FOREST AND RURAL FIRE RESEARCH

Fire Technology Transfer Note

Number - 4 October 1994

Applications of rate of spread information to fire suppression planning

By Grant Pearce

Rate of Spread Relationships

One obvious use of fire behaviour information in presuppression and/or suppression planning is to utilise the relationships between headfire rates of spread (ROS) and components of the Fire Weather Index (FWI) System that have been derived for numerous fuel types (Forestry Canada Fire Danger Group 1992) to predict the position of a fire front at time intervals following either a simulated or an actual ignition. With a knowledge of the range of fire danger conditions that can be experienced in a particular locality, these relationships can be used to predict fire spread under "average" or "worst case" conditions, for use in prevention and preparedness planning of, for example, public evacuations in rural-urban interface areas. Add to these relationships a knowledge of the effect of slope on rate of fire spread, and this tool becomes much more widely applicable to the New Zealand rural fire situation.

By way of an example to illustrate the use of these relationships in suppression planning, consider a grass fire burning on flat ground in continuous fuels under moderate fire danger conditions in, say, February on the Canterbury Plains. If the Fine Fuel Moisture Code (FFMC) is 85 with wind speeds of 10 km/h, how far will the fire spread in the first hour? (i.e., if it takes approximately one hour to mobilise fire crews and travel to the fire, how far will the fire have spread by the time initial attack crews arrive?)

1. Fuel type - for pasture grasslands, we can use the Natural (Standing) Grass (O-1b) fuel type from the New Zealand Fire Danger Rating System (NZFDRS) (Alexander 1994).

2. Fire danger conditions - the Initial Spread Index (ISI) can be determined from FWI System Tables (Anon. 1993); in this case, with an FFMC of 85 and winds of 10 km/h, the ISI is 3. Assuming average weather conditions for Canterbury in February, the Degree of Curing[1] in grasslands would most likely be around 90%.

3. Rate of spread - using the O-1b natural (standing) grass fuel type, an ISI of 3 and 90% degree-of-curing, the rate of fire spread on flat ground is 238 m/h (refer to Appendix 1 for a tabular version of the ROS relationship for the O-1b fuel type).

Hence, the fire would have spread approximately 240 m under these conditions by the time fire crews arrived at the scene. In addition, using the fuel load of 3.5 t/ha assumed for Grassland fuels in the NZFDRS (Alexander 1994), the fire would have a headfire intensity of 400 kW/m and could readily be suppressed by direct attack on the head of the fire with hand tools and backpack pumps. This scenario is illustrated using a fire spread calculation form in Appendix 2; a blank form is also attached for photocopying to allow calculation of fire spread using local scenarios.

[1] Grassland curing is an indication of fuel moisture content which affects fire behaviour, and the *Degree of Curing* is an "estimate of the proportion of dead material expressed as a percentage of the total volume of grass" (Gates 1987).

If, however, wind speeds were to increase to 45 km/h ahead of an approaching cold front, how far could the fire be expected to spread during the next hour? Again, from FWI System Tables, an FFMC of 85 and winds of 45 km/h correspond to an ISI of 20. Assuming the same fuel type and degree of curing, an ISI of 20 equates to a rate of spread of 3736 m/h (Appendix 1). The fire will spread approximately 3.7 km in one hour under these conditions and, based on the fuel load of 3.5 t/ha assumed for Grassland fuels, it will now have a frontal fire intensity of 6500 kW/m (see Appendix 2) which is above the recognised limit to control using conventional means (4000 kW/m), including aerial suppression with chemical additives (Alexander 1994).

It is important to remember that the passage of a cold front is often associated with increasing wind speeds and, most notably, with a change in wind direction of up to 90°. This can cause flank fires to suddenly become head fires, with more rapid rates of spread and greater fire intensities. Figure 1 illustrates the effect of a change in wind direction associated with a cold front passage on fire growth during one of the many fires in Victoria, Australia during the 1983 Ash Wednesday fires. These changes in the direction of fire spread can seriously endanger fire crews working on the flanks when the cold front hits.

