Fire behavior in immature and mature aspen stands under severe spring burning conditions: does fire history matter?

Final Report

Submitted to
Foothills Model Forest
P.O. Box 6330
Hinton, Alberta
As part of the Chisholm Fire Research Initiative

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October 15, 2003

Executive Summary

Aspen forest types involved in the Chisholm Fire of May 2001 served as both fuel for intense fire runs, as well as fire breaks. The re-burning under extreme burning conditions of Canadian Forest Service experimental fire behavior plots from the 1970s created an opportunity to study aspen fire behavior on the same sites with documented fire histories. The Chisholm Fire slowed and stopped spreading in extensive young aspen stands that regenerated after the 1968 Vega Fire, creating an opportunity to study this fire break effect under extreme burning conditions and different fire history from the nearby experimental plots. Fuel loads, fuel consumption and fire intensities were compared with predicted values from the Canadian Forest Fire Behavior Prediction (FBP) System. Implications of fire history for fuel loads and potential fire behavior in aspen stands are discussed from the standpoint of firebreak effectiveness.

The Chisholm Fire killed all overstory trees on the aspen plots measured in this study, including the re-measured plots from the 1970s and the new plots established on the Vega Fire re-burn. Aspen suckering was present on all burned plots. Fire intensities were estimated as high as 225 000 to 228 000 kW/m on plots re-burned from the 1970s, including the previously un-burned control plot, although these estimates are subject to significant error in the estimated rate of spread component of intensity. Estimated fire intensities on the re-burned Vega Fire area where the Chisholm Fire burned into aspen and stopped after a few hundred metres were much lower, ranging from 8900 to 27 000 kW/m, due to lower rate of spread estimates and fuel consumption estimates approximately half of the CFS plot area.

Downed-woody fuel loads were estimated to have been high on the re-burned CFS plots, and on the unburned control plot, due to falldown of natural mortality and 1972 and 1978 fire-killed trees. By contrast, downed-woody fuel loads were moderate on the re-burn of the Vega Fire, since the area had been salvage-logged following the Vega Fire. Drought conditions in spring 2001 contributed to high consumption of downed-woody fuel and forest floor.

Fuel loads and fuel consumption on the 2001 re-burn of the CFS plots were much greater than predicted by the FBP System model for fuel type D-1 (leafless aspen). Estimated forest floor consumption averaged 1.49 kg/m^2, downed-woody surface fuel consumption averaged 6.12 kg/m^2, and total surface fuel consumption averaged 7.65 kg/m^2 on the CFS plots, while the FBP System predicted total fuel consumption of 1.3 kg/m^2, for the prevailing Buildup Index of 121. By contrast, the re-burn on the Vega Fire in 32-year old aspen as the Chisholm Fire run slowed and stopped had estimated forest floor consumptions ranging from 0.9 to 3.7 kg/m^2 and downed-woody fuel consumption of only 0.49 kg/m^2, and total surface fuel consumption ranging from 1.4 to 4.3 kg/m^2. Also reflecting the differences in fire intensity between the CFS plots and the Vega Fire re-burn were mineral soil exposure, averaging 30% on the CFS plots and zero on the Vega Fire re-burn, and tree bole scorch height, which averaged 3.6m on the CFS plots, but only 0.5m on the Vega Fire re-burn area.

Suckering response from root systems of killed aspen trees was generally vigorous on the CFS plots and the Vega Fire re-burn area, although more vigorous when evaluated in 2002 on the CFS plots, regardless of the variation in CFS plot fire history or past burn intensity. Vegetative response in terms of herbs and shrubs one year post-burn was similarly vigorous on both areas, in terms of biomass, although grass was sparse on the CFS plots and a significant component on the Vega Fire re-burn.

Traditionally, aspen stands have been considered a low-hazard fuel type, suitable for strategic use as fuelbreaks (barriers to fire spread), and fire-prone only for brief windows in spring and fall. Prior to spring leaf-out of deciduous trees and herb/shrub components, aspen stands have been modelled to produce low spread-rate surface fires of low fuel consumption and fire intensity, such as observed on the 1972 CFS plots when originally burned experimentally. However, the 1978 re-burn of CFS plots 3b+c, and the 2001 Chisholm Fire re-burns have shown that either or both downed-woody fuel accumulation and severe spring burning conditions can result in much higher fuel consumption and fire intensities in aspen stands than presently predicted by fire behavior models. Under estimation of potential fire behavior under critical conditions could conceivably result in over-estimation of the benefits of aspen stands as fuelbreaks.

Aspen (D-1) fuel consumption models in the FBP System should be recognized as potentially under-predicting at high BUI values and where downed-dead fuel loads are significant. However, the fuel consumption estimates for the 2001 Chisholm Fire made in the present study were not based on the same pre- and post-burn plots and therefore lack the statistical validity to support the recommendation of specific quantitative changes to the FBP System fuel consumption equation for fuel type D-1.

From a strategic fuel management standpoint, aspen fuelbreaks have been shown here to be effective at slowing and even stopping fire spread under severe spring burning conditions, when downed-dead woody fuels are light and cured grass is not a factor. Aspen fuel breaks should be managed and maintained to maximize canopy closure in order to exclude grass growth, and to ensure that downed-woody fuel loads accumulating from either natural mortality or fire history are reduced to at most a single ground layer.

Acknowledgements

The authors thank Dennis Quintilio for encouraging this study. Marty Alexander, Canadian Forest Service, Edmonton, kindly provided essential office files of original 1972 field forms and data from the aspen fire behaviour research study that was re-measured here. Brad Hawkes, Canadian Forest Service, Victoria, provided access to oven-drying facilities and the services of George Dalrymple for conducting mineral content determinations. Murray Maffey, retired Canadian Forest Service research technician, who had worked on the 1972 fire research study, assisted in this re-measurement. Karen Sherman assisted with typing the manuscript.

Alberta Sustainable Resource Management fire management staff at Slave Lake District assisted with helicopter transportation and reconnaissance flights to new plots on the re-burn of the 1968 Vega Fire, and with GIS maps and air photos to support the locating of new plots.

Lou Foley advised on access to Vanderwell's operating and salvage areas for potential study sites.

Greg Baxter, FERIC Wildland Fire Operations Research Centre, kindly reviewed the manuscript.

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1.0 INTRODUCTION

The Chisholm Fire of May 2001 was one of Alberta's most devastating and expensive fire events. The erratic fire behaviour characteristics of this fire have been documented (Quintilio et al. 2001). An independent fire review panel recommended improved knowledge, understanding and utilization of fire behaviour prediction capability, particularly with respect to potentially extreme wildland fire behaviour related to drought and night burning conditions (Chisholm Fire Review Committee 2001). Aspen forest types involved in the Chisholm Fire served as both fuel for intense fire runs, as well as fire breaks. The unprecedented intensity of the Chisholm Fire, as well as the role of young aspen stands originating from the adjacent 1968 Vega Fire in slowing the Chisholm Fire's progress south of Slave Lake, provided an opportunity to study fire behaviour in aspen under extreme burning conditions and different fire histories.

The Chisholm Fire re-burned 13 benchmark fire behaviour research plots that had been prescribe burned originally in May 1972, and two of them experimentally re-burned in May 1978. The experimental burning in semi-mature 44 year-old pure aspen stands in 1972 by Canadian Forest Service Fire Research contributed data points on rate of fire spread, fuel consumption and frontal fire intensity to the Canadian Forest Fire Behaviour Prediction (FBP) System national model for Leafless Aspen (D-1). While the 1972 research burns and the 1978 re-burns on two of the plots were conducted under low and moderate burning conditions, the 1978 re-burns were characterized by a 10-fold increase in fire intensity, attributed to the aspen mortality and subsequent increase in surface fuel load following the 1972 burns.

An assessment of the impact of the 1972 burns on aspen mortality and understory vegetation response was made in August 1972, and again in August 1978, following the re-burns. In addition to the significant differences in fire behaviour on the re-burns, the virtual elimination of aspen was noted after the combined fire treatments (Quintilio et al. 1991). Aspen suckering was minor after burning in 1972, but some vegetative species re-sprouted prolifically.

The Chisholm Fire also burned into 33 year-old aspen stands that regenerated following the intense Lesser Slave Lake (Vega) Fire of May, 1968, immediately to the west of the Chisholm Fire. These aspen stands were observed to retard, then stop the forward and flanking spread of the Chisholm Fire, acting as a "firebreak," once the fire penetrated a few tens to hundreds of metres.

The present study and this report document a re-evaluation of the 1972 and 1978 CFS aspen fire research plots re-burned in the Chisholm Fire, as well as the fire behaviour on a portion of the Chisholm Fire that re-burned and then stopped in standing aspen forest that regenerated after the 1968 Vega Fire. Inferences concerning aspen fire behaviour modeling with respect to drought, greenup of vegetation, stand age and fire history are offered, within the context of the Canadian FBP System and the use of aspen stands as community fuelbreaks.

2.0 OBJECTIVES

The original study objectives as submitted to the Chisholm Fire Research Initiative were:

i) To quantify fuel consumption in aspen stands of various ages and fire histories, burned in the 2001 Chisholm Fire, including fire research plots from the 1970s.

ii) To compare estimated fuel consumption with predicted values from the Canadian Forest Fire Behaviour Prediction (FBP) System, and recommend FBP System Fuel Type parameter changes, if warranted.

3.0 DESCRIPTION OF STUDY AREAS

3.1 Locations

Geographically, the 100 000 ha Chisholm Fire extended some 55 km from southeast to northwest, on both sides of the Athabasca River, stopping its run some 12 km south of the town of Slave Lake, Alberta, approximately 200 km north of Edmonton (Figures 1 and 2).

The 1972 CFS Fire Research study area is located along the north side of Highway 2, 48 km south of Slave Lake and just west of the Athabasca River Bridge, some 6 km northwest of the settlement of Hondo (Figures 1 and 2), and within a fire research reserve established during the early 1970s.

The CFS study area consisted of eight primary blocks bounded by a perimeter fire guard around the 228 × 236 m area (Figure 3), whose Lat./Long. At the southwest corner (Test Fire Area," Block 2) was recorded by GPS as 55°05.38 N × 114°08.08 W.

The 1968 Vega Fire re-burn study area is located 12.0 km south of Mitsue Lake, 2 km east of Vanderwell Contractors Camp 8 Road (Figure 2), near the northwest perimeter of the Chisholm Fire, an area of overlap with the east perimeter of the 1968 Vega Fire.

The Vega Fire study area consists of six 25 × 25 m plots, laid out along a northwest-southeast salvage logging road (Figure 4, Photo 1) without driveable access from the Camp 8 Road, although a north-south cutline provides direct access by foot or quad. The junction of the salvage road and cutline provided helicopter access to the northeast corner of the plots and was recorded by GPS as 55°08.514 Lat. by 114°38.265 Long. The Chisholm Fire Research Initiative has designated this area as Research Reserve No. 1.

