FOREST AND RURAL FIRE RESEARCH

Fire Technology Transfer Note

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Firebombing effectiveness - *interim* recommended foam consistencies and aerial attack guidelines

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Introduction

The properties and uses of suppressants and retardants were reviewed as background to the discussion of factors that influence firebombing effectiveness in *Fire Technology Transfer Note* (FTTN) 11. The major points of the review were (from NWGC 1992, NWGC 1995, Alexander *et al* 1989):

- wet to fluid foams will penetrate forest or scrub canopies, as well as dense understoreys;
- dry foam will adhere to scrub or forest canopies;
- as the density of the canopy and/or understorey increases, multiple drops may be required to ensure penetration;
- as the time until ground support arrives increases, the type of foam needs to be drier; and
- if ground crews are unable to reach foam drops before re-ignition occurs, then multiple foam drops or long term retardants (or a mix of retardant and foam) should be used.

Using similar information and knowledge gained from experience at many wildfires, some Canadian fire researchers and managers have produced guidelines on "recommended foam consistencies for aerial attack on wildfires in fuel types recognised in the Canadian Forest Fire Behaviour Prediction (FPB) System" (Alexander *et al.* 1989). The Canadian guidelines are outlined in Table 1.

These guidelines suggest that in order to contain fire spread, foam type needs to be varied with "characteristics of the overstorey tree canopy (open or closed), thickness of the forest floor layer (shallow or deep), and whether or not ground support will be used following the application" (Alexander *et al.* 1989). These guidelines apply only to the initial knockdown of actively spreading fires with intensities up to 2000 kW/m.

Currently, there is insufficient information and expertise to develop similar guidelines with the same level of confidence for New Zealand. However, the combination of: (i) the Canadian guidelines; (ii) information on the properties of water, foam and retardant; and (iii) an assessment of the structural characteristics of some forest and rural vegetation types, can be used to develop some *interim* guidelines for use by New Zealand fire managers (Appendix 1). The aim of this Technology Transfer Note is to present such guidelines, as well as to review their basis, discuss the points that need to be considered during their application, and define a process for their operational testing and improvement.

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Te mana ahi ma ngā o te motu

Table 1. Recommended foam consistencies for aerial attack on wildfires in fuel types recognised in the Canadian Forest Fire Behaviour Prediction (FPB) System (from Alexander *et al.* 1989).

Tree Canopy	**Ground support (within 30 minutes)**			**No ground support**	
	Forest floor			Forest floor	
	Deep	Shallow		Deep	Shallow
Open	Foam type: WET FBP System Fuel Types[#]: C-1, C-7, S-1, O-1	Foam type: FLUID FBP System Fuel Types: C-2, S-2, S-3		Foam type: FLUID FBP System Fuel Types: C-1, C-7, S-1, O-1	Foam type: DRY FBP System Fuel Types: C-2, S-2, S-3
Closed	Foam type: FLUID FBP System Fuel Types: C-4, C-5, C-6, D-1	Foam type: WET followed by FLUID* FBP System Fuel Types: C-3, M-1, M-2, M-3, M-4		Foam type: WET followed by DRY-optional* FBP System Fuel Types: C-4, C-5, C-6, D-1	Foam type: WET followed by DRY* FBP System Fuel Types: C-3, M-1, M-2, M-3, M-4

[#] Codes refer to different fuel types from the Canadian Forest Fire Behaviour Prediction (FBP) System. The fuel types relevant to New Zealand are C-6 Conifer Plantation, S-1 Jack or Lodgepole pine slash, and O-1 Grass (see Alexander 1994 for details).

* Indicates that two loads are required.

Interim recommended foam consistencies and aerial attack guidelines.

Basis

Interim recommended foam consistencies and aerial attack guidelines for knockdown of wildfires in New Zealand vegetation types are shown in Appendix 1. Derivation of the guides follows the approach of the Canadian ones, where vegetation types are classified according to their structural characteristics. In doing this, the following assumptions were made:

1. Pasture and low open tussock grasslands are interchangeable with Canadian O-1 pasture fuel types.
2. *Pinus radiata* plantation forests that have reached canopy closure are similar to the Canadian C-6 Conifer Plantation fuel type. Recently thinned plantations have an open canopy.
3. Light logging slash is similar to the Canadian Jack or Lodgepole pine slash fuel type (S-1). It occurs when pulp grades are utilised. Heavy slash will result from sawlog-only harvesting operations.
4. The effect of canopy cover on the interception of aerial drops in tall scrublands is similar to the closed forests types represented in the original guides.
5. Scrub less than 1.5 m in height, or more continuous tussock grass will have similar characteristics to open forests with a deep understorey.