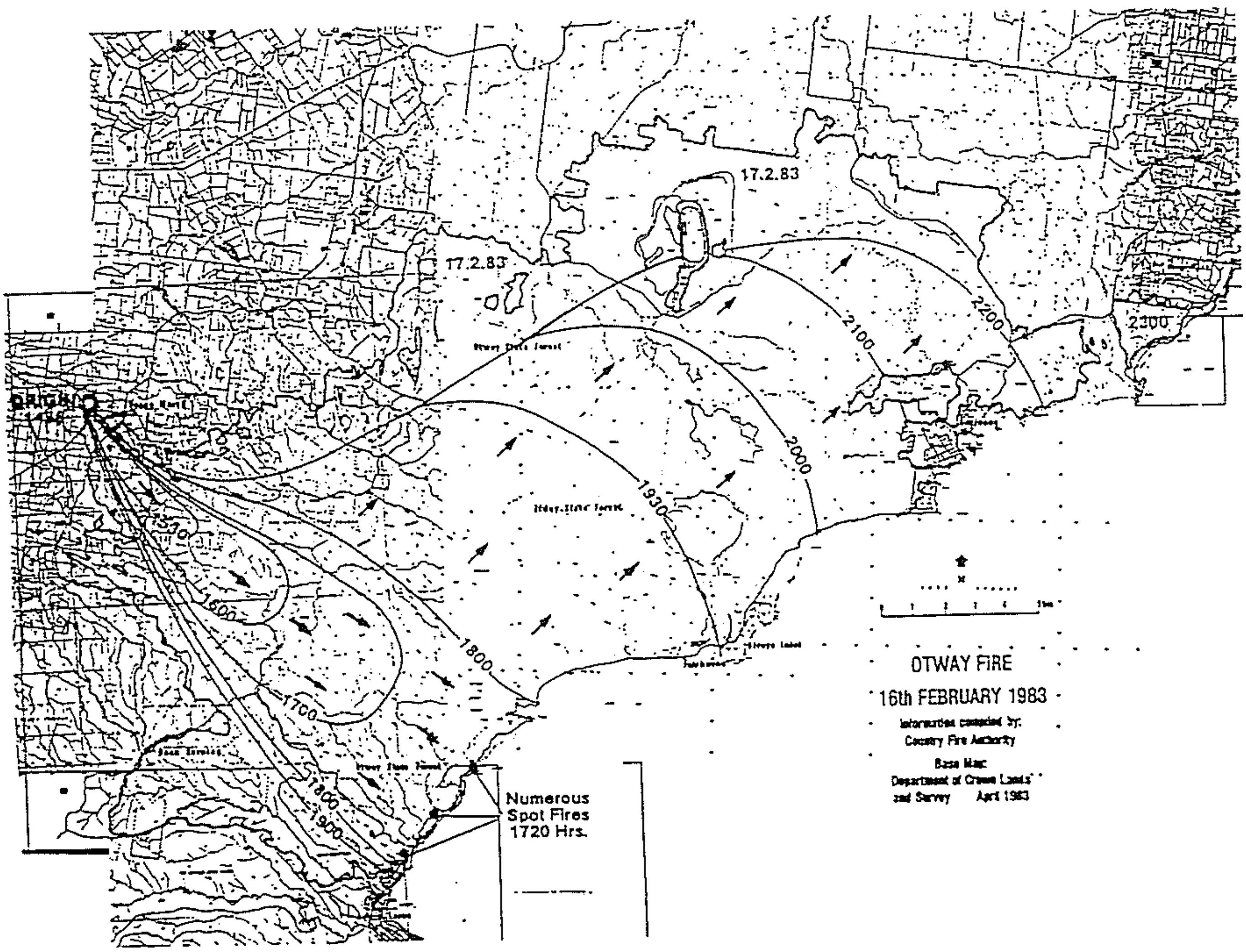

Figure 1. Fire progress map for the Otway Fire in southern Victoria on February 16, 1983 illustrating the effect of a cold front passage on fire spread and area burned (after CFA 1983).

Effect of Slope on Rate of Spread

Slope steepness affects rate of fire spread and, in turn, frontal fire intensity by preheating unburned fuels ahead of the fire. On a slope, the flames are tilted towards uphill fuels (even in the absence of wind), thus enhancing preheating through radiation by reducing the distance between the flame and unburned fuels, and also increasing the chances of convective gases contacting the fuels. In addition, spotting potential is increased by convection currents carrying firebrands upslope. Therefore, fires burn more rapidly and intensely upslope than either downslope or on the level.

