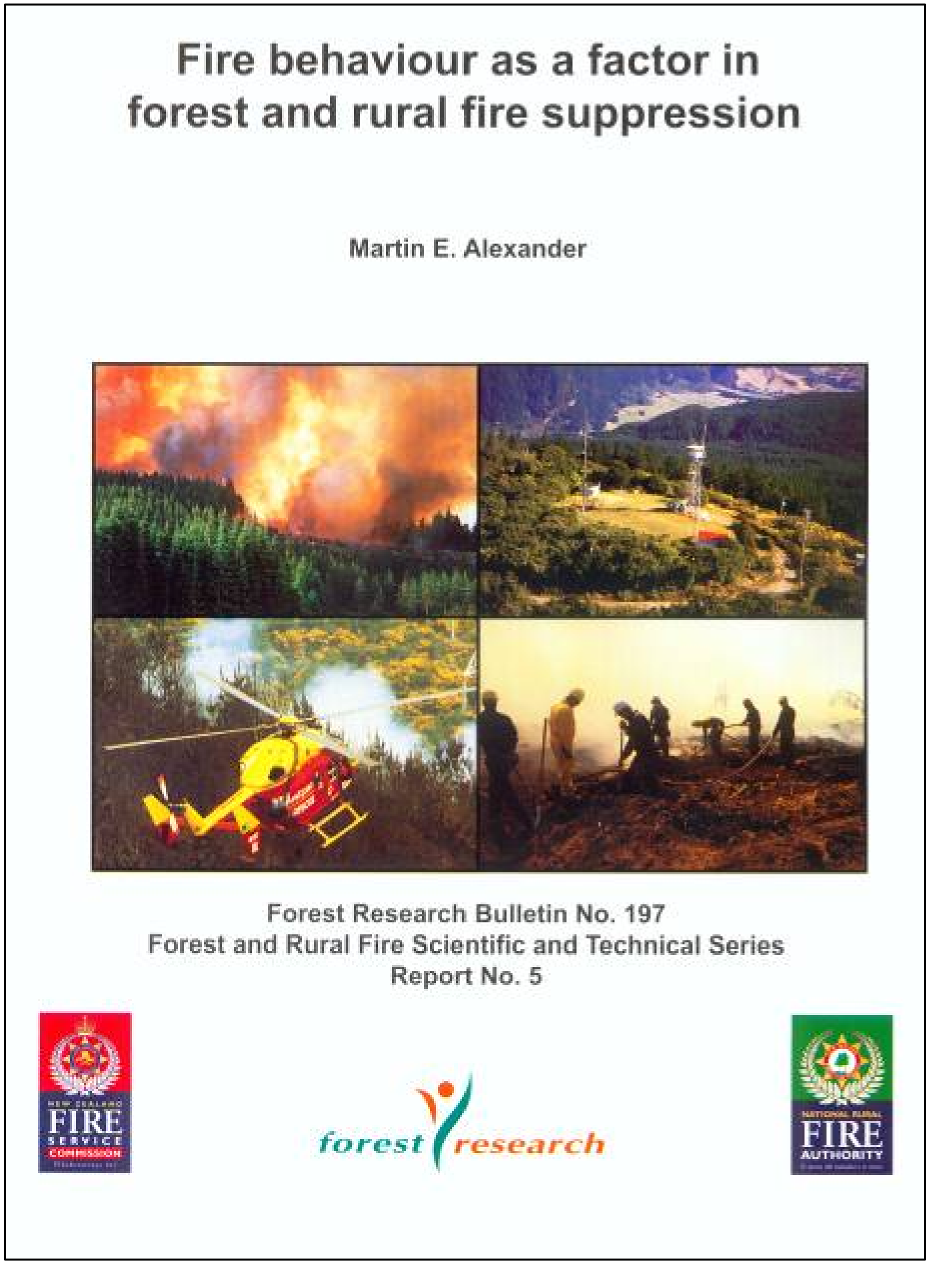
• **We know nothing specific about fuel and fire behavior characteristics in young, post-harvest stands in western Canada**