Of these assumptions, numbers 4 and 5 (the ones referring to scrublands) have the least basis and warrant greatest attention during use, testing and refinement of the guide. The New Zealand guide also differs from the original in the following ways:

- it reduces the time until ground support arrives;
- it includes the use of retardant when fires are likely to re-ignite before ground support arrives;
- it highlights the need to monitor drop effectiveness and to adjust strategies and tactics.

The time until ground support arrives was reduced because aerial drops at two recent wildfires spreading in logging slash[1], and gorse under an open coniferous forest canopy[2], were observed to contain

[1] Observations were made by the authors at the Mohaka Forest Fire (19/11/96), which burnt more than 100 ha. The fire burnt mostly logging slash and a small area of mature Douglas-fir (*Pseudotsuga menziesii*) forest. Midday weather and FWI conditions on the day of these observations (20/11/96) were 31.5 km/h wind speed, FFMC 92.6, ISI 30, BUI 60, and FWI 50. Drops were applied to fires spreading in logging slash where flame heights occasionally reached 2 m, but were usually lower than 1 m. The foam type was mostly wet, and drops were effective for less than five minutes.

[2] Observations were made by firefighters at the recent Harakeke Forest Fire (23/10/97), which burnt several hundred hectares of stocked plantation forest. Weather and FWI conditions at midday were 16 km/h wind speed, FFMC 85.6, ISI 5.1, BUI 23, and FWI 8.8. The wind speed and ISI increased to a mximum of 33 and 12.1 respectively during the afternoon. Flame heights of back and flank fires burning in 1m to 2 m gorse extended 1 m to 2 m above the gorse. Flames were knocked-down for less than two minutes by wet foam from aerial drops.

fire spread for less than five minutes, whereas the Canadian guides indicate that foam drops can contain fire spread for at least 30 minutes. Other guides which suggest that water may only contain fire spread for less than five minutes, and that the impact of foam lasts no more than five to ten minutes (NRE 1996), confer more with observations of drop effectiveness made at the 1996 Mohaka and 1997 Harakeke forest fires. Differences in the length of time before ground support is required is probably due to the use of larger aircraft that deliver more water in Canada compared with the use of low volume, low drainage rate delivery systems in New Zealand, and to the presence of dense gorse fuels at the 1997 Harakeke Forest Fire.

The inclusion of retardant reflects the experience at many fires, where a combination of steep terrain, dense scrub and/or insufficient ground resources has made it difficult for ground crews to keep up with air attack operations. The need to monitor and adjust air attack strategies and tactics is explicitly stated because this is necessary to improve the standards of aerial attack operations.

Application

Attempting to knock down fires that are burning too vigorously for effective suppression (i.e., when fire behaviour exceeds the fire break breaching threshold) is one of the most common causes of failure during firebombing operations. The interim guides are recommended for use up to fireline intensities of 2000 kW/m. As a general rule of thumb, this level of intensity is likely to be exceeded when flame heights are greater than 2.5 m (Alexander *et al.* 1989). Firebombing operations working beyond this threshold should be monitored closely to ensure that drops are still being effective.

The re-ignition of fireline that has been knocked-down by firebombing indicates that air attack operations are working beyond the capabilities of ground crews. Options for overcoming this problem include adjusting tactics to ensure that crews and aircraft are working together, deploying more ground support, or using long term fire retardants.

While the interim guides suggest the most appropriate type of foam (i.e., wet, fluid, dry) for New Zealand fuel types, they provide no guidance on how to achieve different consistencies, or the required depth of water-based firebreak needed to hold a fire. The anecdotal evidence from wildfires, and information from drop trials (see FTTN 11) suggests that insufficient volumes of water-based firebreak may have caused aerial suppression failures during some recent forest fires. Therefore, development of application guidelines will require some trial and error. It is preferable that this is not done at wildfires, and the aerial drop trial procedure detailed in FTTN 12 could be used by fire managers to determine how to generate different types of foam.

Of the drop trials that we have conducted to date, even the drop with highest mix-ratio (3%), fastest drop speed (74 km/hr) and greatest height (20 m) only generated a wet to wet/fluid foam. Therefore increased drop heights and/or speeds are necessary to generate the drier foam types recommended for use as second drops in stands with closed canopies and/or deep surface fuels.