The effect of slope on fire rate of spread, and the application of the relationships between ROS and components of the FWI System for various fuel types to preparedness planning, can be illustrated using the Queenstown gondola and the terminus restaurant located at the top of Bob's Peak (Figure 2) as an example. Assuming that a fire ignited at the base of the slope burns uphill through the conifer stand beneath the gondola, how long will the fire take to reach the restaurant at the top of the hill? How long do authorities have to evacuate patrons from the facility?

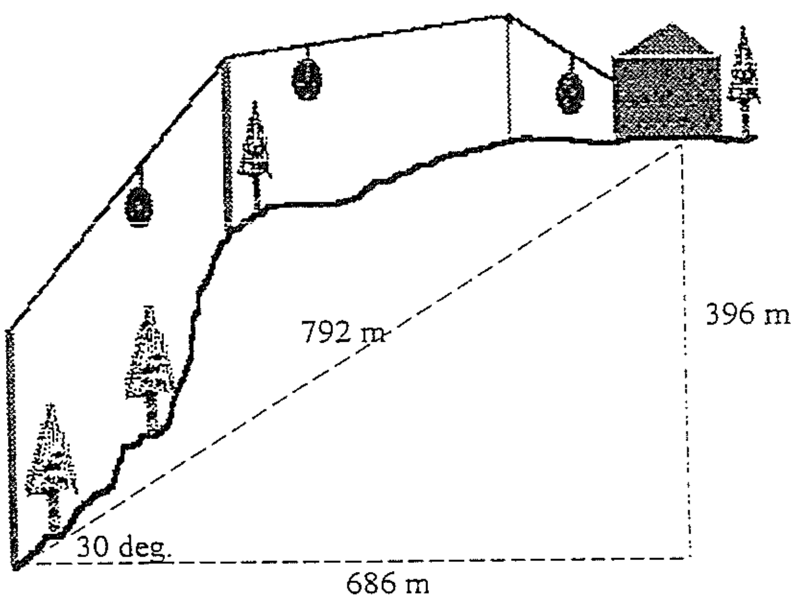

Figure 2. Diagrammatic representation of the Queenstown gondola.

1. Fuel type - if we assume that a fire burning in the conifer stand beneath the gondola can be represented by a fire burning in a mature radiata pine stand, we can use the ISI-ROS relationships from the plantation fuel model (C-6) in the New Zealand Fire Danger Rating System (NZFDRS) to determine the fire's rate of spread (Alexander 1994).

2. Fire danger conditions - assuming some average weather conditions for Queenstown during mid-summer, a typical Fine Fuel Moisture Code (FFMC) value might be 89, and wind speeds (assumed to be blowing directly upslope) about 10-15 km/h; hence, the ISI is around 7 (Anon. 1993). A reasonable BUI value for this time of year would be about 50.

3. Rate of fire spread (unadjusted for slope) - using the C-6 plantation fuel type, an ISI value of 7, and a BUI of 50, the rate of fire spread unadjusted for the effect of slope is 136 m/h (refer to Appendix 1 for a tabular version of the ROS relationship for the C-6 fuel type).

4. Slope angle - from a topographic map, the vertical distance (or "rise") can be determined from the height contours, and the horizontal distance (or "run") calculated by multiplying the measured distance by the appropriate map scale; thus, the slope angle is then calculated using simple trigonometry; i.e., slope (degrees) = *tan* (rise/run). In this case, from Figure 2, the slope angle is *tan* (396/686) = 30°.

5. Effect of slope on rate of fire spread - using the relationship defined in the Canadian Forest Fire Behaviour Prediction (FBP) System (Figure 3), the slope correction factor for a 30° slope is approximately 6; hence, the adjusted rate of spread is 136 m/h × 6 = 816 m/h.