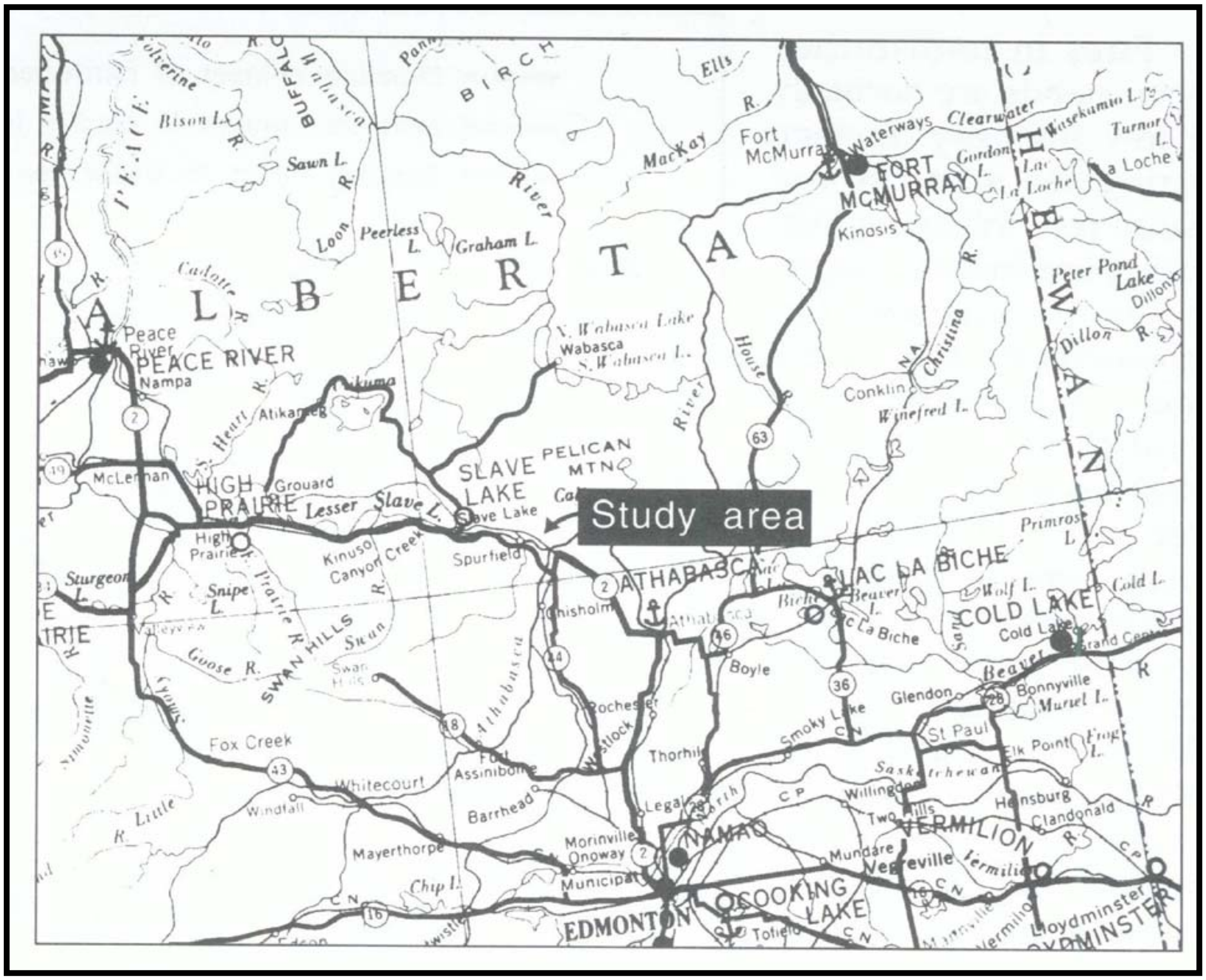

Figure 1. Geographical location of study areas near Slave Lake, Alberta

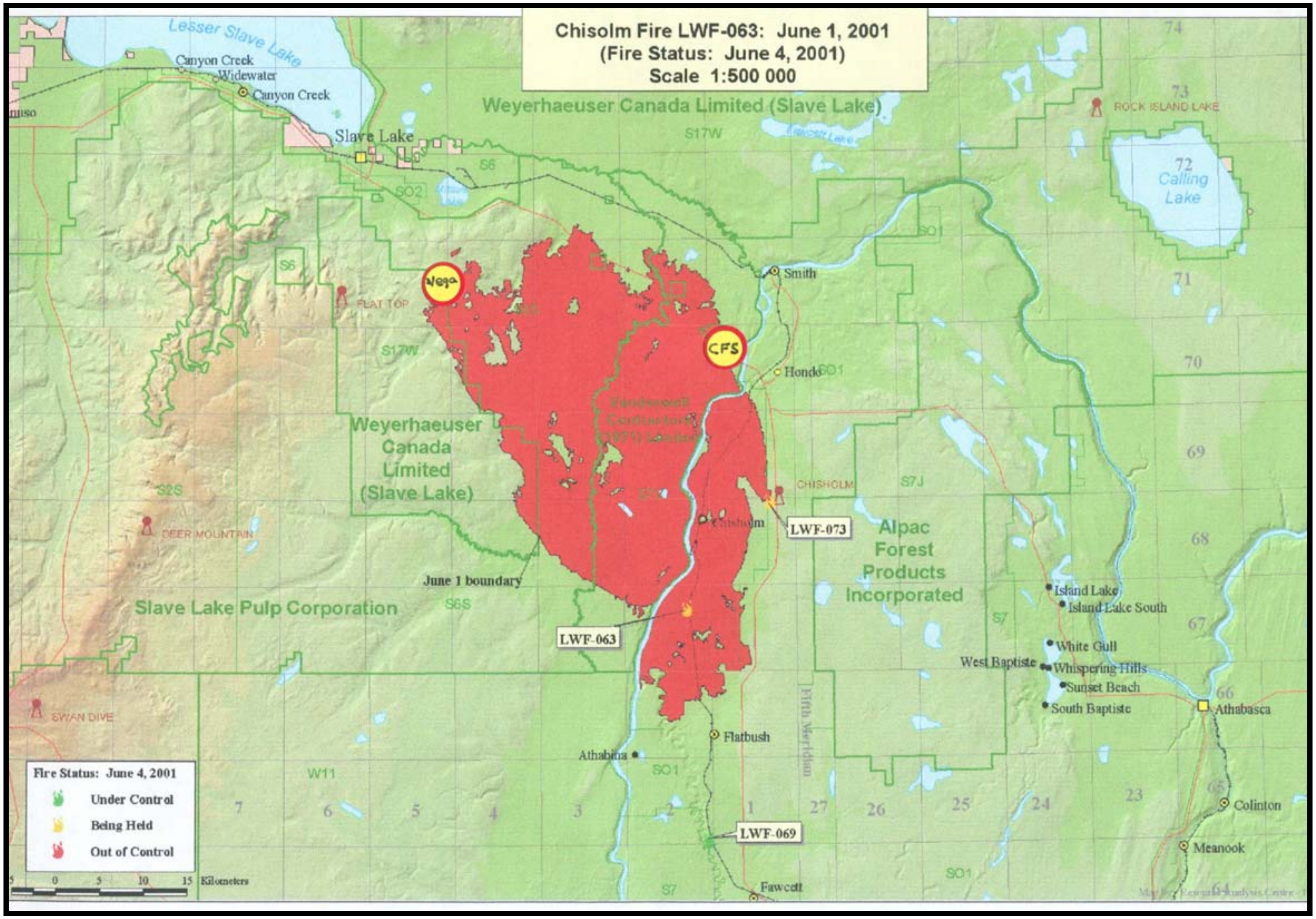

Figure 2. Final perimeter of Chisholm Fire and locations of 1972 CFS fire research area and 2002 plots in re-burn area of 1968 Vega Fire

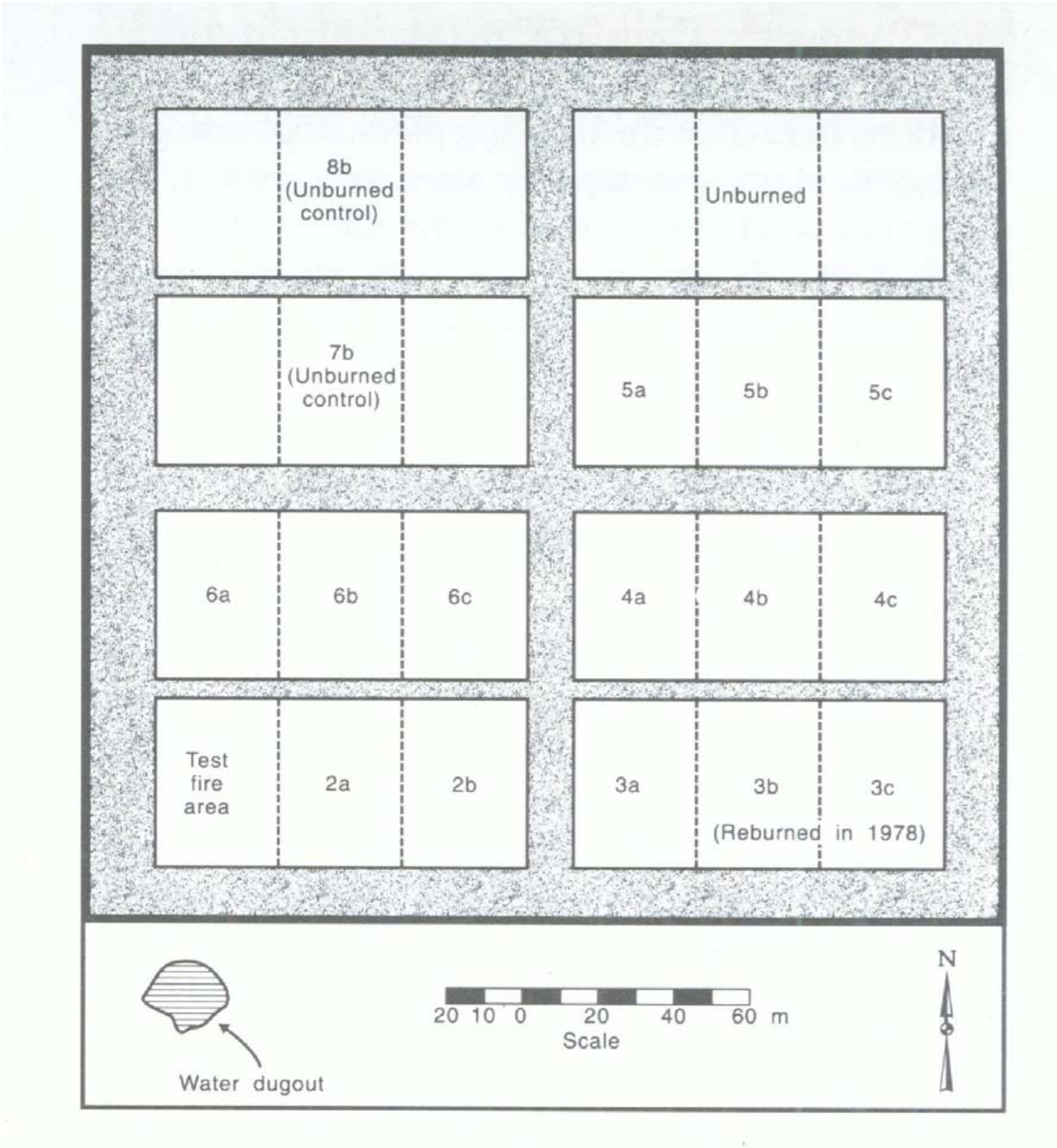

Figure 3. Plot layout, CFS study area

(source: Quintilio et al. 1991, p. 3)

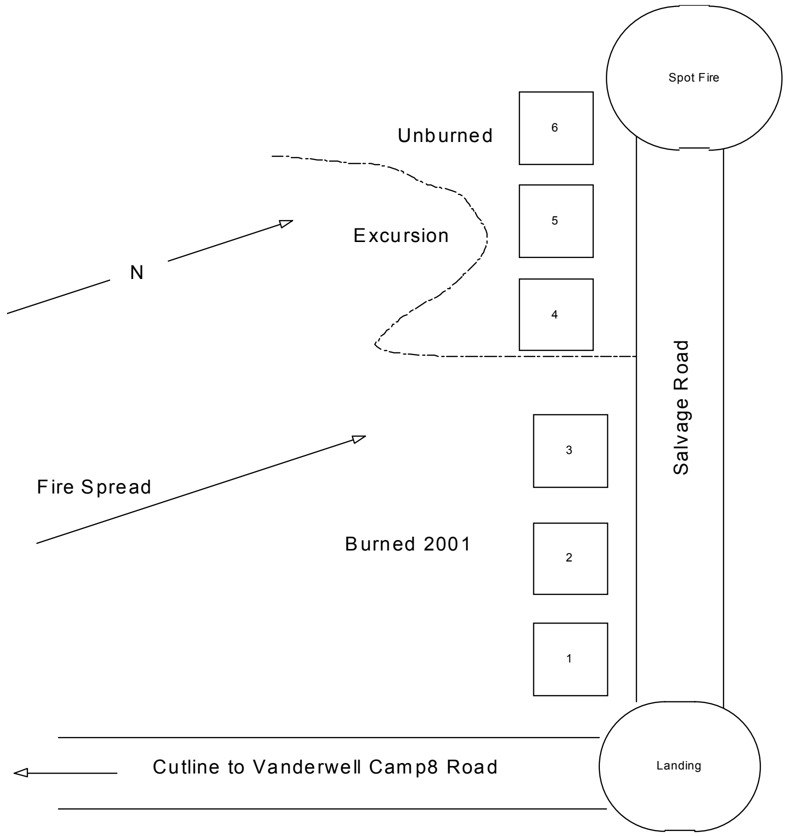

Figure 4. Plot layout, 1968 Vega Fire re-burn area

Photo 1. Aerial view of plots located in Chisholm Fire re-burn of 1968 Vega Fire area. Looks NW from helispot (foreground) along salvage road, from burned plots 1-3 to unburned plots 4-6, all on west side of road

3.2 Site description and burning conditions

The CFS 1972 fire research study site was described by Quintilio et al. (1991) as a nearly pure stand of semi-mature trembling aspen with scattered white spruce, jack pine and white birch clumps. Understory tall shrubs included green alder, pin cherry and beaked hazel. Predominant herbs included twin flower, pea vine, sarsaparilla, dewberry and bunchberry. They described the ecosystem as Populus-Corylus, within the Boreal Mixedwood Ecoregion (No. 8). The CFS site is a well-drained loamy sand over deep layers of coarse and fine sand. The area elevation is 590 m (MSL), and microtopography is strongly undulating, with slope less than 10%, while the study area was surrounded by open grassed black spruce muskeg.

1968 Vega Fire, 1972 and 1978 CFS experimental fire and 2001 Chisholm Fire weather and Canadian Forest Fire Weather Index (FWI) System component calculations are tabulated in Appendix 2.

4.0 METHODS

4.1 Plot establishment

All CFS research plots were re-located, GPS Lat./Long. recorded and plot centers marked with metal conduit, but funding did not allow all plots to be re-measured. All plots were visually inspected, and at least one representative plot from each block of three plots was selected for re-measurement, with the exception of the two control blocks, of which only Plot 7B was re-measured.

Six plots were established on the 1968 Vega Fire using metal conduit at the road frontage corners of each plot and at the plot centers, and the GPS Lat./Long. of the plot centers recorded to aid in future re-measurement. Plot centre conduits were also identified with copper tags containing Plot number, date and project identification. Digital photographs from plot centers were taken in four directions (Photo 2).

4.2 Fuel and vegetation assessments

Overstory trees were tallied on each plot by species and diameter (dbh) class of all live and standing dead trees within a circular fixed radius plot. CFS plots were re-measured using 0.04 ha (11.28 m radius) sample plots, while Vega Fire plots used 0.01 ha (5.64 m radius) sample plots. Five sample trees per plot were selected for additional measurements of crown position (dominant, co-dominant, intermediate, suppressed), height, diameter and suckering around the base. Number of suckers and their average height was recorded for a 1 m radius around each sample tree. Tree bole scorch height was estimated for each sample tree.

Downed woody surface fuels were inventoried using the line intersect sampling method on a 30 m long transect per plot. Mineral soil exposure (%) was estimated for each 10 m transect segment. Remaining litter/moss depth and duff (F and H layers) depths were measured on a 25-point sampling grid laid out on each plot. Remaining litter and duff load by 2 cm depth increment was destructively sampled from five 0.1 m^2 bulk density samples per plot and oven dried.

F+H layer samples by 2 cm increments were chosen from CFS and Vega Fire plots, both burned and unburned, for inorganic content determination. A total of 26 of the 0.1m^2 duff samples were selected and ground up. Sub-samples were incinerated in a muffle furnace at Pacific Forestry Centre, and the percentage inorganic material of the oven-dry duff sample calculated.

Understory shrubs and herbs less than 0.5 m tall were tallied by species composition (% cover) on 25 1.0 m^2 hoop plots per plot. Herbs and low shrubs were destructively clipped for oven-dry weight estimation on four 1.0 m^2 hoop plots per plot. Oven-dry weight was estimated from the wet weights using the moisture contents calculated for a sub-sample of herbs and low shrubs taken from the four destructive hoop plot samples from each plot.

Tall shrubs, greater than 0.5 m tall, were tallied by number of stems and average height by species on each 1.0 m^2 hoop plot.

Photo 2. Vega Fire Plot 1-NE Re-burned Chisholm Fire, all trees killed

4.3 Fuel consumption 1972, 1978, 2001

Surface fuel consumption for the CFS plots was calculated as the sum of L-(litter) layer consumption, plus understory vegetation consumption, plus woody surface fuel consumption, as reported by Quintilio et al. (1991) for the 1972 burns and 1978 re-burns. It should be noted that these authors used a mix of pre-burn area means and plot-specific fuel loads to calculate their surface fuel consumptions.

For the 2001 Chisholm Fire, surface fuel consumption (SFC) was again calculated as the sum of forest floor consumption (FFC) plus woody fuel consumption (WFC) plus understory vegetation consumption. However, assumptions had to be made about pre-burn fuel loads, since the most recent CFS plot measurements were done post-burn in 1972 and 1978 (in the case of the re-burn plots). We assumed:

- L-layer consumption in Chisholm Fire was the same as 1972 pre-burn litter load = 0.30 kg/m^2, i.e., the entire L-layer was assumed to be consumed in 2001;
- F and H-layer consumption was assumed to be the 1972 pre-burn area average F + H layer load (2.57 kg/m^2) minus 2002 duff (F + H) load remaining by Plot, except Plots 3B and 3C re-burned in 1978, where post-burn 1978 F + H layer load assumed to be pre-1972 F + H load (2.57 kg/m^2) minus 1978 re-burn F + H consumption (0.218 kg/m^2) = 2.35 kg/m^2, and 2001 F + H layer consumption on 1978 re-burned plots 3B and 3C = 2.352 minus F + H load remaining in 2002 re-measurement;
- WFC was assumed to be 1978 pre-burn WF load = 2.996 kg/m^2 minus 2002 Total Woody Fuel remaining per plot, except plots 3B and 3C re-burned in 1978, where post-burn 1978 Total Woody Fuel load assumed to be (2.996 – 1.738 =) 1.258 kg/m^2, and 2001 WFC = 1.258 minus Total Woody Fuel load remaining in 2002 re-measurement.
- Vegetation Consumption was assumed to be the same as Vegetation Consumption in 1972 burns = 0.043 kg/m^2 for all CFS Plots.