• **Existing knowledge should be summarized and made available to managers & other researchers in order to continue the process of communication across disciplines**

Examples



• **Consider extension of the *Forest Vegetation Simulator* to post-harvest stand development as a means of integrating and "housing" our collective knowledge, not just for fire considerations**



Fire behaviour as a factor in forest and rural fire suppression

Martin E. Alexander

Forest Research Bulletin No. 197
Forest and Rural Fire Scientific and Technical Series
Report No. 5

forest research

... further major advances in combating wildfire are unlikely to be achieved simply by continued application of the traditional methods. What is required is a more fundamental approach which can be applied at the design stage … Such an approach requires a detailed understanding of fire behaviour ...

Drysdale (1985)
Introduction to Fire Dynamics

Acknowledgments

Wildland Fire Operations
Research Group

Miguel Cruz
CSIRO Australia

Ron Wakimoto
University of Montana

Thank you for your attention! ☺

See Supplementary Handout. Questions?

Post-Harvest Stand Development Conference
Edmonton, Alberta

Forest Health: Fire Behaviour Considerations

Marty Alexander, Canadian Forest Service

Marty Alexander provided an overview for the non-specialist of fire behaviour terms and concepts, existing tools for predicting fire behaviour at the stand level (with particular emphasis on the development of and propensity for crown fire activity), and offered some suggestions for future directions. The limitations of present-day fire behaviour models and systems were highlighted.

FOREST HEALTH:
Fire Behavior Considerations[1]

Marty Alexander, PhD, RPF
Senior Fire Behavior Research Officer
Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta

This presentation will provide a overview (for the non-specialist) of relevant fire behavior terms and concepts, existing tools for predicting fire behavior at the stand level (with particular emphasis on the development and propensity for crown fire activity), and finally, to offer some suggestions for future direction. The limitations of present day fire behavior models and systems are highlighted.

Most of the references that either support this presentation or are mentioned/referred to in the presentation are provided here. Items available from the Canadian Forest Service Online Bookstore (http://bookstore.cfs.nrcan.gc.ca/default.htm) are denoted by a "(*)" at the end of the citation.

The seven scenarios presented in the graph near the end of the PowerPoint presentation (i.e., image 40, fifth from the end) are described in the **Annex** of this document.

Postscript

I agonized over the fact that the conference organizers asked me to limit my remarks to fire behavior at the stand level. I had wanted to touch on some issues regarding fire behavior at the landscape level. In this regard, the following passage comes from Alexander (1998, p. 6):

> *Logic would dictate that the chance(s) of a high-intensity crown fire occurrence would gradually increase as the size of the total plantation estate increases. The value of a dispersed pattern of relatively small to moderately sized plantations, especially in fire-prone environments exhibiting very high ignition risk coupled with an adverse fire climate, was demonstrated during the 1983 Ash Wednesday Fires in the southeastern portion of South Australia and Victoria … State-owned plantations in the region managed by the Woods and Forests Department amount to approximately 80 000 ha and are comprised of a few large, more or less contiguous blocks of land. On February 16, 1983, some 21 000 ha of*

[1]Supplement to PowerPoint presentation made at the Post-Harvest Stand Development Conference held in Edmonton, Alberta, January 31-February 1, 2006, a collaborative initiative of the Foothills Growth & Yield Association, Foothills Model Forest, and Alberta Forest Genetic Resources Council, and sponsored by the Forest Resource Improvement Association of Alberta. PowerPoint presentations made at the conference available for viewing at: http://www.fmf.ca/

exotic pine plantations were burnt over in South Australia alone[2]*, most very severely, by eight fires that covered a gross area of around 120 000 ha. In contrast, private forest industry in the region, with a comparable estate of around 70 000 ha, but comprised of many smaller parcels scattered across the region more as a result of circumstances rather than by any strategic design, suffered only minor (40 ha) wildfire losses …*