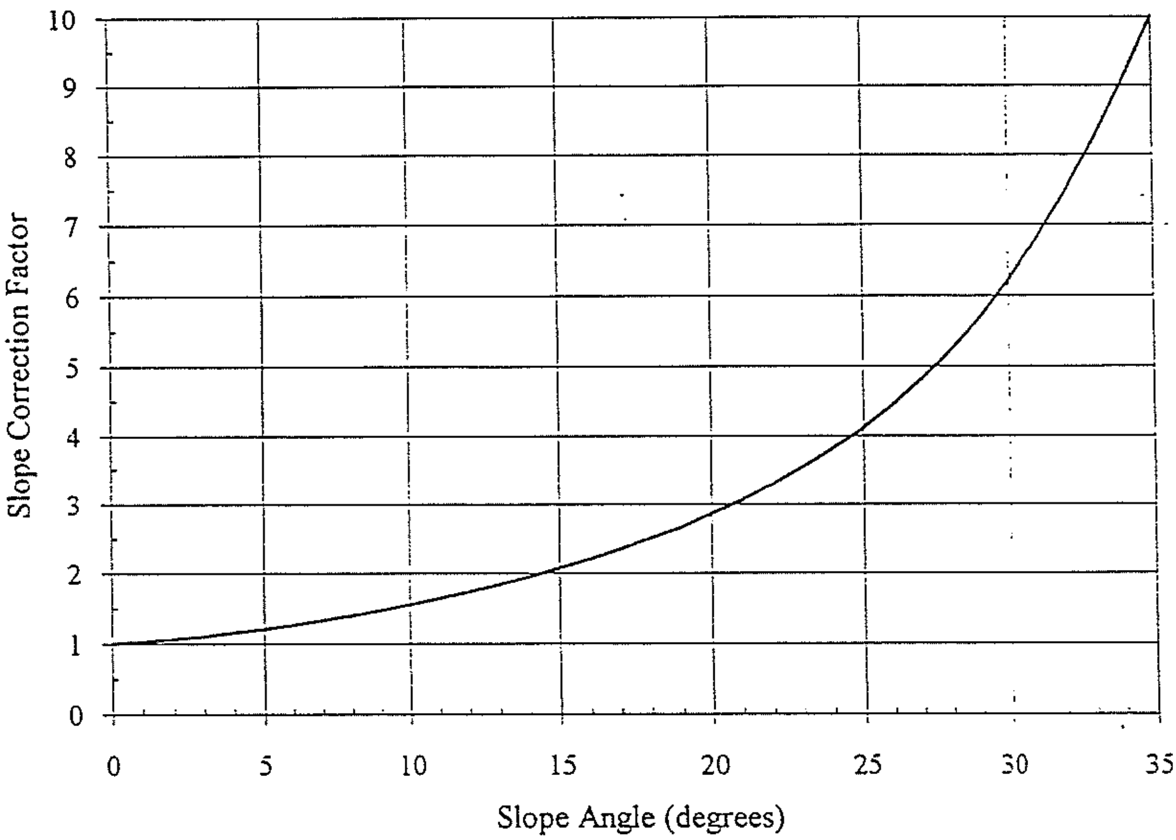

FIGURE 3. The effect of slope steepness on increasing the headfire spread rate as described in the Canadian Forest Fire Behaviour Prediction (FBP) System (after Forestry Canada Fire Danger Group 1992).

6. Forward spread distance - the forward spread or slope distance the fire must travel from the base of the slope to the top of the hill can again be determined by simple trigonometry (see Figure 2), using either: distance = run/[*cos*(angle°)], or distance = $\sqrt{(rise^2 + run^2)}$; in this case, distance = 686/[*cos*(30°)] or $\sqrt{(396^2 + 686^2)}$ = 792 m.

7. Time - how long the fire will take to travel this forward spread distance is then calculated by dividing the distance by the rate of fire spread; i.e., time (hours) = distance/ROS = 792/816 = 0.97 hours or 58 minutes.

Therefore, some 58 minutes are available from the time a fire ignites at the bottom of the slope until it reaches the restaurant at the top. Provided the fire is detected and reported immediately, then authorities basically have one hour to evacuate everyone from the facility.