Fuel consumption calculations for the 1968 Vega Fire re-burn plots were simply a matter of subtracting 2001 burn plot-specific fuel remaining values from the 3-plot average values obtained on the adjacent unburned plots.

5.0 RESULTS

5.1 CFS aspen fire research plots burned 1972, 1978, 2001

5.1.1 Overstory trees, scorch height and suckering response

After the 2001 Chisholm Fire, all trees were dead in the 2002 re-measurement. Table 1 shows the diameter distribution of these standing dead trees by species and plot. At the time of the Chisholm Fire, aspen predominated, although a significant birch component less than 8 cm dbh was present on most plots, except for Plots 6A, 6B and 6C. Birch was most dense on the 1978 re-burned Plots 3B and 3C. The Control plot 7b, unburned until 2001, while it had no small aspen, did have a component of small birch. Plot 2b had no large trees at all, while Plots 6A, 6B, 6C, burned with low intensity in 1972, had a similar distribution of aspen stems in 2002 as the Control Plot 7B (Photos 3 and 4), predominantly middle diameters 13-26 cm. Plots 3A, 4A and 5A, on the other hand, had predominantly small diameter aspen, less than 10 cm dbh.

Table 2 shows the average height and diameter of the five sample trees measured per CFS plot, by species and crown position. Dominant and co-dominant aspen trees averaged 24 cm dbh and 20 m tall on the CFS plots.

Table 3 shows the suckering response by species and the average bole-scorch height per plot on the CFS plots. Ignoring Plot 2B which had no large trees, aspen suckering ranged from a low of 13 on the re-burn Plot 3C to a high of 42 on Plot 6b, burned originally at low intensity. However, Plot 5a also had only 13 aspen suckers, although it was also originally a low intensity burn plot. Height of aspen suckers ranged from 0.5 to 1.0 m. Other tree species produced some suckering, including alder, birch and willow, willow most notably on re-burn Plot 3B. Bole-scorch height ranged from 1.68 m to 5.28 m and averaged 3.58 m over 10 CFS plots.

Photo 3. **CFS Plot 7b, unburned control in 1972, 73 year-old aspen stand burned in 2001 high intensity wildfire, all trees killed, bole scorch height 3m, duff consumption nearly complete (0.4 cm remains), mineral soil exposure high (42%), aspen suckering vigorous, most downed-woody fuel consumed (0.44 kg/m^2 remains)**

Photo 4. **CFS Plot 6a, burned low intensity in 1972, re-burned 2001 high intensity wildfire, all trees killed, bole scorch height 3m, duff consumption nearly complete (0.4cm remains), mineral soil exposure low (13%), aspen suckering vigorous, most downed-woody fuel consumed (0.27 kg/m^2 remains)**

Table 1. Distribution (stems/ha) of live and dead trees by CFS plot, species and diameter class

	Plot Number																					
	2b		3a			3b			3c		4a		5a		6a		6b	6c			7b		
	Dead		Dead			Dead			Dead		Dead		Dead		Dead		Dead	Dead			Dead		
DBH Class (cm)	**Aw**	**Bw**	**Aw**	**Bw**	**Lt**	**Aw**	**Bw**	**Lt**	**Aw**	**Bw**	**Aw**	**Bw**	**Aw**	**Bw**	**Aw**	**Lt**	**Aw**	**Aw**	**Bw**	**Lt**	**Aw**	**Bw**	**Pj**
1 - 2	75		25			125	175		25	300	50	25	150	150	75		25					225	
3 - 4	75		350	50		425	175		50	325	775	50	775	100					25			75	
5 - 6			425	75		150	50			175	550	75	625	25									
7 - 8		25	500							50	625	25	525										
9 - 10			25							25	250		50			25		75					
11 - 12			25		25					25	175							25					
13 - 14															50		175				50		
15 - 16											25				100		175	75			75		
17 - 18						25									150		250	175			150		25
19 - 20									25		25		25		225		225	75			125		
21 - 22											25		50		175		100	300			200		
23 - 24						25									75		50	50		25	150		
25 - 26					25	25							25		50		75				50		
27 - 28						25					50												
29 - 30			25			25																	
31 - 32			25								25												
33 - 34									25														
35 - 36								25															
Total	150	25	1400	125	50	825	400	25	125	900	2575	175	2225	275	900	25	1075	775	25	25	800	300	25

Note: There are no live trees present in the CFS plots

Legend:
- Aw= trembling aspen
- Bw= white birch
- Lt= tamarack (larch)
- Pj= jack pine

Table 2. Average tree height and diameter by CFS plot, species and crown position, based on five sample trees per plot

	Aspen				Birch				Tamarack			
	Dom./Codom.		Int./Supp.		Dom./Codom.		Int./Supp.		Dom./Codom.		Int./Supp.	
Plot No.	Diam. (cm)	Ht. (m)	Diam. (cm)	Ht. (m)	Diam. (cm)	Ht. (m)	Diam. (cm)	Ht. (m)	Diam. (cm)	Ht. (m)	Diam. (cm)	Ht. (m)
2b			3.0	3.5			5.0	5.6				
3a	30.0	19.3	8.6	11.3					25.4	16.5		
3b	26.4	20.1							34.1	18.5		
3c	27.2	20.0	8.6	5.8	10.1	7.5	8.6	5.8				
4a	25.7	18.5	10.7	10.8								
5a	26.2	19.3	7.7	9.5								
6a	19.7	16.9										
6b	21.0	20.4										
6c	18.7	21.4							23.2	16.5		
7b	20.7	21.6										
Average	23.9	19.7	7.7	8.1	10.1	7.5	6.8	5.7	27.6	17.2	-	-

Table 3. Suckering response and bole scorch height by CFS plot and species, based on five sample trees per plot

Plot No.	Average Bole Scorch Height (m)	Aspen Suckering Average No.	Aspen Suckering Average Ht. (m)	Birch Suckering Average No.	Birch Suckering Average Ht. (m)	Alder Suckering Average No.	Alder Suckering Average Ht. (m)	Willow Suckering Average No.	Willow Suckering Average Ht. (m)
2b	4.32	0	-	9	0.30	2	0.20	0	-
3a	5.28	30	0.78	2	0.25	2	0.30	0	-
3b	3.66	18	0.50	7	0.30	36	0.60	24	0.40
3c	2.10	13	0.47	11	0.50	3	0.40	0	-
4a	1.68	29	0.98	23	0.20	1	0.10	0	-
5a	5.26	13	0.88	11	0.62	40	0.50	0	-
6a	3.12	28	0.58	0	-	29	0.35	1	0.30
6b	4.04	42	0.70	5	0.50	52	0.60	0	-
6c	3.42	23	0.48	7	0.50	51	0.50	0	-
7b	2.90	30	0.76	14	0.82	7	0.55	0	-
Average	3.58	22.71	0.68	8.80	0.44	22.20	0.41	2.50	0.35

5.1.2 Downed-woody fuel load

Table 4 summarizes downed-woody surface fuel load by CFS plot and diameter class, based on post-Chisholm Fire measurements taken in 2002. Fine fuels less than 1 cm in diameter were very light, totaling ≤ 0.02 kg/m^2 on all plots. Large fuels greater than 7 cm diameter varied widely, from a low of 0.075 kg/m^2 on Plot 6A, to a high of 4.358 kg/m^2 on Plot 2B, where no large standing dead trees remained. The average total downed-woody fuel load remaining (2.165 kg/m^2) was almost six times the pre-1972 burn area average load of 0.369 kg/m^2, although similar to the pre-1978 re-burn fuel load of 2.996 kg/m^2.

Table 4. Downed-woody surface fuel load by CFS plot and diameter class

	Downed-woody fuel load (kg / m^2)						
Plot No.	0.1 - 0.5 cm	0.6 - 1.0 cm	1.1 - 3.0 cm	3.1 - 5.0 cm	5.1 - 7.0 cm	>= 7.1 cm	Total
2b	0.000	0.003	0.062	0.300	0.605	4.358	5.328
3a	0.000	0.012	0.144	0.266	0.121	0.888	1.431
3b	0.000	0.000	0.021	0.067	0.121	1.745	1.954
3c	0.000	0.012	0.103	0.233	0.121	2.913	3.382
4a	0.000	0.006	0.062	0.167	0.363	1.714	2.312
5a	0.000	0.006	0.103	0.100	0.121	2.694	3.024
6a	0.002	0.003	0.000	0.067	0.121	0.075	0.268
6b	0.000	0.020	0.021	0.067	0.121	0.453	0.682
6c	0.000	0.020	0.021	0.100	0.000	2.680	2.821
7b	0.004	0.009	0.133	0.067	0.000	0.232	0.445
Average	0.001	0.009	0.067	0.143	0.169	1.775	2.165

5.1.3 Duff layer remaining and mineral soil exposure

Table 5 summarizes average moss/litter depth and duff depth remaining by CFS Plot, based on 25 depth measurements per plot. Average duff load remaining per plot is shown, based on five 0.1 m^2 destructive samples per plot. Average mineral soil exposure (%) is shown per plot, based on three 10 m transect segment estimates per plot. An average of 2 cm moss/litter depth remained and 1.3 cm of duff, although remaining duff depth varied significantly plot to plot. The previously unburned control Plot 7B had one of the shallowest remaining duff depths (0.45 cm) while the previously twice burned Plot 3C had the greatest remaining duff depth (2.66 cm).

Remaining litter load averaged 0.258 kg/m^2, not much different from the pre-burn 1972 litter load of 0.30 kg/m^2.

However, remaining duff load averaged 2.231 kg/m^2, almost as much as the pre-burn 1972 F + H layer load of 2.57 kg/m^2, although the average remaining duff depth of 1.3 cm was only half the original F + H layer depth (2.37 cm).

Mineral soil exposure as tallied along 30 m of line transect of each CFS plot varied from a low of 3% on the Plot 2B to a high of 63% on Plot 6B. While highly variable, mineral soil exposure averaged 30%.

Table 5. Average moss/litter and duff depths and load remaining and percent mineral soil exposed by CFS plot, based on 25 depth points and three 10 m transect segments respectively. Duff load sampled on five 0.1 m^2 sub-plots per plot

Plot No.	Average Moss/Litter depth (cm)	Average Duff depth (cm)	Average Moss/Litter load (kg/m^2)	Average Duff load (kg/m^2)	Average Mineral Soil Exposed (%)
2b	2.99	1.86	1.74	4.56	3
3a	1.94	1.28	1.75	1.30	47
3b	2.07	1.44	0.38	2.20	17
3c	2.18	2.66	1.29	3.64	5
4a	2.59	1.78	1.28	4.41	50
5a	2.44	2.21	1.53	4.12	13
6a	1.27	0.38	1.15	0.68	13
6b	1.55	0.48	1.32	0.92	63
6c	1.66	0.43	0.93	0.80	50
7b	2.07	0.45	1.01	1.60	42
Site Avg.	2.08	1.30	1.24	2.42	30
Site Std Dev.	0.512	0.833	0.408	1.591	22.2

5.1.4 Understory vegetation

Understory herbs and low shrub responses one year after the 2001 re-burn of CFS plots are presented in Table 6, as percent frequency (% of sampled sub-plots per plot with a species present) and percent cover (average % cover of sampled sub-plots per plot). Grass cover ranged from less than 1% (plots 3a, 6a) to a high of 27%, on the 1978 re-burned plot 3c. Trembling aspen was present on all sub-plots of plot 7b (unburned 1972 control), averaging 11.5% cover, by far the most significant aspen response. Similarly, paper birch response was most significant on plot 7b (6.2% cover). Fireweed was frequent, but accounted for significant cover only on plots 2b (11.7%) and plot 4a (8.4%). Beaked hazel was significant only on plot 7b as was geranium.

Tall shrub density and height one year after the 2001 re-burn of CFS plots is presented in Table 7. Plot 7b (unburned 1972 control) had the 2nd highest density of trembling aspen, behind plot 6c, but all plots had significant tall aspen regeneration. As with low birch (Table 6), tall birch was most dense on plot 7b, but present on most plots. Green alder and beaked hazel had significant density on some plots, but were absent on the 1978 re-burned plots 3b&c.

Table 8 shows the one-year post-burn vegetation load recovery by CFS plot. Grass was not present in significant enough quantity for separate sampling. Herbs and shrub load did not vary much by plot, and averaged 0.040 kg/m^2. Tree suckers varied widely by plot, from a low of 0.006 on plot 2b to high of 0.220 kg/m^2 on the previously unburned control, for an average 0.090 kg/m^2, and an average total vegetation load at time of sampling, early June 2002, of 0.130 kg/m^2, similar to the total on the re-burned Vega Fire plots.

Table 6. Understory vegetation (<0.5 m tall) frequency (%) and cover (%) by species and CFS plot

		2b		3a		3b		3c		4a		6a		6b		6c		7b	
		Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover
Scientific Name	**Common Name**	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Corylus cornuta	beaked hazel	-	-	38	1.9	8	0.1	-	-	15	0.5	-	-	-	-	-	-	77	4.2
Geranium bicknelli	Bicknell's geranium	23	0.2	54	1.4	77	1.8	38	1.4	62	3.8	56	0.6	92	1.9	100	3	100	5.9
Vaccinium myrtilloides	blueberry	-	-	-	-	-	-	-	-	-	-	24	0.2	-	-	-	-	-	-
Cornus canadensis	bunchberry	15	0.1	15	0.1	15	0.1	31	0.1	8	0.2	-	-	15	0.1	69	1.1	31	0.2
Rubus pubescens	dewberry/running raspberry	-	-	8	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Epilobium angustifolium	fireweed	100	11.7	69	2.5	92	3.8	100	3.7	69	8.4	24	0.2	69	1	85	6.4	15	1.3
Grass sp.	grass	92	11.3	85	0.8	92	10.5	100	26.9	92	18.5	100	1.0	100	15.8	92	9.9	85	7.5
Alnus crispa	green alder	15	1.8	23	0.5	-	-	-	-	31	4.3	48	0.5	-	-	-	-	-	-
Equisetum palustre	horsetail	38	0.2	69	0.1	23	0.1	15	0.1	15	0.2	88	0.9	77	0.8	62	0.5	46	0.6
Galium boreale	northern bedstraw	8	0.1	8	0.1	77	0.2	38	0.1	15	0.2	-	-	8	0.1	38	0.4	-	-
Petasites palmatus	palmate-leaved coltsfoot	15	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Betula papyrifera	paper birch	31	0.8	23	2.6	-	-	15	0.1	-	-	-	-	15	0.2	-	-	62	6.2
Rosa acicularis	prickly rose	46	2.4	62	1.1	100	2.5	92	1.2	54	1.8	56	0.6	54	0.5	69	0.8	15	0.4
Ribes sp.	ribes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	0.1	-	-
Amelanchier alnifolia	saskatoon	-	-	-	-	-	-	8	0.1	-	-	-	-	-	-	38	0.2	-	-
Aster conspicuus	showy aster	-	-	-	-	15	0.1	-	-	-	-	-	-	-	-	-	-	-	-
Symphoricarpos albus	snowberry	-	-	8	0.2	-	-	8	0.1	-	-	-	-	-	-	-	-	-	-
Mertensia paniculata	tall mertensia	-	-	-	-	15	0.4	38	0.4	8	0.2	-	-	-	-	8	0.1	-	-
Populus tremuloides	trembling aspen	23	0.4	77	4.8	54	1.3	23	0.3	69	7.3	96	1.0	92	3.4	77	8.7	100	11.5
Lonicera dioica	twining honeysuckle	-	-	-	-	8	0.1	-	-	-	-	-	-	-	-	-	-	-	-
Maianthemum canadense	wild lily of the valley	-	-	-	-	-	-	15	0.3	-	-	-	-	8	0.1	8	0.1	-	-
Rubus idaeus	wild red raspberry	54	3.5	-	-	46	0.1	54	0.8	46	1.0	32	0.3	69	1.5	46	0.2	62	2.7
Aralia nudicaulis	wild sarsaparilla	15	0.1	-	-	38	0.1	46	0.2	38	0.8	-	-	-	-	-	-	8	0.1
Fragaria virginiana	wild strawberry	-	-	-	-	8	0.1	8	0.1	-	-	-	-	-	-	-	-	-	-
Vicia americana	wild vetch	-	-	-	-	8	0.1	23	0.1	-	-	-	-	-	-	-	-	-	-
Salix sp.	willow	15	0.4	-	-	-	-	-	-	-	-	-	-	46	2.2	-	-	-	-