Bibliography and References Cited

Alexander, M.E. 1982. Calculating and interpreting forest fire intensities. Canadian Journal of Botany 60: 349-357. (*)

Alexander, M.E. 1988. Help with making crown fire hazard assessments. Pages 147-156 *in* Fischer, W.C.; Arno, S.F. (compilers). Protecting People and Homes from Wildfire in the Interior West: Proceedings of the Symposium and Workshop. USDA Forest Service, Intermountain Research Station, Ogden, Utah. General Technical Report INT-251. (*)

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Short Biographical Sketch

Dr. Marty Alexander is a Senior Fire Behavior Research Officer, Canadian Forest Service (CFS), Northern Forestry Centre, Edmonton, Alberta. He has been employed by the CFS since 1976. His research interests are wildland fire behavior and forest/grassland fire danger rating, including the practical and scientific application of such knowledge to fire/fuel management and other disciplines. Marty was one of the architects of the Canadian Forest Fire Behavior Prediction System and also served as one of the co-coordinators of the International Crown Fire Modelling Experiment in the Northwest Territories from 1995-2001. He has been heavily involved in fire behavior training on a national and international basis.

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Annex[3]

Fire behavior models are quite commonly used to judge the impacts or effectiveness of fuel treatments on potential fire behavior in the U.S. both from a research standpoint (e.g., Fule et al. 2001) and in training (Johnson 2005). It's important to recognize that different models (and how the inputs are handled) can produce widely varying results The graph shown on image 40 of the PowerPoint presentation was based on a fuel and stand characteristics for a lodgepole pine stand near Whitecourt, Alberta (Dam 2000), the treated (i.e., precommercial thinning) portion of which had been undertaken by Millar Western Forest Products Ltd. The analysis of potential fire behavior in treated/untreated areas of the stand was examined based on the 97th percentile fire weather and fire danger conditions for the area. Seven distinct scenarios were examined:

- **Scenario 1:** Application of the Rothermel (1972) surface fire spread model considering changes in fuelbed structure induced by the silvicultural treatment and assuming identical fuel moisture and within stand wind speed.

- **Scenario 2:** Same as **Scenario 1** but modeling changes in fuel moisture of fine fuels by application of Rothermel et al. (1986) model (i.e., fine fuel moisture content in the treated portion of the stand was predicted to be 0.5% lower than in untreated portion.

- **Scenario 3:** Same as **Scenario 1**, but considering the fuel moisture differences as sampled by Dam (2000) in the study site (i.e., fuel moistures in the litter of the treated portion of the stand were consistently lower, averaging 2.6% in needles and 2.0% for small twigs);

- **Scenario 4:** Wind speed threshold for crowning based on the Cruz et al. (2004) model and considering the same fuel moisture as for **Scenario 1**.

- **Scenario 5:** same as **Scenario 4** but with fuel moisture as for **Scenario 3**.

- **Scenario 6:** Wind speed threshold for active crowning as per NEXUS (Scott and Reinhardt 2001) but using the Cruz et al. (2004) model.

[3]Adapted from: Cruz, M.G.; Alexander, M.E. 2005. Implication for evaluation of fuel treatments effectiveness in reducing potential fire behavior: A case study in a lodgepole pine stand. Unpubublished.

- **Scenario 7: Scenario 6** but with fuel moisture as for **Scenario 3**.

The graph below shows the relative increases in surface fire intensity (**Scenarios 1-3**) and crowning potential (**Scenarios 4-7**). For **Scenarios 1-3**, the relative variation in fire potential is with respect to the predicted surface fire intensity of the untreated plot. For **Scenarios 4-7,** the relative variation in fire potential is with respect to the wind speed threshold for crowning in the treated plot.