Note that this example assumes some "average" conditions — the time available under "worst case" fire danger conditions will be much less. For example, with an FFMC of 92 and winds of 50 km/h, the ISI is 70 (Anon. 1993); at a BUI of 120, the rate of spread using the C-6 model is 2000 m/h unadjusted for slope; on a 30° slope, the adjusted ROS = 2000 × 6 = 12 000 m/h; i.e., the time available is only 4 minutes! Both examples are again illustrated using the fire spread calculation form in Appendix 2.

Interim Rate of Spread Tables for New Zealand

Currently, rate of spread relationships for three major fuel types are considered representative of similar New Zealand vegetation types; i.e., mature pine plantations (C-6), logging slash (S-1), and grasslands, both cut/matted (O-1a) and natural/standing (O-1b). However, it is important to realise that these three models can be applied more broadly than just to their direct New Zealand equivalents. For example, with some circumspection and experience, the grassland models can be used to provide an estimate of the rate of fire spread for pasture, grain crops and crop stubble, tussock grasslands, and even possibly to fine, elevated wetlands or other vegetation. The lack of quantified information on fire rate of spread in relation to the components of the FWI System for scrublands is one of the most glaring gaps in our fire knowledge at present, and the New Zealand Forest Research Institute's Fire Research programme is currently working towards addressing this problem through its experimental burning programme.

The Rate of Spread (ROS) tables attached as Appendix 1 to this paper represent the current state of knowledge with respect to fire behaviour in New Zealand fuel types. They are based on the more than 20 years of experimental burning and wildfire documentation by Forestry Canada fire researchers which was recently released in the Canadian Forest Fire Behaviour Prediction (FBP) System (Forestry Canada Fire Danger Group 1992).

Similar experimental burning and wildfire documentation programmes are needed in New Zealand to verify these existing models and to produce fire behaviour guidelines for specific New Zealand fuel types such as manuka/kanuka and gorse scrublands. Experimental burning has been initiated by the Fire Research programme at NZ FRI, and new information from this research is being released as it becomes available through, for example, the *Fire Research Update* newsletter.

Hence the attached tables should be recognised as an **interim** edition only, representing the current state of knowledge at the time of publication; they are a first step in the development of a New Zealand Fire Behaviour Prediction (FBP) System. As more data become available, it is hoped to produce a pocket-sized field guide which contains rate of spread and headfire intensity tables, together with other tools and equations which can be used in fire suppression and preparedness planning.

References Cited

Alexander, M.E. 1994. Proposed revision of fire danger class criteria for forest and rural areas in New Zealand. National Rural Fire Authority, Wellington. Circular 1994/2. 74 pp.

Anon. 1993. Fire Weather Index System Tables for New Zealand. National Rural Fire Authority in association with the New Zealand Forest Research Institute. Wellington, N.Z.

CFA. 1983. The major fires originating 16th Februray, 1983. Country Fire Authority of Victoria, East Kew, Victoria. 39 pp.

Forestry Canada Fire Danger Group. 1992. Development and structure of the Canadian Forest Fire Behavior Prediction System. Forestry Canada, Ottawa. Information Report ST-X-3. 63 pp.

Gates, A. 1987. Fuel state reports 1987-88 fire season. Bushfire Council of New South Wales, Sydney.

Appendix 1:

PLEASE NOTE

The following tables have been generated from equations contained in the following publication:

Forestry Canada Fire Danger Group. 1992. Development and structure of the Canadian Forest Fire Behaviour Prediction System. Forestry Canada, Ottawa, Ontario. Information Report ST-X-3. 63 pp.

The predictions have not yet been validated for the New Zealand fuel types indicated.

$$\text{Head Fire Intensity (kW/m)} = \frac{\text{Available Fuel Load (t/ha)} \times \text{Head Fire Rate of Spread (m/h)}}{2}$$

NOTE: Flat terrain is assumed (i.e., 0 slope)
An available fuel load of 3.5 t/ha is assumed for the grass (O-1) fuel types.