Table 7. Tall (> 0.5 m) shrub and tree regeneration density (stems/ha) and height (m) by species and CFS plot

		2b		3a		3b		3c		4a		5a		6a		6b		6c		7b	
		Density	Ht.	Density	Ht.	Density	Ht.	Density	Ht.	Density	Ht.	Density	Ht.	Density	Ht.	Density	Ht.	Density	Ht.	Density	Ht.
Scientific Name	**Common Name**	(sph)	(m)	(sph)	(m)	(sph)	(m)	(sph)	(m)	(sph)	(m)	(sph)	(m)	(sph)	(m)	(sph)	(m)	(sph)	(m)	(sph)	(m)
Corylus cornuta	beaked hazel			30000	0.6					20000	0.7	10000	0.5							30000	0.6
Alnus crispa	green alder	46700	0.8	10000	0.6					45000	0.6					20000	0.5				
Viburnum edule	low-bush cranberry																				
Betula papyrifera	paper birch	33300	0.6	50000	0.7			10000	0.6			27100	0.8			15000	0.6			41000	0.8
Rosa acicularis	prickly rose																				
Populus tremuloides	trembling aspen	15000	0.7	42900	0.7	25000	0.6	10000	0.7	42000	1.0	28200	1.0	45000	0.5	35500	0.6	58600	0.6	49200	0.7
Lonicera dioica	twining honeysuckle																				
Rubus idaeus	wild red raspberry																				
Salix sp.	willow	40000	0.5																		

Table 8. Understory vegetation (herbs, shrubs and trees < 0.5 m tall) load (kg/m^2) by CFS plot

Plot No.	Grass	Herbs/Shrubs	Trees	Total
2b	0.000	0.049	0.006	0.055
3a	0.000	0.037	0.076	0.113
3b	0.000	0.032	0.039	0.071
3c	0.000	0.021	0.018	0.039
4a	0.000	0.095	0.117	0.212
5a	0.000	0.062	0.108	0.170
6a	0.000	0.024	0.104	0.128
6b	0.000	0.020	0.151	0.171
6c	0.000	0.031	0.065	0.096
7b	0.000	0.028	0.220	0.248
Average	0.000	0.040	0.090	0.130

5.1.5 Fuel consumption 1972, 1978

Surface fuel consumption of litter layer, understory vegetation and downed-woody fuel for the 1972 and 1978 re-burned Plots 3B and C are recorded in Table 9 from various sources in Quintilio et al. (1991). It should be noted that the 1972 burns consumed no portion of the F + H layer, but the 1978 re-burn of part of Plot 3B and all of Plot 3C consumed all the litter layer (0.188 kg/m^2), and a small portion (0.022 kg/m^2) of the F + H layers, but the total forest floor consumption on the 1978 re-burn is shown in Table 9 as 0.218 kg/m^2 of L-layer. The 1978 re-burn consumed more than twice the forest floor (litter) depth and load of the 1972 average forest floor consumption. The 1978 re-burn also consumed four times as much understory vegetation load as the 1972 burn average, and almost ten times the downed-woody fuel consumption of the moderate intensity plots of 1972. Similarly, the 1978 re-burn total surface fuel consumption was about ten times the average 1972 plot total SFC.

Table 9. Surface fuel load pre- and post-burn 1972 and 1978, and surface fuel consumption 1972 and 1978, by CFS plot

				Surface Fuel Consumption				
Plot No.	Pre-burn L-layer depth (cm)	Pre-burn L-layer load (kg/m^2)	Forest Floor Reduction L-layer (%)	Depth of Burn (cm)	L-layer consumption (kg/m^2)	Understory vegetation consumption (kg/m^2)	Woody Surface Fuel Consumption (kg/m^2)	Total Surface Fuel Consumption (kg/m^2)
5c	4.56	0.284	47.2	2.15	0.134	0.043	0.000	0.177
6a	3.07	0.285	27.2	0.85	0.079	0.043	0.000	0.122
6b	3.07	0.282	26.2	0.81	0.074	0.043	0.000	0.117
2b	4.68	0.282	24.8	1.16	0.070	0.043	0.000	0.113
5a	4.56	0.283	40.3	1.84	0.114	0.043	0.150	0.307
5b	4.56	0.285	37.5	1.71	0.107	0.043	0.150	0.300
2a	3.99	0.285	28.4	1.13	0.081	0.043	0.000	0.124
3a	4.06	0.284	39.5	1.60	0.112	0.043	0.150	0.305
3c	4.06	0.283	33.6	1.37	0.095	0.043	0.369	0.507
4c	4.21	0.285	43.2	1.82	0.123	0.043	0.369	0.535
4a	4.21	0.284	51.1	2.15	0.145	0.043	0.369	0.537
4b	4.21	0.284	44.7	1.88	0.127	0.043	0.369	0.539
3b	4.06	0.283	33.5	1.36	0.095	0.043	0.369	0.507
Average	4.1	0.284	36.71	1.45	0.104	0.043	0.200	0.347
Std Dev.	0.512	-	-	0.480	0.024	-	0.151	0.163
3b&c	4.55	0.288	75.8	3.45	0.218	0.188	2.996	3.402

5.1.6 Fuel consumption 2001

Table 10 summarizes estimated forest floor consumption, understory vegetation consumption and downed-woody fuel consumption by CFS plot for the Chisholm Fire re-burn. Assumptions regarding pre-re-burn forest floor loads include:

1) Litter layer load and consumption was the same average pre-burn load pre-1972 burn, 0.3 kg/m^2.
2) F+H layer pre-re-burn load was the same average pre-burn load measured pre-1972 burn, 2.57 kg/m^2
3) F+H layer bulk density was 0.108 g/cm^3, as calculated from the pre-1972 burn average measurements of the F+H layer, 2.57 kg/m^2 and 2.37cm depth (incorrectly reported by Quintilio et al. 1991 as 0.0013).
4) F+H layer consumption was the difference between pre-re-burn F+H layer load (2.57 kg/m^2) and the CFS plot-specific estimate of F+H layer load remaining, the latter calculated as the pre-re-burn bulk density (0.108 g/cm3) multiplied by the post-re-burn plot average depth of duff remaining, as measured on a grid of 25 points per plot.
5) Forest Floor Consumption (FFC) is the sum of L-layer consumption + F+H layer consumption.

These assumptions produce generally reasonable FFC results, although somewhat low relative to the FFCs calculated for the re-burned Vega Fire plots (Table 19), and the FFC of 0.0 for the 1978 re-burned plot 3c is not reasonable, even assuming the same pre-1972 F+H layer load (2.57 kg/m^2) rather than reducing it to 2.35 kg/m^2 to allow for the 1978 F+H layer consumption. It is possible that some net increase in F+H layer load accumulated between the 1972, 1978 and 2001 burns, that contributed to F+H layer consumption in 2001 but has not been recognized in our assumptions.

The assumption of 2001 vegetation consumption being the same as the measured 1972 vegetation consumption (0.043 kg/m^2) may also under-estimate actual understory vegetation load and consumption.

Woody surface fuel assumptions include:

1) Pre-2001 re-burn downed-woody fuel loads include contributions of all pre-1972 standing dead trees.
2) Pre-2001 re-burn downed-woody fuel loads include contributions of all post-1972 burn fire-killed trees, and in the case of plot 3c re-burned in 1978, the standing trees killed in the 1978 re-burn also contribute to the pre-2001 re-burn downed-woody fuel load.
3) Standing dead trees that fall and contribute to the downed-woody pre-re-burn fuel load can be converted from their standing diameters (dbh) to downed-woody fuel load (kg/m^2) by the trembling aspen biomass equation of Singh (1982):

$$W = 23.61521 - 7.88903D + 0.78372D^2 - 0.00362D^3$$

Where, W = dry weight (kg) whole tree above ground without foliage

D = dbh (cm)

4) The tree mortality measured in 1976 for the 1972 burns under estimates the probable downed-woody fuel load contribution to the 2001 re-burn for "low" intensity 1972 burn plots, and it is reasonable to increase this fuel load contribution by using the "moderate" 1972 intensity tree mortality results for all 1972 plots, including unburned 1972 control plot.

5) Woody surface fuel consumption (WFC) in 2001 is the difference between estimated pre-burn 2001 woody fuel load and post-burn 2001 woody fuel remaining.

Calculation of downed-woody fuel consumption by CFS plot is shown in Appendix 3. These assumptions produce generally reasonable WFC results, with a range of 2.58 to 7.89 kg/m^2, averaging 6.12 kg/m^2. The lowest WFC was on plot 2b, which had the least number of trees left standing and the greatest downed-woody fuel remaining, possibly reflecting higher than normal post-re-burn tree fall 2001-2002. Plot 2b also had one of the lowest forest floor consumption estimates, and the lowest mineral soil exposure, which agrees with its low WFC.

Total surface fuel consumption estimates ranged from 3.48 (plot 2b) to 10.14 kg/m^2 (plot 6a), averaging 7.65 kg/m^2. The low end of this range matches the reported 1978 re-burn SFC (Table 9). The average SFC compares closely to the immediate post-Chisholm Fire sampling of mature aspen by Quintilio et al (2001) which estimates SFC of 8.5 kg/m^2; however, the latter SFC was comprised of a higher FFC (7.2) and a lower WFC (1.3) kg/m^2 was only calculated for 0 - 7cm diameter downed-woody fuel.

Table 10. Estimated surface fuel consumption in 2001 Chisholm Fire, by CFS plot

Plot No.	L-layer consumption	F+H layer remaining 2002	Pre-burn F+H layer load (1972, 2001)	Forest Floor Consumption L+F+H 2001	Understory Vegetation Consumption 1972, 2001	Downed-Woody Surface Fuel Consumption 2001	Total Surface Fuel Consumption 2001
	(kg/m^2)	(kg/m^2)	(kg/m^2)	(kg/m^2)	(kg/m^2)	(kg/m^2)	(kg/m^2)
2b	0.3	2.01	2.57	0.86	0.043	2.58	3.48
3a	0.3	1.38	2.57	1.49	0.043	6.48	8.01
3c	0.3	2.87	2.57	0.00	0.043	7.89	7.93
4a	0.3	1.92	2.57	0.95	0.043	5.60	6.59
5a	0.3	2.39	2.57	0.48	0.043	4.89	5.41
6a	0.3	0.41	2.57	2.46	0.043	7.64	10.14
6b	0.3	0.52	2.57	2.35	0.043	7.23	9.62
6c	0.3	0.46	2.57	2.41	0.043	5.09	7.54
7b	0.3	0.49	2.57	2.38	0.043	7.67	10.09
Average	0.3	1.38	2.57	1.49	0.043	6.12	7.65

5.2 Vega (1968) Fire plots burned and unburned 2001

5.2.1 Overstory trees, scorch height and suckering response

After the 2001 Chisholm Fire, all trees on the re-burned area of the 1968 Vega Fire (Plots 1-3) were dead in the 2002 re-measurement. Table 11 shows the diameter distribution of these trees, predominantly aspen, as well as the diameter distribution of live and dead trees on the unburned 2001 Vega Fire Plots 4-6. Stand density increased significantly going west from Plot 1 to Plot 3 through the re-burned area, while in the unburned area, Plot 5 was the least dense, flanked by denser stands in Plots 4 and 6 on either side. Plot 6 had a much higher proportion of naturally dead small diameter aspen than the other two unburned plots (Photo 5). Burned Plot 3 and unburned Plot 6 had similarly high densities of small diameter aspen stems. Birch and white spruce were present as minor species in some plots.

Table 12 shows the average height and diameter of the five sample trees measured per plot, by species and crown position. Dominant and co-dominant aspen trees averaged 11.9 cm dbh and 11.5 m tall, very similar to the average diameter (11 cm) and height (13 m) of the original CFS research area aspen trees in 1971, when the stand was 43 years old. The 1968 Vega Fire plot area aspen trees were verified by increment bore check counts to be 32 years old, regenerating after the 1968 Vega Fire and apparent follow-up salvage logging, indicated by few remaining live veteran trees, standing snags or large-diameter downed wood.

Table 13 shows the suckering response by species and the average bole-scorch height, per plot on the Vega Fire Plots 1-3 re-burned in 2001. Aspen suckers ranged from 7 to 12 per tree on the burned Vega Fire plots, lower than observed on the CFS plots. Bole-scorch height ranged from 0.44 to 0.59 m by Vega Fire plot, on average, significantly lower than the average scorch height on the CFS plots (3.58 m).