Research into the application of retardants provides insight into the best way to produce dry foam that penetrates dense canopies or deep surface fuels. When released from a fixed-wing aircraft, retardant is flung toward the ground at speeds of up to 200 km/hr (Howard 1980). If given sufficient time before a drop reaches the surface, it will break up and slow to the speed of free fall (approximately 33 km/hr), thus losing its ability to penetrate through a canopy (Howard 1980). Even foam drops are likely to respond in a similar fashion, so increasing drop speed may be the best method of achieving penetration with dry foam.

From the review of the properties of foam (FTTN 11), it is possible to suggest that foam drops are best placed ahead of the fire, allowing the foam to coat and penetrate the fuel-bed before the fire reaches the firebreak. This should not be so far ahead that the foam breaks down and begins to drain more freely (i.e., within 1 to 2 minutes of the drop) before the fire reaches it. In contrast, the guidelines by Alexander *et al.* (1989) suggest that drops should be placed on the flaming zone. While this approach will minimise loss through drainage, radiant and convective energy from the fire will cause some of the drop to evaporate and disperse before the foam reaches the surface fuels. In scrub fuels, placing the drop directly on the flames will also reduce the influence of canopy interception and drainage.

When firebombing in scrub fuels, delivering drops from over the burnt out area, with the bucket angled over the flame is the method of application used in some areas of New Zealand. This allows the drop to be placed on the burning fuel with little loss from interception (Wallace *pers. comm.*[3]). By attacking the back of the flame, loss through evaporation and dissipation may also be reduced, but when compared with dropping on or ahead of the fire, there is a higher chance that some of the drop will fall in the burnt-out area where it will not be effective.

We have insufficient information to recommend confidently where foam or water drops are best placed during knockdown. But as a starting point, fire managers should follow the current New Zealand and Canadian practices of placing foam drops on the burning zone. Retardant should be dropped in unburnt fuels ahead of the fire.

In the short term, improved standards of firebombing will only be achieved if strategies and tactics are adjusted to suit fuel, weather and fire danger conditions at each wildfire. The aim should be to use the minimum amount of additive needed to hold the fire and to ensure that each load is positioned to have maximum effect. The deployment of an Air Attack Boss, as suggested by Peter Smart in 1993 (see FTTN 2), would improve aircraft operations at wildfires by ensuring that tactics are adjusted to suit conditions. This will also provide information to test and review the interim recommendations for New Zealand fuel/vegetation types.

Testing and improvement

Ideally, the interim guides presented here should have been tested before release, but as no funding is available to support this research, this was not possible. The guidelines are only a starting point. By monitoring the effectiveness of the firebombing operations using the guidelines, fire managers can help gather some of the information needed to improve their own knowledge as well as the guidelines. To assist this process, guidelines and procedures for assessment of firebreak effectiveness (Appendix 2) have been developed.

Summary and Conclusion

Some *interim* guidelines, for foam consistencies and aerial attack, have been proposed. The guides are an adaptation of those used in Canada, which are based on the assumption that decisions about the most appropriate foam types should consider the factors of canopy cover, fuel depth, the length of time until follow-up by ground crews, and the chances of re-ignition. Information about when to use retardant instead of suppressant has also been included to provide another option when re-ignition is likely.

While the interim guidelines require further testing and refinement, they should provide a useful starting point for air attack decision making. Information from further research, as well as feedback from operational testing, is necessary to produce comprehensive aerial attack guidelines.

Acknowledgments

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[3] Gavin Wallace, Controller, Wainuiomata Bushfire Force.

Appendix 1. *Interim* recommended foam consistencies and aerial attack guidelines for knockdown of wildfires in New Zealand fuel/vegetation types (adapted from Alexander *et al.* 1989)[1].

Tree or Scrub	**Ground support within 5 to 10 minutes**[2]		**Ground support within 10-20 minutes**	
	Understorey		Understorey	
	Shallow	Deep	Shallow	Deep
Open canopy	Foam type: WET[3] Example fuel types: Light logging slash (S-1)[4], pasture (O-1) and low open tussock grasslands, recently thinned coniferous forest (C-6) with litter understorey.	Foam type: FLUID Example fuel types: Heavy logging slash or slash with scrub understorey, scrub or tussock less than 1.5 m, and recently thinned coniferous forest with fern, sedge or scrub understorey.	Foam type: FLUID Example fuel types: Light logging slash (S-1), pasture (O-1) and low open tussock grasslands, recently thinned coniferous forest (C-6) with litter understorey.	Foam type: DRY or WET followed by DRY* Example fuel types: Heavy logging slash or slash with scrub understorey, scrub or tussock less than 1.5 m, and recently thinned coniferous forest with fern, sedge or scrub understorey.
Closed canopy	Foam type: FLUID Example fuel types: Coniferous forest (C-6) or tall manuka/kanuka with litter understorey.	Foam type: WET followed by FLUID* Example fuel types: Coniferous forest and tall scrub/tusscock fuels (> 1.5 m) with fern, sedge or other scrub understorey, "old man" gorse.	Foam type: WET followed by DRY* - optional Example fuel types: Coniferous forest (C-6) or tall manuka/kanuka with litter understorey.	Foam type: WET followed by DRY* Example fuel types: Coniferous forest and tall scrub fuels (> 1.5 m) with fern, sedge or other scrub understorey, "old man" gorse.