H.G. Pearce & L.G. Fogarty
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Available Fuel Load (t/ha)

	FBP System Fuel Types	
BUI	C-6: Mature Radiata Pine Stand	S-1: Radiata Pine Logging Slash
10	0.4	20.4
20	1.7	35.5
30	4.0	46.7
40	6.9	55.0
50	10.1	61.2
60	13.6	65.9
70	17.0	69.3
80	20.4	72.0
90	23.6	73.9
100	26.5	75.4
110	29.3	76.5
120	31.8	77.3

Head Fire Rate of Spread (m/h)

ISI	FBP System Fuel Type C-6 (Mature Radiata Pine Stand)											
	BUI											
	10	20	30	40	50	60	70	80	90	100	110	120
0.5	0	0	0	0	0	0	0	0	0	0	0	0
1.0	0	1	1	1	1	1	1	1	1	1	1	1
1.5	1	2	2	2	2	3	3	3	3	3	3	3
2.0	2	4	5	5	6	6	6	6	6	6	6	6
2.5	4	7	9	10	10	11	11	11	11	11	12	12
3	7	12	14	16	17	17	18	18	18	19	19	19
4	15	25	31	33	35	37	38	38	39	40	40	40
5	25	44	53	58	62	64	66	67	68	69	70	70
6	39	68	82	90	96	99	102	104	105	107	108	109
7	56	97	117	129	136	141	145	148	150	152	154	155
8	75	130	157	172	182	189	194	198	201	204	206	207
9	95	167	201	220	233	242	248	253	257	261	263	265
10	118	206	248	272	288	299	307	313	318	322	325	328
12	166	290	349	383	405	420	432	440	447	453	458	461
14	216	377	454	499	527	547	562	573	582	589	595	600
16	266	464	559	614	649	673	691	705	716	725	733	739
18	314	548	660	724	766	795	816	833	846	856	865	872
20	359	627	755	829	876	910	934	953	968	980	990	998
25	456	797	960	1054	1114	1157	1188	1212	1231	1246	1259	1269
30	531	927	1117	1226	1296	1345	1381	1409	1431	1449	1464	1476
35	585	1022	1231	1351	1428	1482	1522	1553	1577	1597	1613	1627
40	623	1089	1311	1439	1522	1579	1622	1654	1680	1701	1719	1733
45	650	1135	1367	1500	1586	1647	1691	1725	1752	1774	1792	1807
50	668	1167	1405	1542	1631	1693	1738	1773	1801	1823	1842	1858
55	680	1189	1432	1571	1661	1724	1771	1806	1834	1857	1876	1892
60	689	1203	1449	1590	1682	1745	1792	1828	1857	1880	1899	1915
65	694	1213	1461	1604	1696	1760	1807	1844	1872	1896	1915	1931
70	698	1220	1469	1612	1705	1769	1817	1854	1883	1906	1926	1942

Head Fire Rate of Spread (m/h)

ISI	FBP System Fuel Type S-1 (Radiata Pine Logging Slash)											
	BUI											
	10	20	30	40	50	60	70	80	90	100	110	120
0.5	6	13	17	19	20	22	22	23	23	24	24	24
1.0	16	32	41	47	50	52	54	56	57	58	58	59
1.5	27	54	69	78	84	88	91	93	95	97	98	99
2.0	38	78	100	112	121	127	131	135	137	139	141	143
2.5	51	104	132	149	160	168	174	178	182	185	187	189
3	64	130	166	187	201	211	218	224	228	232	235	237
4	91	186	236	266	286	300	311	319	325	331	335	339
5	119	244	310	349	375	394	408	418	427	433	439	444
6	148	303	385	435	467	490	507	520	531	539	546	552
7	177	364	462	521	560	588	608	624	636	647	655	662
8	207	425	540	609	654	686	710	728	743	755	765	773
9	237	486	618	696	748	785	812	833	850	864	875	885
10	267	547	695	784	842	884	914	938	957	973	985	996
12	326	669	850	958	1029	1080	1118	1147	1170	1189	1204	1217
14	384	788	1001	1129	1213	1273	1317	1351	1379	1401	1419	1435
16	441	904	1149	1296	1392	1461	1512	1551	1582	1608	1629	1647
18	496	1017	1293	1458	1566	1643	1701	1745	1780	1809	1833	1853
20	549	1127	1432	1614	1735	1820	1883	1932	1971	2003	2029	2051
25	673	1382	1756	1980	2128	2232	2310	2370	2418	2457	2489	2516
30	785	1611	2048	2308	2481	2602	2693	2763	2819	2864	2902	2934
35	884	1815	2307	2600	2794	2932	3034	3113	3176	3227	3269	3305
40	972	1995	2536	2859	3072	3223	3335	3422	3491	3547	3594	3633
45	1049	2154	2737	3085	3316	3478	3600	3693	3768	3828	3879	3921
50	1117	2292	2913	3284	3529	3702	3831	3931	4010	4075	4129	4174
55	1176	2413	3067	3458	3716	3898	4034	4139	4222	4290	4347	4395
60	1227	2519	3201	3609	3878	4069	4210	4320	4407	4478	4537	4587
65	1272	2611	3318	3741	4020	4217	4364	4477	4568	4641	4702	4754
70	1311	2691	3419	3855	4142	4346	4497	4614	4707	4783	4846	4899