Photo 5. Vega Fire Plot 6-SW Unburned in Chisholm Fire

Table 11. Distribution (stems/ha) of live and dead trees by Vega Fire plot, species and diameter class

	Plot Number														
	1	2		3	4					5			6		
	Dead	Dead		Dead	Live			Dead		Live		Dead	Live		Dead
DBH Class (cm)	Aw	Aw	Bw	Aw	Aw	Bw	Sw	Aw	Bw	Aw	Bw	Aw	Aw	Bw	Aw
1 - 2	600	100	100	600		300	100	200							1200
3 - 4	1200	800	100	3700	400	100						100	1100		1500
5 - 6	1700	1800		3000	1000				100	700	200	200	1300	100	900
7 - 8	900	2300		2200	200	100		100		800		300	1700		100
9 - 10	700	1700		900	800			100		500			1800		
11 - 12	300	500			600					300			500		
13 - 14					400	100	100			100			200		
15 - 16	100				100					100		100	100		
17 - 18										100					
19 - 20															
21 - 22										100					
Total	5500	7200	200	10400	3500	600	200	400	100	2700	200	700	6700	100	3700

Table 12. Average tree height and diameter by Vega Fire Plot, species and crown position, based on five sample trees per plot

	Aspen				**Birch**			
	Dom./Codom.		**Int./Supp.**		**Dom./Codom.**		**Int./Supp.**	
Plot No.	**Diam. (cm)**	**Ht. (m)**	**Diam. (cm)**	**Ht. (m)**	**Diam. (cm)**	**Ht. (m)**	**Diam. (cm)**	**Ht. (m)**
1	11.3	10.1	5.9	8.2				
2	10.6	10.4	7.9	8.5				
3	9.1	8.5						
4	13.9	14.0			12.9	14.5		
5	14.5	13.9						
6	11.9	12.3						
Average	11.9	11.5	6.9	8.4	12.9	14.5	-	-

Table 13. Suckering response and bole scorch height by Vega Fire plot and species, based on five sample trees per plot

		Aspen Suckering		Birch Suckering		Alder Suckering		Willow Suckering	
Plot No.	Average Bole Scorch Height (m)	Average No.	Average Ht. (m)	Average No.	Average Ht. (m)	Average No.	Average Ht. (m)	Average No.	Average Ht. (m)
1	0.44	12	0.52	3	0.20	0	-	0	-
2	0.59	11	0.36	0	-	0	-	0	-
3	0.46	7	0.36	0	-	20	0.40	0	-
4	-	0.4	0.50	0	-	0	-	0	-
5	-	0	-	0	-	0	-	0	-
6	-	0	-	0	-	0	-	0	-
Average	0.50								

5.2.2 Downed-woody fuel load

Table 14 summarizes downed-woody surface fuel load remaining after the 2001 re-burn of Vega Fire plots (1-3) and on the Plots 4-6 not re-burned. Most of the downed-woody fuel load remaining is large diameter fuel greater than 7.1 cm diameter, and highly variable plot to plot. Total downed-woody fuel load averaged 3.61 kg/m^2 for the re-burned Vega Fire Plots and 4.141 kg/m^2 for the not re-burned plots. While these fuel loads are approximately 10 times the pre-1972 fuel loads on the CFS plots, and a little higher than the pre-1978 re-burn fuel load on CFS Plots 3B and C, they are moderate fuel loads and indicate that fuel consumption of woody fuels was quite low, as will be discussed in section 5.2.5.

Table 14. Downed-woody surface fuel load by Vega Fire plot and diameter class, based on 30 m line transect per plot

	Downed-woody fuel load (kg / m^2)						
Plot No.	0.1 - 0.5 cm	0.6 - 1.0 cm	1.1 - 3.0 cm	3.1 - 5.0 cm	5.1 - 7.0 cm	>= 7.1 cm	Total
1	0.000	0.003	0.019	0.033	0.120	6.542	6.717
2	0.005	0.006	0.019	0.000	0.120	3.430	3.580
3	0.003	0.009	0.000	0.066	0.000	0.577	0.655
Average	0.003	0.006	0.013	0.033	0.080	3.516	3.651
4	0.007	0.011	0.010	0.000	0.000	3.340	3.368
5	0.008	0.011	0.096	0.033	0.000	1.315	1.463
6	0.007	0.009	0.086	0.197	0.060	7.233	7.592
Average	0.007	0.010	0.064	0.077	0.020	3.963	4.141

5.2.3 Duff layer remaining and mineral soil exposure

Table 15 summarizes average moss/litter depth and duff depth remaining by Vega Fire plot, based on 25 depth measurements per plot. Plots 1-3, re-burned in 2001 averaged 2.92 cm moss/litter and 5.58 cm duff remaining, while non re-burned Plots 4-6 averaged 3.99 cm moss/litter and 9.92 cm duff depth. While the non re-burned moss/litter depth was almost identical to the (4.10 cm) pre-1972 burn CFS Plots, the non re-burned duff depth was four times the (2.37 cm F + H layer) depth pre-1972 burn on the CFS Plots.

Litter layer load remaining on the Vega Fire burned plots averaged 0.35 kg/m^2, and 0.85 kg/m^2 on the non re-burned plots, the latter value considerably higher than the litter load of 0.30 kg/m^2 reported for the pre-burn CFS Plots. Similarly, F + H layer averaged 4.29 kg/m^2 for the re-burned Vega Fire Plots and 4.75 kg/m^2 for the non re-burned Vega Fire Plots, both considerably higher than the pre-burn CFS Plot average of 2.57 kg/m^2.

The F + H layer duff loads above were not corrected for inorganic content. Inorganic contents of 26 sub-samples of CFS Plot residual F + H layers taken in 2002, and burned and non re-burned Vega Fire Plot F + H layer samples are reported in Appendix 4 and discussed in Section 5.6.

No mineral soil exposure was tallied along 30 m of line transect on any of the Vega Fire Plots.

Table 15. Average moss/litter and duff depths and load remaining and percent mineral soil exposed by Vega Fire plot, based on 25 depth points and three 10 m transect segments respectively. Duff load sampled on five 0.1 m^2 sub-plots per plot

Plot No.	Average Moss/Litter depth (cm)	Average Duff depth (cm)	Average Moss/Litter load (kg/m^2)	Average Duff load (kg/m^2)	Average Mineral Soil Exposed (%)
1	3.15	4.38	0.22	3.75	0
2	2.90	4.29	0.36	4.72	0
3	2.71	8.08	0.46	4.40	0
Average	2.92	5.58	0.34	4.29	0
4	4.56	8.71	0.68	3.30	0
5	3.57	8.12	0.80	4.76	0
6	3.83	12.92	0.91	6.20	0
Average	3.99	9.92	0.80	4.75	0
Site Avg.	3.45	7.75	0.57	4.52	0
Site Std.Dev	0.852	3.5	0.300	1.002	-

5.2.4 Understory vegetation

Understory herbs and low shrub responses one year after the 2001 re-burn of 1968 Vega Fire, and the comparison un-burned Vega Fire plots 4-6 are presented in Table 16. Plot 6 showed grass present, but averaged only 2.2% cover, while grass cover on the re-burned plots ranged from 12.5 to 45.8%. Aspen cover was significant only on plot 1 (17%). Honeysuckle was significant on burned and unburned plots, while fireweed responded from a minor presence on un-re-burned plots to significant cover on burned plots (6-8%).

Tall shrub density and height one year after the 2001 re-burn of 1968 Vega Fire and the comparison un-re-burned plots 4-6 are presented in Table 17. Tall aspen was present on all plots except burned plot 2. Honeysuckle was present on all plots, and had the highest density of any tall shrubs at 70 000 stems/ha on plot 1.

Table 18 shows that re-burned Vega Fire Plot vegetation load consisted of an average of 0.048 kg/m^2 grass, 0.071 kg/m^2 herbs and shrubs, and 0.036 kg/m^2 of trees (suckers), for a total of 0.155 kg/m^2, when sampled June 2002. These vegetation components contrast with the non re-burned Vega Fire Plots which had no grass or tree sucker components, and a herb/shrub component totaling 0.068 kg/m^2, comparable to the 0.043 kg/m^2 pre-burn 1972 vegetation load reported for the CFS Plots.

Table 16. Understory vegetation (< 0.5 m tall) frequency (%) and cover (%) by species and Vega Fire plot

		1		2		3		4		5		6	
		Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover
Scientific Name	**Common Name**	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Geranium bicknelli	Bicknell's geranium	50	0.2	67	0.5	17	1.0	-	-	-	-	-	-
Cornus canadensis	bunchberry	17	1.0	83	1.5	17	1.2	11	13.5	67	4.7	33	0.3
Taraxacum officinale	common dandelion	-	-	-	-	17	0.1	-	-	-	-	-	-
Vaccinium caespitosum	dwarf blueberry	-	-	-	-	17	0.1	7	1.3	17	7.5	-	-
Epilobium angustifolium	fireweed	83	8.2	67	6.0	67	8.3	7	1.0	50	0.8	50	0.8
Grass sp.	grass	100	21.8	100	12.5	100	45.8	9	0.5	67	0.7	100	2.2
Arnica cordifolia	heart-leaved arnica	-	-	17	6.7	-	-	-	-	-	-	-	-
Equisetum palustre	horsetail	83	6.8	100	3.5	100	2.3	13	1.5	-	-	67	1.2
Viburnum edule	low-bush cranberry	67	1.5	50	0.5	67	2.5	13	17.5	83	6.2	50	6.2
Gymnocarpium dryopteris	oak fern	17	1.7	-	-	-	-	4	1.5	33	4.5	-	-
Petasites palmatus	palmate-leaved coltsfoot	-	-	-	-	-	-	2	0.2	-	-	50	0.1
Betula papyrifera	paper birch	-	-	17	0.5	-	-	2	0.2	-	-	-	-
Rosa acicularis	prickly rose	83	15.2	83	11.5	67	1.2	9	1.2	67	4.2	83	6.0
Ribes sp.	ribes	-	-	-	-	-	-	-	-	17	0.2	-	-
Mertensia paniculata	tall mertensia	17	0.2	17	0.2	33	1.0	-	-	-	-	-	-
Populus tremuloides	trembling aspen	67	17.0	83	1.7	83	1.0	4	0.8	33	1.2	50	1.2
Lonicera dioica	twining honeysuckle	50	13.8	50	8.3	33	10.0	7	8.5	67	18.8	83	15.8
Rubus idaeus	wild red raspberry	50	0.7	100	4.8	100	5.7	7	1.7	83	3.8	83	2.2
Aralia nudicaulis	wild sarsaparilla	33	0.3	50	2.0	67	2.2	9	8.0	100	19.3	67	3.0
Fragaria virginiana	wild strawberry	17	0.7	-	-	-	-	7	0.8	-	-	17	1.0
Vicia americana	wild vetch	-	-	-	-	-	-	2	0.5	-	-	-	-
Salix sp.	willow	-	-	-	-	-	-	0	0.7	-	-	-	-

Table 17. Tall (> 0.5 m) shrub and tree regeneration density (stems/ha) and height (m) by species and Vega Fire plot

		1		2		3		4		5		6	
		Density	Ht.	Density	Ht.	Density	Ht.	Density	Ht.	Density	Ht.	Density	Ht.
Scientific Name	**Common Name**	(sph)	(m)	(sph)	(m)	(sph)	(m)	(sph)	(m)	(sph)	(m)	(sph)	(m)
Corylus cornuta	beaked hazel												
Alnus crispa	green alder												
Viburnum edule	low-bush cranberry	20000	0.5					15000	0.9	15000	0.7	20000	0.8
Betula papyrifera	paper birch												
Rosa acicularis	prickly rose	17500	0.7	10000	0.6			20000	0.7			10000	0.5
Populus tremuloides	trembling aspen	22500	0.6			10000	0.6	10000	1.7	20000	1.7	10000	1.1
Lonicera dioica	twining honeysuckle	70000	0.7	10000	0.5	20000	0.6	30000	1.5	40000	1.0	26700	1.1
Rubus idaeus	wild red raspberry					10000	0.6						
Salix sp.	willow							20000	1.5				

Table 18. Understory vegetation (herbs, shrubs and trees < 0.5 m tall) load (kg/m^2) by Vega Fire plot

Plot No.	Grass	Herbs/Shrubs	Trees	Total
1	0.031	0.080	0.088	0.200
2	0.050	0.083	0.010	0.143
3	0.064	0.050	0.008	0.122
Average	0.048	0.071	0.036	0.155
4	0.000	0.055	0.000	0.055
5	0.000	0.076	0.000	0.076
6	0.000	0.073	0.000	0.073
Average	0.000	0.068	0.000	0.068

5.2.5 Fuel consumption

Table 19 summarizes depth of burn and surface fuel consumption for 1968 Vega Fire re-burned Plots 1-3. Calculations of depth of burn of litter and F + H layers are subject to various errors, including the assumption that the average pre-burn depths of litter and F + H layers measured on the unburned adjacent Plots 4-6 are representative of what the pre-re-burned depths of these layers were on the re-burned Plots 1-3. Further, these inferred depths of burn were combined with sampled bulk densities by 2 cm depths on Plots 4-6 to infer forest floor consumption on the burned Plots 1-3. The calculated forest floor consumptions were similar on Plots 1 and 2, but dropped more than half on Plot 3, due to a much reduced depth of F + H layer burned. However, even the inferred depth of burn on Vega Fire Plot 3 of 3.12 cm was similar to the 1978 re-burn depth of burn on CFS Plots 3b and c (3.45 cm), while Vega Fire Plots 1 and 2 had depths of burn almost twice as deep as the 1978 re-burned CFS Plots.

Understory vegetation consumption of 0.068 kg/m^2 was assumed to be the herb and shrub load measured on the Vega Fire unburned Plots 4-6, and was a very minor contribution to total surface fuel consumption. Similarly to the assumption of representativeness of the unburned Vega Fire Plots for forest floor conditions on the burned Vega Fire Plots, the assumed downed-woody fuel consumption was based on difference in Plot average downed-woody fuel loads on the unburned vs. the burned plots. This value (0.49 kg/m^2) for downed-woody fuel consumption was similar to the average value attributed to the higher intensity CFS Plots burned in 1972 (0.369 kg/m^2) (Table 9).

Total surface woody fuel consumption on Vega Fire Plots 1-3 ranged from 1.4 to 4.3 kg/m^2, comparable to the fuel consumption measured on the 1978 re-burned Plots 3b and c (3.402 kg/m^2, Table 9); however, this high value in 1978 was due primarily to the high downed-woody fuel consumption (2.996 kg/m^2), while the Vega Fire 2001 re-burned fuel consumption was due primarily to the high forest floor consumption.

Table 19. Estimated surface fuel consumption in 2001 Chisholm Fire, by Vega Fire plot

	Depth of Burn						
Plot No.	L+F+H (cm)	L (cm)	F+H (cm)	Forest Floor Consumption (kg/m2)	Understory Vegetation Consumption (kg/m2)	Woody Surface Fuel Consumption (kg/m2)	Total Surface Fuel Consumption (kg/m2)
1	6.38	0.84	5.54	3.502	0.068	0.490	4.060
2	6.72	1.09	5.63	3.775	0.068	0.490	4.333
3	3.12	1.28	1.84	0.877	0.068	0.490	1.435

5.3 Fire intensity

5.3.1 Estimated 2001 frontal fire intensities

Frontal fire intensities were calculated for the 2001 Chisholm Fire plots from Byram/s formula:

$$I = \frac{Hwr}{60}$$, where

I = frontal fire intensity (kW/m), H = fuel low heat of combustion (kJ/kg), w = weight of fuel consumed in the active combustion zone (kg/m^2), and r = linear rate of fire spread (m/min). H was set to 18000 kJ/kg for the 2001 re-burns by the Chisholm Fire and the 1968 Vega Fire, while the 1972 and 1978 CFS Plot burns and re-burns used an adjusted H for moisture content, so the I calculations of Quintilio et al (1991) were used as reported. Fire intensity calculations are listed in Table 20.

Fuel consumption of 3.1 kg/m^2 was assumed for the original 1968 Vega Fire, the average value reported by Kiil and Grigel (1969) for mixedwood (M-1) fuel types, which was assumed applicable (white spruce-aspen) in 1968 to the stand re-burned in the 2001 Chisholm Fire.

Rates of spread in Table 20 were derived as follows:

- 1968 Vega Fire average rate of spread of 6.5 km/h (108.3 m/min) for May 23, 1968 was assumed applicable to the 2002 plot area.
- 2001 re-burn of 1968 Vega Fire plot area was assumed to burn at the rate of spread predicted for 1700h May 28, 2001, 20.7 m/min for FBP Fuel Type D-1 (leafless aspen). A GPS location of the fire front was recorded by an aerial observer over the 2002 Vega Fire re-burn plot area at 1713h May 28, 2001 (Quintilio et al. 2001).
- 1972 and 1978 re-burn rates of spread on CFS Plots repeated as reported by Quintilio et al. (1991).

- 2001 rates of spread on re-burns of CFS Plots were assumed to coincide with the observations of the fire crossing the Highway after the merger of Fires 063 and 073. The fire run of 7.2 km between 1824-2000h May 28, 2001, was averaged through various fuel types (C-2, C-3, M-1, D-1) at 4.5 km/h (75 m/min) (Quintilio et al. 2001). Fire weather as recorded at the Chisholm Fire Base Station ameliorated sharply at 2000h, due to rain showers and a marked increase in humidity, however, we have assumed that the CFS Plots re-burned before this weather change, such that the burning conditions (Appendix 2) calculated for 1900h are probably representative of the plots.

Estimated fire intensities for the CFS plots reburned in 2001 (Table 20) range from 78000 to 228 000 kW/m greatly exceed the FBP System predicted values for 1900h May 28, 2001 for fuel type D-1 (rate of spread = 22.1 m/min, total fuel consumption = 1.3 kg/m^2, head fire intensity = 8862 kW/m). Some of this discrepancy may be due to the rate of spread estimate being subject to large eror, and the fuel consumption estimates also being subject to errors resulting from inferring rather than measuring pre-burn fuel loads. Quintilio et al. (2001) estimated an average Chisholm Fire intensity of 158 000 kW/m, based on an average rate of spread for fuel types D-1, M-1, and C-2 of 4.0 km/h (67 m/min), and average fuel consumption of 6.8 kg/m^2. Our fuel consumption estimates for the CFS plots are slightly higher (average SFC = 7.65 kg/m^2) than the overall Chisholm Fire average estimated by Quintilio et al. (2001), because of the previous fire history on the CFS plots contributing to heavy downed-woody fuel loads.

Estimated fire intensities for the Vega Fire plots re-burned in 2001 (Table 20) range from 8 900 to 27 000 kW/m, much lower than estimates for the CFS plots, because both the estimated rate of spread and the range of estimated fuel consumptions were lower. The FBP System predicted values for 1700h May 28, 2001 for fuel type D-1 (rate of spread = 20.7 m/min, total fuel consumption = 1.3 kg/m^2, head fire intensity = 8294 kW/m) were similar to our estimates of fuel consumption and fire intensity for the lowest plot 3, which is the plot burned as the fire was stopping its forward spread. The original 1968 Vega Fire values of average rate of spread, fuel consumption for mixedwood (M-1) and intensity (100 000 kW/m) as estimated by Kiil, and Grigel (1969) are included in Table 20 for comparison.

Tables 20. Estimated frontal fire intensities 1972, 1978, 2001, by plot

	Surface Fuel Consumption (kg/m^2)		Estimated or Measured Rate of Spread (m/min)		Frontal Fire Intensity (kW/m)	
Plot No.	1972	2001	1972	2001	1972	2001
5c	0.177	-	0.28	75	15	-
6a	0.122	10.14	0.45	75	17	228 150
6b	0.117	9.62	0.47	75	18	261 450
2b	0.263	3.48	0.75	75	60	78 300
5a	0.307	5.41	0.75	75	71	121 725
5b	0.300	-	0.77	75	71	-
2a	0.274	-	0.87	75	73	-
3a	0.305	8.01	0.88	75	82	180 225
3c	0.507	7.93	1.41	75	219	178 425
4c	0.535	-	1.48	75	243	-
4a	0.557	6.59	1.62	75	277	148 275
4b	0.539	-	2.13	75	353	-
3b	0.507	-	2.51	75	390	-
7b	-	10.04	-	75	-	225 900
1978						
3b&c	3.402	7.93	4.6	75	4 392	178 425
Year	1968	2001	1968	2001	1968	2001
2001						
1	3.1	4.060	108	20.7	100 440	25 213
2	3.1	4.333	108	20.7	100 440	26 889
3	3.1	1.435	108	20.7	100 440	8 911

5.4 Tree mortality

All overstory trees within inventory plot boundaries on all CFS plots and on all re-burned Vega Fire plots of all species were killed by the 2001 Chisholm Fire, reflecting the much higher wildfire intensities in 2001 than in the 1972 and 1978 experimental fires on the CFS plots. However, aspen trees are killed at rather low fire intensities. Even the 1978 CFS re-burn of plots 3b&c killed all aspen trees except for a few larger than 17.5 cm (Quintilio et al. 1991), with a fire intensity of 4 400 kW/m, and the 2001 re-burn of the Vega Fire killed all trees, with an intensity of 8 500 kW/m. As the killed trees fall over the next decade or so, they will again contribute to the large diameter component of downed-woody fuel load, as occurred after the 1972 and 1978 experimental fires. This time, however, the CFS plots are missing the small diameter trees that were present in 1972, as they have fallen and burned. However, on the Vega Fire re-burn area, the entire range of tree diameters is available to fall and contribute to a heavy load of downed-woody fuel that will accumulate over the next decade or so.

5.5 Vegetative greenup

Fire behaviour in aspen stands is greatly affected by the state of lesser vegetation and tree foliage. The FBP System defines fuel type D-1 (leafless aspen) as representing pure aspen stands before bud break in spring or following leaf fall and curing of the lesser vegetation in autumn, the principal fire-carrying surface fuel consisting chiefly of deciduous leaf litter and cured herbaceous material directly exposed to wind and solar radiation (CFS Fire Danger Group 1992). These authors note also that in the spring, the duff (F + H layers) seldom contributes to the available combustion fuel due to its high moisture content.

However, the normally short spring burning window for aspen prior to vegetative greenup can be extended by drought from the typically four or five weeks from late April to late May into a six or seven week window where greenup is not complete until mid-June. Such drought conditions were associated with the 1968 Vega Fire and 2001 Chisholm Fire, both late May fires in which high BUIs and pre-greenup conditions contributed to fire spread and forest floor and downed-woody fuel consumption in aspen stands.

Kiil and Grigel (1969) note that vegetative growth usually starts in mid-May, but a general greening of the forest landscape does not occur for several weeks. These authors noted further that in 1968 when the outbreak of wildfires including the Vega Fire began the third week of May, aspen and poplar leaves were about 25% developed and understory vegetation about 10 or 15% developed, allowing equal drying of fuels in hardwood, mixedwood and conifer stands such that fires could spread with equal ease across the landscape. The 2001 Chisholm Fire began the fourth week of May, and while deciduous trees had begun to leaf out by the start of the fire, the dry spring weather had retarded any greenup of grass and herbaceous vegetation under forest canopies (Quintilio et al 2001).

5.6 Inorganic content

Inorganic content of the forest floor is a source of error in the calculation of available fuel and fuel consumption, because it contributes mass (weight) to the samples of forest floor pre- and post-burn, but cannot burn in a normal forest fire environment. Quintilio et al. (1991) reported inorganic content averaged 59% on eight F+H layer sub-samples from the CFS plots processed in 1978, although their reported forest floor loads pre- and post-burn were not corrected for this inorganic content.

Inorganic content as a percentage of oven-dry F+H 2cm depth increment for 26 sub-samples selected from 2002 forest floor samples collected on CFS plots and Vega Fire plots (burned and unburned) are tabulated in Appendix 4.

Generally, the 2002 inorganic content samples are lower than the 1978 samples reported for the CFS plots, and for consistency with the 1991 publication, our present report has not corrected forest floor load calculations for inorganic content.

The 2002 inorganic content averaged 42% for all remaining F+H depths on the CFS plots, and ranged from an average 36% for 0-2cm sub-samples to a high of 52% for lower depths of 2-6cm.

Vega Fire plots, burned and unburned, had generally lower inorganic contents than the CFS plots. Re-burned Vega Fire plots averaged 31% inorganic content for all depths, while non-re-burned Vega Fire plots averaged only 17% for all depths. The same trends continued, with Vega Fire burned plots averaging 19% inorganic content for 0-2 cm depths, but 36% for depths > 2cm. Un-re-burned Vega Fire plots had only 12% inorganic for depths 0-4cm, but 22% inorganic for depths > 4cm.

6.0 DISCUSSION

6.1 Fuel consumption in re-burned aspen stands vs. forest floor moisture conditions

The original CFS plots were burned in 1972 and 1978 under low Duff Moisture Code (DMC), Drought Code (DC) and Buildup Index (BUI) conditions (Appendix 2) and high forest floor moisture contents (Quintilio et al. 1991), which resulted in very low forest floor consumption, confined to the litter layer in 1972 and litter plus a portion of the F + H layers in 1978. Downed-woody fuel consumption was also very low (0.2 kg/m^2), as was surface vegetation consumption (0.043 kg/m^2), resulting in an average 1972 total fuel consumption of only 0.347 kg/m^2. Much higher downed-woody fuel consumption (3 kg/m^2) occurred on the 1978 re-burned plots, not because of higher BUIs, which were similar to the burning conditions of 1972, but because of much higher downed-woody fuel loads in 1978, resulting from the dead-tree falldown after the 1972 burns (Table 9) and resulting mortality. Downed-woody fuel loads were very light prior to the 1972 burns at 0.369 kg/m^2, and as a result, contributed little to fire behaviour and impact (Quintilio et al. 1991).

The 1972 and 1978 re-burns of the CFS plots demonstrated that downed-woody fuel load was the most significant variable affecting fuel consumption and fire intensity in the leafless aspen fuel type under moderate burning conditions. Even though burning conditions were similar in 1972 and 1978, fuel consumption and fire intensity increased 10-fold and rate of spread doubled in the 1978 re-burns, because of the increased availability of downed-woody fuel resulting from tree mortality from the earlier 1972 burns.

In 1968, forest floor moisture conditions were much drier than those affecting the 1972 and 1978 burns, with a BUI of 77 representing the 1968 Vega Fire (Appendix 2), while 1972 and 1978 BUIs were $\leq$ 33. Kiil and Grigel (1969) estimated total surface fuel consumption of 3.1 kg/m^2 for M-1 (mixedwood) fuel types on the 1968 Vega Fire, the most likely fuel type that existed on the area re-burned in 2001, in view of the young aspen stand that regenerated after the 1968 fire, and the presence of scattered large white spruce stump remnants. While the 1968 estimated fuel consumption of 3.1 kg/m^2 was noted by Kiil and Grigel to be highly variable in mixedwood stands, with depth of burn ranging from 2-15 cm, consumption of forest floor, tree needles and branchwood, and tree stems was not complete. Even in deciduous stands, while all of the 5-7 cm litter layer was consumed, mineral soil exposure was infrequent, according to these authors. While the estimated surface fuel consumption amounts on the 1968 Vega Fire were similar to the measured consumption on the 1978 CFS re-burn, it is likely that more of the 1968 fuel consumption was contributed by forest floor than by downed-woody fuel, in contrast to the 1978 CFS re-burn, because of the higher BUI in 1968.

Unlike the 1978 CFS plot re-burns, where the fuel load was dominated by fallen trees from the 1972 burns, the 2001 Vega Fire re-burn fuel load was apparently dominated by the accumulation of new litter and forest floor since the 1968 fire, rather than a dominant large-diameter downed-woody fuel load. We have assumed that the mature fire-killed trees from 1968 were mostly salvaged, since there were no large standing snags found, and the downed-woody fuel load, while variable, ranged from 1.5 to 7.6 kg/m^2, mostly medium-diameter material. While the downed-woody fuel loads on the 1978 CFS re-burn plots (5.2 kg/m^2) and on the 2001 Vega Fire re-burn plots (4.1 kg/m^2) were similar, the much higher BUI on 2001 of 121 (Appendix 2) probably accounted for a much higher proportional fuel consumption contribution in 2001 from the forest floor (75%), vs. 25% contributed from downed-woody fuel and a minor amount of understory vegetation. The nature of the downed-woody fuel load on the 1978 CFS re-burn plots was quite different from the woody material on the 2001 re-burn of the Vega Fire plots. The 1978 woody fuel was sound and much of it elevated, since most of it accumulated over a few years since the 1972 burns. This material would have been quite dry and available for combustion in 1978, even though the forest floor was quite wet. By contrast, most of the Vega Fire 2001 re-burned downed-woody fuel originated more than 30 years ago, was punky or rotten and in contact with the forest floor, resulting in it being probably much wetter than its 1978 CFS Plot counterpart, even though the BUI was much higher in 2001.

Quintilio et al. (1991) found their measurements of depth, weight, bulk density and inorganic content of the litter and F + H layers on the 1972 CFS aspen plots to be similar to aspen studies from other Alberta and North American locations. However, we found for our 1968 Vega Fire un-reburned plots that, while litter depth was similar to the 1972 CFS plots (4 cm), our litter layer load and therefore bulk density were much higher (0.8 vs. 0.3 kg/m^2; 0.020 vs. 0.007 g/cm^3). Similarly, our Vega Fire un-reburned plot F + H layer measurements were much deeper (10 cm vs. 2.37 cm), heavier (4.75 vs. 2.57 kg/m^2) and higher bulk density (0.067 vs. 0.0013 g/cm^3 as reported by Quintilio et al. (1991). However, these authors' calculations of bulk density appear to be in error for the 1972 CFS plots, since our calculation check of their data indicates a bulk density of 0.108 g/cm^3 for an F + H layer load of 2.57 kg/m^2 and depth of 2.37 cm).

6.2 Implications of fire history on fuel consumption and fire intensity in aspen stands

The fire and logging history of the 1972 CFS fire research study area was not provided by Quintilio et al. (1991), so we will not speculate on why the then 43 year old aspen stand had so little downed-woody fuel load that this component contributed little to 1972 fire behaviour.

However, these authors cite a pre-greenup spring 1969 prescribed fire (Kiil 1970) in a partially cut aspen - white spruce (selectively logged for spruce in 1950s) stand in which litter and minor vegetation consumption (0.587 kg/m^2) was similar to the highest fuel consumption CFS plots of 1972, while none of the 3.35 kg/m^2 F + H layer was consumed. The litter layer was 4 cm and F + H layer was 6 cm deep. Downed-woody fuel load and consumption was not reported by Kiil, except to mention the desirability of burning soon after logging when slash accumulations and lack of lush herbaceous vegetation would contribute to greater fire intensities. The work file on Kiil's 1969 burn contained prescribed fire plan information on an area cruise that tallied slash loads of 0.08 kg/m^2 < 5 cm, 0.11 kg/m^2 5-10 cm, and 2.00 kg/m^2 > 15 cm, totaling 2.19 kg/m^2.

It is significant to note that the downed-woody slash fuel load on the Kiil partial cut area that was ignored as a factor of fuel consumption was less than half the downed-woody fuel load on the 1978 CFS re-burn and 2001 re-burn of the Vega Fire.

It appears that downed-woody fuel load's contribution to spring fire intensity in aspen stands may depend on several factors:

- Prior to spring greenup of herbaceous vegetation and leaf flush of deciduous trees, litter layers of approximately 4 cm depth and low bulk density are common, regardless of fire and logging history, and are sufficient to carry a low-intensity surface fire that consumes primarily the litter layer under normal spring weather conditions. Small diameter aspen trees are killed.
- Abnormally dry spring weather can delay greenup of herbaceous vegetation and leaf flush of deciduous trees, contributing to greater fuel availability for combustion and higher fire intensities. Higher than normal BUIs will be accompanied by dry enough F + H layers to contribute to fuel consumption and higher frontal fire intensities. Small and medium diameter aspen trees are killed. Mineral soil exposure minimal.
- If the recent fire history or logging history of the stand has resulted in significant downed-woody fuel loads, the consumption of these fuels depends on their arrangement, condition and the burning conditions:
    - (i) If the downed-dead fuels are mostly sound and elevated, a significant portion of them will be consumed even if spring burning conditions are mild, contributing to high fire intensities. All or most trees are killed. Mineral soil exposure significant. Forest floor consumption (L, F + H layer) significant.
    - (ii) If the downed-dead fuels are mostly punky, rotten and in contact with the forest floor, a small portion of these fuels will be consumed, not contributing significantly to fire intensity, even if spring burning conditions are severe. Small and medium diameter trees killed, significant forest floor consumption, but minimal mineral soil exposure even if burning conditions severe.

6.3 Implications of aspen fuel consumption estimates under severe burning conditions on FBP System models

FBP System Fuel Type D-1 (leafless aspen) has an equation for fuel consumption predicted from BUI, based on 26 fires, 13 of them being the 1972 CFS experimental fires discussed here, but not including the 1978 CFS re-burn of Plots 3B & C, nor the estimated aspen fuel consumption of Kiil and Grigel for the 1968 Vega Fire of 2.0 kg/m^2 at BUI 77. The FBP dataset included only one fire with high fuel consumption, the Minnesota experimental fire in partial-cut white spruce-aspen, 3.2 kg/m^2 at BUI 24. The remaining 25 FBP database fires covered a small range of BUI 14-54, and a small range of fuel consumption of 0.12-0.98 kg/m^2.

It is clear from the above FBP data set description that severe spring burning conditions have not been considered in FBP fuel consumption equation development, resulting in potential under-estimation of fuel consumption and fire intensity in the D-1 fuel type under some burning conditions and fuel configurations and loads. In turn, such an under-estimation of potential fire behaviour under critical conditions could conceivably result in over-estimation of the benefits of aspen stands as barriers to fire spread ("fuelbreaks").

The present study of aspen stand re-burns under severe spring burning conditions and increased fuel loads resulting from tree mortality from previous burns cause us to question the following interpretation of the 1972 CFS aspen fires by Quintilio et al. (1991) p.18 if extrapolated beyond the limits of their experimental data, as was done in the FBP equation:

> "The light surface fuel loads and lack of ladder fuels contribute to this relatively low fire hazard condition, a fact that is reflected in various rating schemes. The amount of fuel potentially available for combustion in the trembling aspen fuel type is also limited because the duff layer typically exhibits very high moisture contents during the narrow 'burning window' in the spring (before leaf-out and development of understory vegetation). Thus, any variation in frontal fire intensity is primarily due to changes in forward rate of fire spread, as determined by the MC of fine dead surface fuels and wind velocity."

We have seen with the Chisholm Fire how severe spring droughts as occurred in 2001 can extend the normally brief burning window of leafless aspen, retarding greenup and allowing forest floor (F and H layers) and downed-woody fuels to contribute significantly to fuel consumption and fire intensity. Figure 5 shows 2001 fuel consumption for Vega Fire re-burn plots vs. FBP System database fires for fuel type D-1 (For. Can. Fire Danger Group 1992). The FBP equation is S-shaped with leveling off applied at high BUI. Figure 5 shows one of the 2001 plots "on the line," while the other two plots are high outliers from the equation, along with the 1978 CFS plot re-burn and the Minnesota fire of Perala that was included in the original FBP regression. The calculated intensities for the 2001 Vega Fire re-burns are subject to high possible errors in rate of spread assumptions, but range from 8900 to 27000 kW/m (Table 20), falling within Intensity Classes 5 and 6, beyond direct suppression and certainly not reflective of fire behaviour associated with "fuelbreaks."

However, the Chisholm Fire did cease its run abruptly in this leafless aspen fuel type (Photo 1), apparently before the evening weather change that brought much higher humidities and rain. Why did the fire stop here, precisely at the narrow band of 32 year-old aspen representing the overlap with the perimeter of the 1968 Vega Fire? We cannot say for certain, but we noted that our unburned plots contained aspen stands of sufficient density and canopy closure to exclude grass growth. Perhaps the absence of cured grass was sufficient to slow the fire spread, especially acting with the effect of the salvage road as a fuel discontinuity.

While the intensity of the Chisholm Fire burning in aspen fuel types, especially those with significant downed-woody fuels, surprised fire suppression personnel and were accompanied by observations of "crowning in aspen," earlier aspen wildfires exhibiting extreme fire behaviour had been noted by Quintilio et al. (1991). They noted (p. 20):

> "…extremely fast-spreading surface fires (> 25 m/min) that have frontal intensities of > 10000 kW/m and significant spotting distances…applies only to severe burning conditions in the spring."

They went on to cite the Little Sioux wildfire of May 14, 1971 in Minnesota which reached an estimated intensity of 13000 kW/m in aspen at a BUI of 45, noting that under such conditions, aspen appears to crown because of the associated flame heights and the consumption of some fine dead crown fuel, but such fires are high-intensity surface fires. These authors go on to describe possible exceptions of crown fires in aspen under severe burning conditions and drought in the fall, citing the Bar Harbour Fire, Maine, Oct. 23, 1947, or crown fires in aspen under less severe conditions when fuels have been disturbed by herbicides, cutting or a recent fire.

Our measurements and post-burn observations of the 2001 Chisholm Fire re-burn of the 1968 Vega Fire do not indicate that the aspen stand crowned before the fire stopped its spread May 28, 2001. Bole scorch heights were only 0.5 m and no crown fuel consumption was noted. While the Chisholm Fire re-burn of the CFS plots produced much higher bole scorch heights (3.5 m), presumably because of heavier loads and greater consumption of downed-woody fuels created by the previous fire(s), little crown fuel consumption was noted. The Chisholm Fire re-burn of the CFS plots would also have been classified as a high-intensity surface fire. Fast rates of spread would have been supported by ample cured grass, which would have thrived under the open canopy.

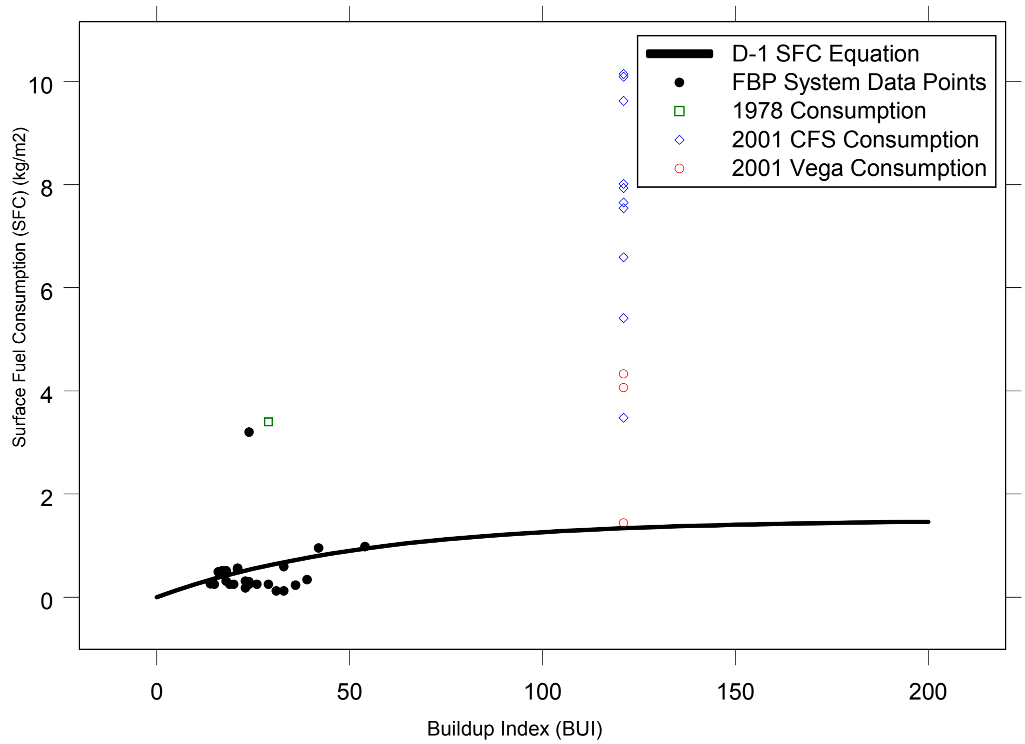

Figure 5. FBP System graph of fuel consumption vs. BUI for fuel type D-1, showing original database fires and 2001 re-burn fires

7.0 CONCLUSIONS

7.1 This study has provided re-measurement data on the 2001 Chisholm Fire re-burn of 1972 and 1978 CFS aspen fire behaviour research plots that will provide a benchmark from which to evaluate future changes to fuels, stands and vegetation succession.

7.2 Estimating 2001 fire behaviour and fuel consumption on the CFS plots proved to be difficult, because there had been no re-measurements since the 1978 re-burns. Frequent (5 year?) re-measurements of these same plots would provide valuable insights into stand and fuel succession through multiple documented fires of low, moderate and high intensities, a rare research opportunity.

7.3 Plots established on the Chisholm Fire re-burn of the 1968 Vega Fire and immediately adjacent un-reburned aspen stand in which the Chisholm Fire stopped spreading have contributed valuable data on aspen fuel consumption under severe spring burning conditions.

7.4 Fuel consumption in aspen stands under severe spring burning conditions was found to be generally greater than predicted by the FBP System fuel consumption equation for fuel type D-1 (leafless aspen). The FBP equation was extrapolated by leveling off beyond the low and moderate burning conditions represented by the model data.

7.5 Fire history of these aspen stands was found to account for higher downed-woody fuel loads and fuel consumption than had been present before and during the 1972 CFS research burns. Salvage logging assumed to follow the 1968 Vega Fire was suspected of reducing downed-woody fuel loads available to the Chisholm Fire, but even so, significant downed-woody fuel and forest floor consumption were estimated.

7.6 Because there were no immediate pre-burn plot measurements on either the CFS plots or the Vega Fire re-burn plots against which to compare post-burn measurements, the fuel consumption estimates from this study were not statistically valid and therefore not definitive enough to warrant recommending changes to the FBP fuel consumption equation for fuel type D-1. Suffice to conclude that we feel the existing FBP equation 16 may significantly under-estimate surface fuel consumption at high BUI (> 100), and at any BUI where fire history of the stand, or other disturbance such as logging, has created significant downed-woody fuel loads. The original FBP model data set included no fires under severe burning conditions or sufficient fires with disturbance histories that a representative range of downed-woody fuel loads was analyzed.

7.7 When aspen stands are managed as fuelbreaks, we conclude that their effectiveness during the pre-greenup spring fire season may require treatment and maintenance to ensure that two conditions are met:

(i) Maintain deciduous species canopy closure in order to shade the forest floor, minimizing the growth of grasses that contribute to pre-greenup fire spread;

(ii) Treat and/or remove downed-dead fuels to ensure remaining fuel loads are light enough to maintain contact with the ground to enhance rapid decomposition and minimize their involvement in a fire front.

These conditions for aspen fuelbreak efficacy were evident in the Chisholm Fire re-burn of the aspen stand that regenerated following the 1968 Vega Fire. It appears that spring drought can extend the pre-greenup burning window in deciduous stands from a few weeks in normal years to as long as six or seven weeks, from late April to mid-June, accompanied by increasing availability for combustion (drying) of downed-woody fuel and forest floor (duff, or F+H) layers. Drying of forest floor and woody fuels is enhanced during spring droughts, since the tree foliage is not a factor in shading the forest floor and the herbaceous vegetation is not yet shading the cured litter and acting as a heat sink to spreading fires. Droughts in late-season can repeat these effects post-greenup, creating a "second fire season" in October to mid-November, where cured and "freeze-dried" grass (if present) or aspen leaf litter and herbaceous vegetation can again support rapid fire spread.

8.0 REFERENCES

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Appendix 1. Plot GPS locations and tag numbers at plot centre

1. CFS 1972 Fire Research Plots

Plot No.	EmberTag Number	Latitude	Longitude
2a	-	55 deg. 05.40'	114 deg. 08.03'
2b	370	55 deg. 05.39'	114 deg. 07.99'
3a	110	55 deg. 05.39'	114 deg. 07.96'
3b	199	55 deg. 05.39'	114 deg. 07.93'
3c	168	55 deg. 05.39'	114 deg. 07.90'
4a	18	55 deg. 05.42'	114 deg. 07.96'
4b	-	55 deg. 05.42'	114 deg. 07.92'
4c	-	55 deg. 05.42'	114 deg. 07.89'
5a	324	55 deg. 05.45'	114 deg. 07.95'
5b	-	55 deg. 05.45'	114 deg. 07.93'
5c	-	55 deg. 05.45'	114 deg. 07.91'
6a	150	55 deg. 05.42'	114 deg. 08.06'
6b	237	55 deg. 05.42'	114 deg. 08.02'
6c	328	55 deg. 05.42'	114 deg. 07.99'
7b	221	55 deg. 05.45'	114 deg. 08.03'

2. Vega (1968) Fire Plots

Plot No.	EmberTag Number	Latitude	Longitude
1	1	55 deg. 08.52'	114 deg. 38.31'
2	2	55 deg. 08.54'	114 deg. 38.34'
3	3	55 deg. 08.55'	114 deg. 38.37'
4	4	55 deg. 08.61'	114 deg. 38.47'
5	5	55 deg. 08.63'	114 deg. 38.48'
6	6	55 deg. 08.64'	114 deg. 38.52'

Appendix 2. Burning conditions, CFS plots 1972, 1978, 2001, and Vega Fire 1968 and Vega Fire Plots 2001

					10m Open Wind		Canadian Fire Weather Index System Components					
Plot	Date	Time MDT	Temp. (Celsius)	RH (%)	Direction	Speed (km/h)	FFMC	DMC	DC	ISI	BUI	FWI
CFS Plots												
5c	13-May-72	10:10	15.6	54	WSW	2.7	84.7	23	45	2.3	23	4
6a	14-May-72	13:54	19.4	22	NNW	10.1	92.4	31	57	10.0	31	18
6b	15-May-72	13:35	13.9	32	SE	9.1	91.2	33	62	8.0	33	15
2b	09-May-72	15:25	22.2	20	SSE	2.7	91.7	14	29	6.3	14	8
5a	12-May-72	14:04	17.1	36	NNW	8.5	91.2	23	45	7.8	23	12
5b	12-May-72	14:50	19.4	27	NW	7.5	91.7	24	46	8.0	24	13
2a	09-May-72	14:00	23.3	25	SSE	6.4	91.3	14	30	7.1	14	9
3a	10-May-72	14:20	23.3	25	SSW	13.9	92.4	18	35	12.1	18	15
3c	10-May-72	16:02	23.3	24	SSW	5.3	92.4	18	35	7.9	18	11
4c	11-May-72	15:29	22.8	26	NW	9.6	92.1	21	41	9.4	21	14
4a	11-May-72	14:07	22.8	24	SSW	11.7	92.5	21	41	11.0	21	15
4b	11-May-72	14:55	23.9	22	WNW	13.3	93.1	21	41	13.0	21	18
3b	10-May-72	15:00	21.7	23	WSW	12.8	92.5	17	25	11.6	17	15
3b&c	05-May-78	14:30	15.5	20	WNW	6.6	91.9	29	53	7.9	29	14
Vega	23-May-68	13:00	21.1	28	SE	35 (54)	94.0	58	284	41.0	77	67
Vega	28-May-01	17:13	27.5	25	SE	45.4	92.6	99	387	57.2	121	100
CFS	28-May-01	19:00	23.0	34	SE	48.8	92.8	99	387	62.6	121	105
CFS	28-May-01	21:00	18.6	62	SE	35.5	80.9[1]	99	387	7.5	121	28

[1] 0.25 mm rain recorded at Chisholm Fire Base Station at 2000h and 2100h.
It is not known if rain fell at CFS plots or exact time period that they re-burned between 1900h and 2100h May 28, 2001

Appendix 3. Calculation of estimated downed-woody fuel load and consumption in Chisholm Fire by CFS plot

	1	2	3	4	5	6
DBH Class mid-point	Natural dead trees	Mod. Int. Mortality 1972	Reburn Mortality 1978	Plot 3c Downed-Woody Fuel Load (1978 re-burn)	Plot 7b, 2b, 3a, 5a, 6a, 6b, 6c Assumed Mod. Intensity Mortality 1972 - 2001	Plot 7b, 2b, 3a, 5a, 6a, 6b, 6c Downed-Woody Fuel Load 2001
(cm)	(sph)	(sph)	(sph)	(kg/m^2)	(sph) (1+2)	(kg/m^2)
3.7	315	0	8	0.0004	315	0.1566
6.2	428	306	28	0.0111	734	0.2912
8.7	100	539	146	0.174	639	0.7615
11.2	42	584	426	1.2133	626	1.783
13.7	14	436	449	2.3942	450	2.3996
16.2	12	213	352	3.0308	225	1.9373
18.7	5	33	112	1.4165	38	0.4806
21.2	0	0	31	0.5397	0	0
24.0	0	0	15	0.3535	0	0
Totals	916	2111	1567	9.1335	3027	7.8098

Calculation of Downed Woody Fuel Consumption - 2001 re-burn

a) Plot **7b** (1972 unburned control)

		kg/m^2
	Pre-burn 1972 woody fuel load	0.30
+	Natural mortality 1972-2001 (mod. Int. burn)	7.81
=	Pre-2001 woody fuel load	8.11
minus	Post-2001 woody fuel remaining	0.44
=	2001 wood fuel consumption (WFC)	7.67

b) Plots

		2b	**3a**	**5a**	**6a**	**6b**	**6c**
		(kg/m^2)	(kg/m^2)	(kg/m^2)	(kg/m^2)	(kg/m^2)	(kg/m^2)
	post-1972 woody fuel load remaining	0.10	0.10	0.10	0.10	0.10	0.10
+	Tree falldown 1972-2001 (Mod. Int. Burn)	7.81	7.81	7.81	7.81	7.81	7.81
=	Pre-2001 woody fuel load	7.91	7.91	7.91	7.91	7.91	7.91
minus	post-2001 woody fuel remaining	5.33	1.43	3.02	0.27	0.68	2.82
=	2001 woody fuel consumption	2.58	6.48	4.89	7.64	7.23	5.09

c) Plot **3c** (1978 re-burn)

		(kg/m^2)
	Pre-1972 woody fuel load	0.30
minus	1972 woody fuel consumption	0.20
=	woody fuel load remaining 1972	0.10
	Pre-1978 re-burn woody fuel load	5.13
minus	1978 woody fuel consumption	3.00
=	woody fuel load remaining 1978	2.13
+	Tree falldown 1978-2001	9.14
=	Pre-2001 woody fuel load	11.27
minus	Post-2001 wood fuel remaining	3.38
=	2001 woody fuel remaining	7.89

Appendix 4. Inorganic content of F+H layers, CFS Plots and Vega Fire Plots

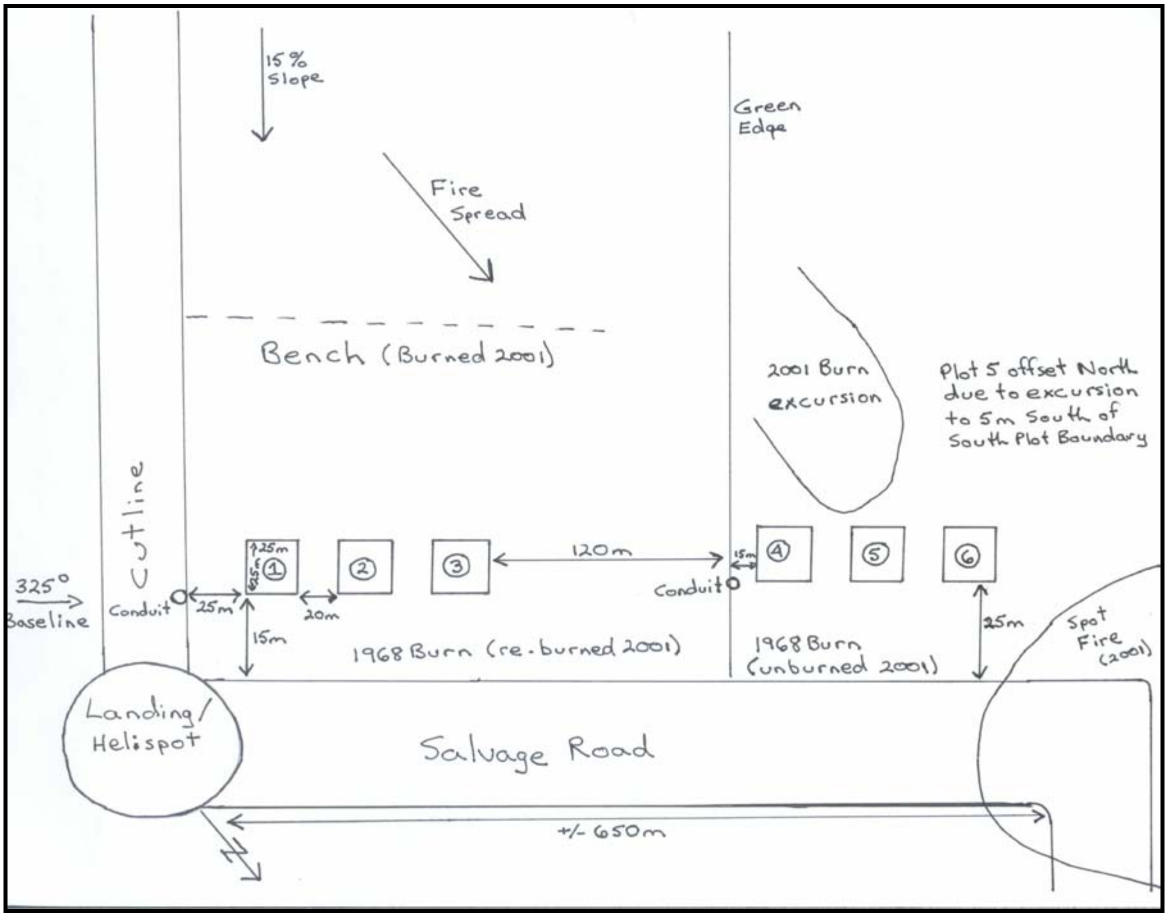
CFS Plots

Plot	Stratum (cm)	Inorganic Content (%)
2b	0-2	26.73
2b	2-4	47.55
3a	0-2	37.05
3c	0-2	32.5
3c	2-4	55.86
4a	0-2	34.88
4a	2-4	44.3
4a	4-6	49.98
5a	0-2	48.63
5a	2-4	61.86
6b	0-2	29.61
7b	0-2	39.48
	Stratum (cm)	**Means (n)**
	0-2	35.55 (7)
	2-6	51.91 (5)
	0-6	42.37 (12)

Vega Fire Plots

Burned Plots	Stratum (cm)	Inorganic Content (%)
1	0-2	24.52
1	2-4	37.06
1	4-6	40.78
3	0-2	12.71
3	2-4	21.06
3	4-6	42.94
3	6-8	38.59
	Stratum (cm)	**Means (n)**
	0-2	18.61 (2)
	> 2	36.90 (5)
	0-8	31.09 (7)
Un-Burned Plots	**Stratum (cm)**	**Inorganic Content (%)**
4	0-2	13.26
4	2-4	12.81
4	4-6	11.73
6	0-2	11.22
6	2-4	11.26
6	4-6	20.44
6	6-8	35.10
	Stratum (cm)	**Means (n)**
	0-4	12.14 (4)
	> 4	22.42 (3)
	0-8	16.55 (7)

Appendix 5. Detailed plot layout, 1968 Vega Fire re-burn area



Appendix 6. Photographs of CFS Fire plots

Photograph 1. Plot 2a N

Photograph 2. Plot 2a S

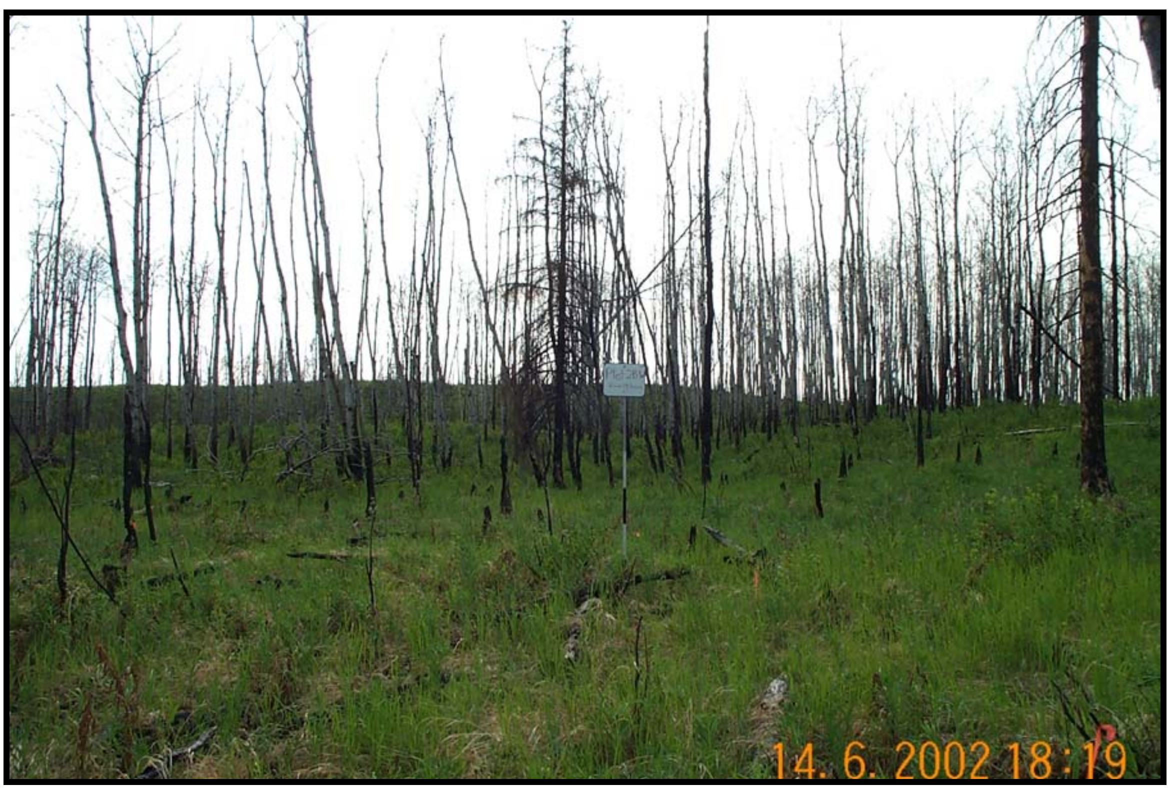
Photograph 1. Plot 2a E

Photograph 2. Plot 2a W

Photograph 1. Plot 2b N

Photograph 2. Plot 2b S

Photograph 1. Plot 2b E



Photograph 2. Plot 2b W

Photograph 1. Plot 3a N

Photograph 2. Plot 3a S

Photograph 1. Plot 3a E

Photograph 2. Plot 3a W

Photograph 1. Plot 3b N

Photograph 2. Plot 3b S

Photograph 1. Plot 3b E

Photograph 2. Plot 3b W

Photograph 1. Plot 3c N

Photograph 2. Plot 3c S

Photograph 1. Plot 3c E

Photograph 2. Plot 3c W

Photograph 1. Plot 4a N

Photograph 2. Plot 4a S

Photograph 1. Plot 4a E

Photograph 2. Plot 4a W

Photograph 1. Plot 4b N

Photograph 2. Plot 4b S

Photograph 1. Plot 4b E

Photograph 2. Plot 4b W

Photograph 1. Plot 4c N

Photograph 2. Plot 4c S

Photograph 1. Plot 4c E

Photograph 2. Plot 4c W

Photograph 1. Plot 5a N

Photograph 2. Plot 5a S

Photograph 1. Plot 5a E

Photograph 2. Plot 5a W

Photograph 1. Plot 5b N

Photograph 2. Plot 5b S

Photograph 1. Plot 5b E

Photograph 2. Plot 5b W

Photograph 1. Plot 5c N

Photograph 2. Plot 5c S

Photograph 1. Plot 5c E

Photograph 2. Plot 5c W

Photograph 1. Plot 6a N

Photograph 2. Plot 6a S

Photograph 1. Plot 6a E

Photograph 2. Plot 6a W

Photograph 1. Plot 6b N

Photograph 2. Plot 6b S

Photograph 1. Plot 6b E

Photograph 2. Plot 6b W

Photograph 1. Plot 6c N

Photograph 2. Plot 6c S

Photograph 1. Plot 6c E

Photograph 2. Plot 6c W

Photograph 1. Plot 7b N

Photograph 2. Plot 7b S

Photograph 1. Plot 7b E

Photograph 2. Plot 7b W

Photograph 2. Plot 7a

Photograph 2. Plot 7c

Photograph 2. Plot 8b

Appendix 7. Photographs of Vega Fire plots

Photograph 1. Plot 1 NE

Photograph 2. Plot 1 NW

Photograph 3. Plot 1 SE

Photograph 4. Plot 1 SW

Photograph 5. Plot 2 NE

Photograph 6. Plot 2 NW

Photograph 7. Plot 2 SE

Photograph 8. Plot 2 SW

Photograph 9. Plot 3 NE

Photograph 10. Plot 3 NW

Photograph 11. Plot 3 SE

Photograph 12. Plot 3 SW

Photograph 13. Plot 4 NE

Photograph 14. Plot 4 NW

Photograph 15. Plot 4 SE

Photograph 16. Plot 4 SW

Photograph 17. Plot 5 NE

Photograph 18. Plot 5 NW

Photograph 19. Plot 5 SE

Photograph 20. Plot 5 SW

Photograph 21. Plot 6 NE

Photograph 22. Plot 6 NW

Photograph 23. Plot 6 SE

Photograph 24. Plot 6 SW