[1] These *interim* recommendations are adapted from Alexander *et al.* (1989) and a review of additive properties (NWGC 1992, 1995). They apply only to the initial knockdown of actively spreading fires with intensities up to 2000 kW/m (i.e., flame heights are less than 2.5 m). If drops are ineffective, the drops should be directed toward less intensely burning sections of the fire (i.e., target areas with lower flame heights).

[2] The impact of drops should be closely monitored and, if drops are failing to hold the fire before ground support arrives, then the presecriptions for "Ground support within 10 to 20 minutes" should be used. If drops continue to re-ignite before ground support arrives, aircraft should be directed more closely to ground resources, or long term retardants should be used. When no ground-based suppression is likely to occur within 20 minutes of the drop, then long term retardants should be considered for use, particularly during the initial attack stage of fire suppression.

[3] Suggested starting foam/suppressant mix ratios are:

- Wet: 0.3 - 0.4%
- Fluid: 0.5-0.6%
- Dry: 0.8 - 1.0%

Drop effectiveness should be monitored, and the minimum mix ratio used where possible. In instances where wet foam is effective and ground crews are able to reach the fire within five minutes or before re-ignition occurs, water or wet-water (i.e., water and wetting agent) should be tried.

[4] Codes refer to different fuel types from the Canadian Fire Behaviour Prediction (FBP) System. The fuel types relevant to New Zealand are C-6 Conifer Plantation, S-1 Jack or Lodgepole pine slash and O-1 Grass.

* Indicates that two loads *may be* required. When light helicopters and low drainage rate buckets are being used, there may be insufficient volumes of foam to penetrate dense fuels. In these instances, additional drops *may be* required, or other aircraft and delivery systems should be used.

Note:

- Water and foam should be dropped on or just ahead of the flaming zone. The accuracy of drops must be monitored and adjusted to ensure that they are not being placed in the burnt area.
- Long-term retardant should be placed ahead of the fire.
- These guidelines have a low level of confidence. During firebombing operations, drops should be monitored so that their location (on and around the fire) and foam consistency is adjusted to better suit conditions. Feedback on the performance of the recommendations should be directed to Fire Research staff at the New Zealand Forest Research Institute, Rotorua, or to your local NRFA Manager, Rural Fire.

Appendix 2. Firebombing effectiveness form

Time	Drop number[1]	Fuel Type	Fuel height (m)	Fuel density[2] (L, M, H)	Location[3] (H,F,B)	Flame height	Fire type[4] (S - C)	Slope (deg)	Means of delivery[5] (H, FW, GC)	Agent[6] (W, F, R)	Mix ratio	Aircraft		Foam type (Wet, Fluid, Dry)	Effectiveness at drop[7] (S, R, N)	Elapsed time until:	
												Height (m)	Speed (km/h)			Crews arrive	Fire reignites

1. Record whether it is a single or multiple drop on a given length of fireline (e.g., 1 of 1 for single drop, 1 of 2 for double etc.)
2. Use (**L**) for open fuels that are easy to walk through, (M) for situations where fuel density impedes progress and, (**H**) when fuel is virtually impenetrable.
3. Use (**H**) for head fire, (**F**) for flank fire and **(B**) for back fire.
4. Use **S** for surface fire, **T** for torching, **I** for intermittent crown fire and **C** for crown fire
5. Helicopter **(H)**, fixed wing **(FW)** or ground crew **(GC)**. If possible identify the aircraft.
6. Use **W** for water, **F** for foam and **R** for retardent.
7. Use **S** for when the fire spread is suppressed, **R** when intensity is significantly reduced and **N** when there is no significant effect.

Time	Temperature (°C)		RH (%)	Wind	
	Wet bulb	Dry bulb		Speed (km/h)	Direction
12 noon					