Head Fire Rate of Spread (m/h)

ISI	FBP System Fuel Type O-1 (Grass)									
	Cut (or Matted-Down) Grass					Natural (Standing) Grass				
	Degree of Curing (%)					**Degree of Curing (%)**				
	60	**70**	**80**	**90**	**100**	**60**	**70**	**80**	**90**	**100**
0.5	7	13	20	26	33	3	6	9	12	15
1.0	17	34	52	69	86	10	20	29	39	49
1.5	30	60	90	120	150	19	38	57	77	96
2.0	45	89	134	178	223	31	62	92	123	154
2.5	60	120	181	241	301	44	89	133	177	222
3	77	154	231	307	384	60	119	179	238	298
4	113	225	338	450	563	94	189	283	377	471
5	151	301	452	602	753	134	268	402	535	669
6	190	381	571	761	952	177	355	532	709	887
7	231	463	694	925	1157	224	448	672	896	1120
8	273	546	819	1092	1366	273	546	819	1092	1366
9	315	631	946	1262	1577	324	649	973	1297	1622
10	358	716	1074	1432	1791	377	754	1132	1509	1886
12	444	887	1331	1775	2219	486	973	1459	1946	2432
14	529	1057	1586	2115	2644	598	1197	1795	2393	2992
16	612	1225	1837	2450	3062	711	1422	2133	2844	3556
18	694	1388	2082	2777	3471	823	1647	2470	3294	4117
20	774	1547	2321	3094	3868	934	1868	2802	3736	4671
25	960	1921	2881	3842	4802	1199	2399	3598	4797	5997
30	1129	2259	3388	4518	5647	1443	2885	4328	5770	7213
35	1280	2560	3840	5120	6400	1661	3322	4983	6644	8304
40	1413	2827	4240	5653	7066	1854	3708	5561	7415	9269
45	1530	3061	4591	6121	7651	2022	4045	6067	8090	10112
50	1633	3265	4898	6530	8163	2169	4337	6506	8675	10843
55	1722	3443	5165	6887	8609	2295	4589	6884	9178	11473
60	1799	3598	5397	7196	8995	2403	4805	7208	9610	12013
65	1866	3732	5598	7464	9331	2495	4990	7484	9979	12474
70	1924	3848	5772	7696	9620	2573	5147	7720	10293	12867

Appendix 2:

FIRE BEHAVIOUR AND FIRE SPREAD PREDICTION CALCULATOR:

Date: 7 February, 1994 Time: 1215 Fire Name: Canterbury Plains
Yesterday's FWI Codes and Indices: Days Since Rain (0.6 mm): 3

FFMC 79 DMC 42 DC 342 ISI 2 BUI 64 FWI 7

	NZST	Current	1 Hour	2 Hour	4 Hour	6 Hour	12 Hour	24 Hour
Actual Time	1200	1215	1315					
Weather								
Wet Bulb Temp (°C)								
Dry Bulb Temp (°C)	27.0	27.5	27.0					
Rel Humidity (%)	51	50	55					
Wind Speed (km/h)	7	10	45					
Wind Direction (°)	NW	NW	SW					
FWI Components								
FFMC	85	85	85					
ISI	3	3	20					
BUI	68	68	68					
FWI	10	10	40					
Fuels								
Fuel Type	O-1b	Grass	Grass					
Fuel Quantity (t/ha)		3.5	3.5					
Degree of Curing (%)		90	90					
Fire Behaviour - Flat Ground								
Head Fire ROS (m/h)		238	3736					
Slope Correction								
Slope (°)	Flat	0	0					
Correction Factor		1	1					
Fire Behaviour - Adjusted for slope								
Head Fire ROS (m/h)		238	3736					
Perimeter Growth (m/h)								
Flame Depth (m)								
Fire Intensity (kW/m)		400	6500					
Spotting Distance (m)								
Fire Suppression Considerations								
Distance Spread (m)								
Total Perimeter (m)								
Warnings			Cold front					

Comments: Caution crews working flanks on potential increase in wind speed and change in directi of fire spread due to cold front passage.

FIRE BEHAVIOUR AND FIRE SPREAD PREDICTION CALCULATOR:

Fire Name: Queenstown Gondola example

Scenario 1 - "average" conditions

	Midday
Actual Time	1200 NZST
Weather	
Wet Bulb Temp (°C)	
Dry Bulb Temp (°C)	22.5
Rel Humidity (%)	45
Wind Speed (km/h)	10-15
Wind Direction (°)	N
FWI Components	
FFMC	89
ISI	7
BUI	50
FWI	17
Fuels	
Fuel Type	C-6 Mature Conifer
Fuel Quantity (t/ha)	10.1
Degree of Curing (%)	N/A
Fire Behaviour - Flat Ground	
Head Fire ROS (m/h)	136
Slope Correction	
Slope (°)	30
Correction Factor	6
Fire Behaviour - Adjusted for slope	
Head Fire ROS (m/h)	816
Perimeter Growth (m/h)	
Flame Depth (m)	
Fire Intensity (kW/m)	4100
Spotting Distance (m)	
Fire Suppression Considerations	
Distance Spread (m)	
Total Perimeter (m)	
Warnings	Extreme

Scenario 2 - "worst case" conditions

	Midday
Actual Time	1200 NZST
Weather	
Wet Bulb Temp (°C)	
Dry Bulb Temp (°C)	33.0
Rel Humidity (%)	38
Wind Speed (km/h)	50
Wind Direction (°)	N
FWI Components	
FFMC	92
ISI	70
BUI	120
FWI	111
Fuels	
Fuel Type	C-6 Mature Conifer
Fuel Quantity (t/ha)	31.8
Degree of Curing (%)	N/A
Fire Behaviour - Flat Ground	
Head Fire ROS (m/h)	2000
Slope Correction	
Slope (°)	30
Correction Factor	6
Fire Behaviour - Adjusted for slope	
Head Fire ROS (m/h)	12 000
Perimeter Growth (m/h)	
Flame Depth (m)	
Fire Intensity (kW/m)	190 000
Spotting Distance (m)	
Fire Suppression Considerations	
Distance Spread (m)	
Total Perimeter (m)	
Warnings	Very Extreme

Comments: Planning scenarios based on "average" and "worst case" weather and fire danger conditions.

FIRE BEHAVIOUR AND FIRE SPREAD PREDICTION CALCULATOR by:

Date: Time: Fire Name:

Yesterday's FWI Codes and Indices: Days Since Rain (0.6 mm):

FFMC DMC DC ISI BUI FWI

	NZST	Current	1 Hour	2 Hour	4 Hour	6 Hour	12 Hour	24 Hour
Actual Time	1200							
Weather								
Wet Bulb Temp (^{O}C)								
Dry Bulb Temp (^{O}C)								
Rel Humidity (%)								
Wind Speed (km/h)								
Wind Direction (^{O})								
FWI Components								
FFMC								
ISI								
BUI								
FWI								
Fuels								
Fuel Type								
Fuel Quantity (t/ha)								
Degree of Curing (%)								
Fire Behaviour - Flat Ground								
Head Fire ROS (m/h)								
Slope Correction								
Slope (^{O})								
Correction Factor								
Fire Behaviour - Adjusted for slope								
Head Fire ROS (m/h)								
Perimeter Growth (m/h)								
Flame Depth (m)								
Fire Intensity (kW/m)								
Spotting Distance (m)								
Fire Suppression Considerations								
Distance Spread (m)								
Total Perimeter (m)								
Warnings								

Comments: