PROJECT FUSE AERIAL SUPPRESSION EXPERIMENTS

NGARKAT CONSERVATION PARK, SOUTH AUSTRALIA, MARCH 2008

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Cover photo: Gel drop (G2) in plot AS1, 3 March 2008, Ian Tanner (Department for Environment and Heritage)

PROGRAM A

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EXECUTIVE SUMMARY

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Three experimental fires were conducted to demonstrate the effectiveness of different fire suppression chemicals delivered by aircraft in March 2008. The fires were conducted in mallee heath fuels in Ngarkat Conservation Park, South Australia, at a site being used for an existing fuel and fire dynamics research project. Each fire was started from a long ignition line and allowed to fully develop before being attacked by suppression. The only suppression applied to these fires came from two single engine air tankers (Airtractor AT-802F) dropping a single suppressant type in each experiment. A water enhancing gel was directly applied to the fire edge in one experiment, while a foam suppressant was applied in another. The third experimental plot involved a fire burning into a pre-laid retardant line.

The different suppression chemicals used in the experiments could not be directly compared. This was because the time taken for fire to burn through most of the drops could not be determined as they were breached by spotting or burnt around and because of the range of conditions experienced for the different drops.

The aerial suppression experiments presented here allowed for the development and testing of aerial suppression assessment methodologies and have produced data that can be used to develop training material. This data highlights the importance of drop placement with regard to fire behaviour and location. Footage captured using a hand held airborne infrared camera in an aerial platform demonstrated some important aerial suppression tactical issues, such as drop coverage, drop accuracy and drop placement. Fire burning through one of the retardant drops highlighted the importance of adequate ground coverage levels for stopping fire propagation.

ACKNOWLEDGEMENTS

The experiments were supported by the South Australian Department for Environment and Heritage and the South Australian Country Fire Service. The Victorian Department of Sustainability and Environment supplied and mixed retardant. The authors would like to thank the members of the research team, suppression crews, incident management team, and aviation services, without which the experiments could not have been conducted. This research was financially supported by the Bushfire Cooperative Research Centre and CSIRO. The in-kind support from the fire agencies is gratefully appreciated.

1) INTRODUCTION

Aerial suppression field experiments were conducted at a site west of the private in-holding (Kirra Station) along the Bordertown-Pinnaroo Road (35° 45 S, 140° 51 E) within the Ngarkat Conservation Park, South Australia (Figure 1.1) on 3, 4, and 5 March 2008. The main aim was to demonstrate the effectiveness of different fire suppression chemicals delivered by aircraft on fire behaviour.

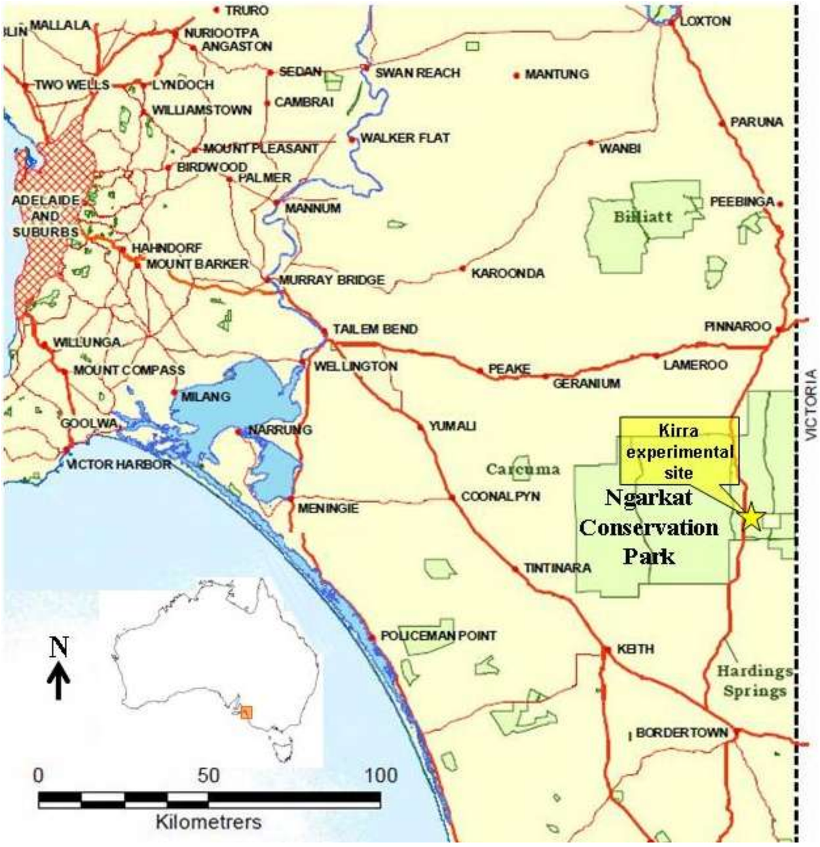


FIGURE 1.1. Location of Ngarkat Conservation Park and Kirra experimental site.

The aerial suppression experiments resulted from an offer from the South Australian Country Fire Service to use aircraft on an existing project (Project FuSE) involving experimental fires in mallee-heath vegetation that was being run by CSIRO and the Bushfire CRC. Project FuSE conducted experimental fires to develop fire behaviour models for a prescribed burning guide for mallee and heath fuel types for the South Australian Department of Environment and Heritage, who manage Ngarkat Conservation Park and other conservation areas with similar vegetation. Details of Project FuSE are given in Cruz *et al.* (2010). Three large plots (>40 ha) at the Kirra experimental site were made available for combined fire behaviour and aerial suppression experiments. Combining the aerial suppression experiments into an existing fire experiment program allowed them to be prepared and conducted in a shorter time period and with fewer dedicated resources than would have been required if they were conducted alone.

1.1) SUPPRESSION CHEMICALS

Suppression chemical additives fit into three classes: foam surfactants, water enhancers and long term retardants, as defined by the US Forest Service (USDA Forest Service 2010). One product from each of the three classes was trialled in the experiments. Foam surfactants and water enhancers are called suppressants as they are primarily designed for direct attack and are only effective while wet. Foams aid the wetting of fuels by lowering the surface tension of the water and assisting saturation. Water enhancing gels contain substances that slow evaporation and increase adherence to fuels. Long term retardants are designed to be applied ahead of the fire as they remain effective after the water they originally contained has evaporated. They work by inhibiting flaming combustion. Class A foam (for fires burning solid fuels) and long term retardants are commonly dropped on bushfires from aircraft in Australia.

The effectiveness of suppression chemicals depends on the coverage level (depth) required on the critical fuel. The more intense the fire, the greater the depth is required (Loane and Gould 1986). Coverage levels vary across drop footprints with the heaviest concentrations located in the centre of the drop and areas of lighter coverage found around the edges. The dimensions of aerial suppression drops vary with a number of factors including the volume, viscosity, aircraft speed and height, delivery system and wind speed and direction. Most of the work investigating effective drop coverage levels has focused on retardants. A range of coverage levels have been recommended for different vegetation (George 1985). These vary from 0.5 mm (0.5 l m^{-2}) for grasslands to 2.5 mm for thick shrubland vegetation. Coverage levels recommended for vegetation similar to the mallee-heath burnt in these experiments would be around 1.5 mm.

The effectiveness of fire retardant formulations has been studied using analytical laboratory tests and flame spread tests in the laboratory and field. Àgueda *et al.* (2008) provide a comprehensive review of these studies. Analytical tests have focused on understanding the pyrolytic behaviour of retardant coated fuel samples. Laboratory based fire spread tests have been used to evaluate the behaviour of controlled fire fronts burning into sections of fuel coated in retardant. The general aim of laboratory experiments has been to make comparisons between different retardant formulations based on measurements of fire spread, rate of weight loss and fuel consumption. Fewer retardant fire spread experiments have been conducted at a field scale. Field evaluation of manually applied retardant solutions on experimental fires in shrublands (e.g. Pastor *et al.* 2006a, Vega *et al.* 2007) have found retardant applications to reduce fire spread rates and severity. Large scale experiments using aerially dropped retardant on high intensity fires in eucalypt forests were used to determine effectiveness thresholds based on fire intensity (Loane and Gould 1986). Loane and Gould (1986) reported upper fire intensity limits of 3000 kW m^{-1} and 2000 kW m^{-1} for retardant drops in stringy-bark forests with and without ground crew support respectively. Beyond these limits drops were breached by spotting.

Research into the effectiveness of suppressants have mainly been through ground applications on experimental fires (e.g. Dando *et al.*1988), small scale laboratory tests of foams on stationary fires (e.g. Schlobohm and Rochna 1988), or investigations of their adhesion to fuels (e.g. Stechishen and Murray 1990). Some field experiments involving the aerial application of foam suppressants on experimental fires have been conducted by Plucinski *et al.* (2006), though this work was limited in scope due to the fuel, fire and weather conditions. Gel suppressants have been in operational use in recent years and their effectiveness has received very little attention in the way of field testing to date. One study conducted in Queensland (Taylor *et al.* 2005) trialled a gel product on fires in pine litter and understorey grass fuels in direct and indirect applications and found it to be potentially useful, though stated that further evaluation work is required.

Evaluations of suppressant drops during wildfire operations are difficult to undertake due to the chaotic nature of wildfire events. Reports of such evaluations have yielded limited results (George 1990, Plucinski *et al.* 2007) as it is virtually impossible to obtain an adequate data set suitable for a detailed analysis from operational fires. The planned nature of aerial suppression field experiments allow for detailed measurements of suppression drop characteristics as well as related information on fire behaviour, vegetation and weather variables affecting drop effectiveness. The aerial suppression experiments presented here allowed for the collection of information on drop effectiveness with a level of detail that cannot be reasonably attained from wildfire operations. The basic experimental procedure was first developed during field experiments investigating helicopter drops on stubble fires (Plucinski *et al.* 2006), however the current experiments are the first to involve comparisons of all three suppression chemical types on fires representative of wildfire conditions.

2) METHODS

2.1) EXPERIMENTAL SITE

The Kirra experimental site had 27 6.25 ha fire behaviour plots prepared with 10 m wide fire breaks for the fire dynamics projects. Three large plots were prepared specifically for the aerial suppression experiments. These were labelled AS1 – AS3, and were 52, 49, and 93 ha respectively. A buffer strip on the southern side of Kirra road was burnt in the spring of 2009. The layout of the site is given in Figure 2.1.

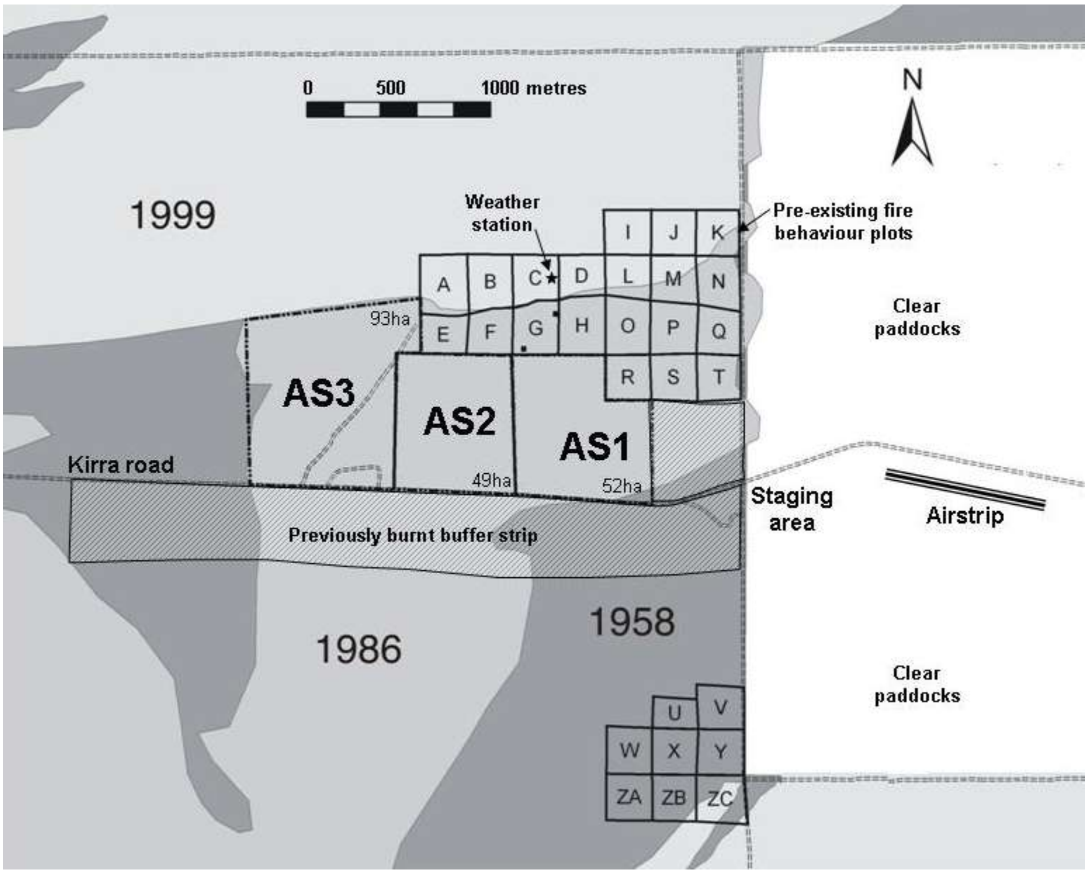


FIGURE 2.1. Layout of Kirra experimental site showing the location of the aerial suppression (AS) plots. The shading indicates the year of the last fire.

The Kirra experimental site has a characteristic dune and swale system comprising large flat areas with relatively small dunes intermixed and an approximate elevation of 130 m above sea level. Soils in Ngarkat are aeolian sands of varying depth, overlying deep alluvial soils of the old River Murray delta (Specht & Rayson 1957).

The aerial suppression plots were covered by a 22-year old mallee fuel complex (last burnt in 1986) characterized as open woodland with *Eucalyptus calycogona*, *E. diversifolia*, *E. incrassata* and *E. leptophylla* as dominant overstorey species and an understorey of *Astroloma conostephioides*, *Adenanthos terminalis*, *Babingtonia behrii*, *Calytrix involucrata*, *C. tetragona*, *Daviesia benthamii*, *Dillwynia hispida*, *Leptospermum coriaceum*, *L. myrsinoides* and *Phyllota pleurandroides*. A ground layer of mixed grasses and sedges was also present.

The fuel complex on the aerial suppression plots had an open mallee overstorey component with cover < 20% and height between 2.2 and 2.8 m (Table 2.1). A shrub component approximately 1 m tall comprising a large variability of sclerophyll shrubs species had a cover between 33 and 37%. A lower layer (0.1 to 0.3 m) of grasses, ephemeral herbs, low sedges, low shrubs and dead suspended material comprised the near-surface layer and occupied about 20% of the area. Overall fuel cover averaged 81%. Other significant component of the fuel complex were the long strands of bark suspended along the stems that constituted ladder fuels that facilitate the transition from a surface to a crown fire and were observed to be the main source of firebrand material that caused short range spot fires in this fuel type. Overall fuel loads, ranged between 3.8 and 5.5 t/ha, and were comparable to other semi-arid mallee-heath environments (see. Specht 1966, McCaw 1997).

TABLE 2.1. Summary of main fuel complex characteristics present in the aerial suppression plots (Cruz *et al*. 2010)

	AS1	AS2	AS3
Mallee cover (%)	6	13	18
Overall fuel cover (%)	81	82	81
Fuel load (t/ha)	5.5	3.8	4.4
Near-surface PCS	1.8	1.2	1.4
Near-surface FHS	2.9	3	3
Near-surface height (m)	0.26	0.22	0.22
Elevated PCS	1.7	1.7	1.9
Elevated FHS	1.7	2.1	2.1
Elevated height (m)	0.7	0.9	0.9
Mallee height (m)	2.8	2.2	2.3

2.2) SUPPRESSION CHEMICALS AND DELIVERY

The suppression chemical additives used in these experiments were the water enhancing gel Thermogel 200L[1], the long term retardant Phoschek D75R[1] and the Class A foam Phoschek WD881[1]. Each of these products was applied on separate experimental fires. All three additives are have been tested by the US Forest Service and have been approved for inclusion on their list of qualified products for use in wildfire suppression (USDA Forest Service 2010). Australian fire agencies have a policy of only using fire suppression chemicals on this list. The retardant and foam used here are regularly used in Australia. The gel is a relatively new addition to the qualified products list and has been trialled operationally in some Australian states during recent fire seasons.

The suppressants were delivered by two single engine air tankers contracted to the National Aerial Firefighting Centre for the fire season and operated by South Australian Country Fire Service. The air tankers were Airtractor AT-802F[1]. models, with longitudinal drop doors fitted. These are the most commonly used model of fixed wing fire suppression aircraft used in Australia. Drop patterns, flow rates

[1] The use of trade names is for information and convenience to the reader. Such use does not constitute an official endorsement or approval by the Bushfire CRC or CSIRO for any products or services to exclusion of any other that may be suitable.

and coverage lengths for this type of aircraft have been characterised by Solaraz and Jordan (2000) and examples relevant to the settings used in these experiments are given in Figure 2.2.

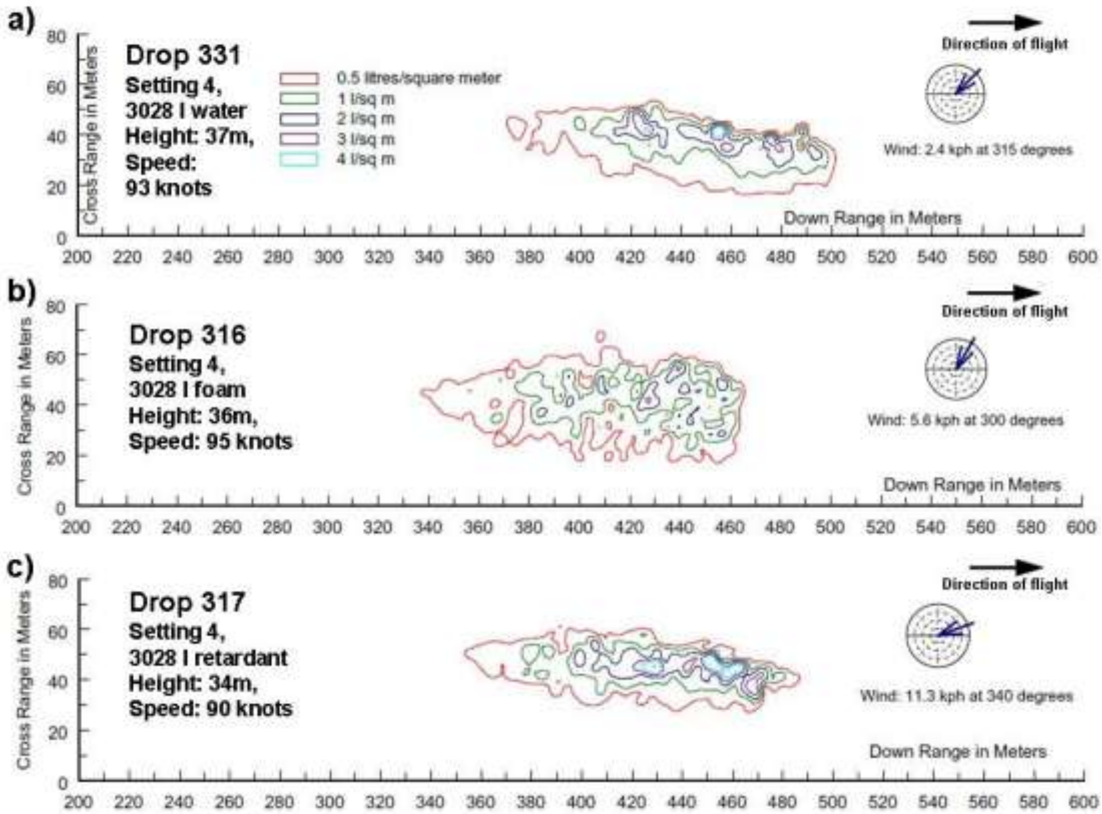


FIGURE 2.2. Drop patterns for AT-802F with the coverage level setting 4 (4 gal/ 100 ft^2, 1.63 L/m^2) from the US Forest Service Technology and Development Center (see: Solarz and Jordan (2000)). a) water, b) foam, c) retardant.

An airstrip was built 1 km east of plot AS1 on the Kirra property (Figure 2.1). All aircraft used in the experiments operated from this strip. Temporary airbase facilities were set up on the eastern end of the airstrip. The airbase included water storages, mixing facilities for the foam, gel and retardant, supplies of suppressants and fuel, and a communications base. The short distance between the plots and airbase allowed rapid turn-around times between drops during the experiments. Suppressants were mixed according to the manufacturer's specifications prior to being loaded on the aircraft. A refractometer was used to calibrate the concentration of the retardant (refractive index ~12.8). Foam was prepared at a concentration of 0.3%. A blue vegetable dye was added to both the gel and foam suppressants so that they could be more easily identified by ground observers. All drops made were full loads. Gel and foam suppressants were applied directly on the active fire edge, while retardant was laid out in lines prior to ignition. Drops were directed by an Air Attack Supervisor (AAS) positioned in a separate aircraft circling the fires. The AAS and pilots had been instructed to deliver drops to head fires in preference to other parts of the fire in order to impact on the most intense flames. The retardant drops were laid in an "L" shape, with one of the lines parallel to and downwind of the ignition line, so that it would be hit directly by the head fire. The other line was impacted by a flank fire. The retardant drops were made more than half an hour prior to ignition in plot AS3. The aerial suppression drops were the only form of suppression applied during the experiments.

2.3) EXPERIMENTAL FIRES

2.3.1) Weather measurements

An automatic weather station (AWS) was placed within an area of low heath in plot C (Figure 2.1) for the lead up and duration of the experiments. The AWS logged air temperature, relative humidity, wind speed and direction (measured at 10-m in the open) which were logged as averages over 10 minute intervals.

For each experimental fire, detailed wind measurements were conducted at two locations in the vicinity of the burn. A 10-m tower with two 2-D sonic wind sensors (WindSonic 1, Gill Instruments Ltd; located at 2 and 10-m heights) was placed 50 to 75 m along the side of the burn plot (Figure 2.3). A smaller tower with one 2-D sonic wind sensor at 2-m was placed 50 to 75 m in the windward side of the ignition line centre. Both towers were located in areas of fuel structure representative of the experimental fire. The 10-m tower with two anemometers provided a rough characterization of the vertical wind profile close to the vegetation.

Long-term fuel dryness measures were collected at Bureau of Meteorology weather stations located in Keith (57 km SW of experimental site) and Lameroo (58 km NW) (Figure 1.1). The Keetch Byram Drought Index (Keetch and Byram 1968) was around 150 and the drought factor (McArthur 1967) was 10 for the time of the aerial suppression experiments.

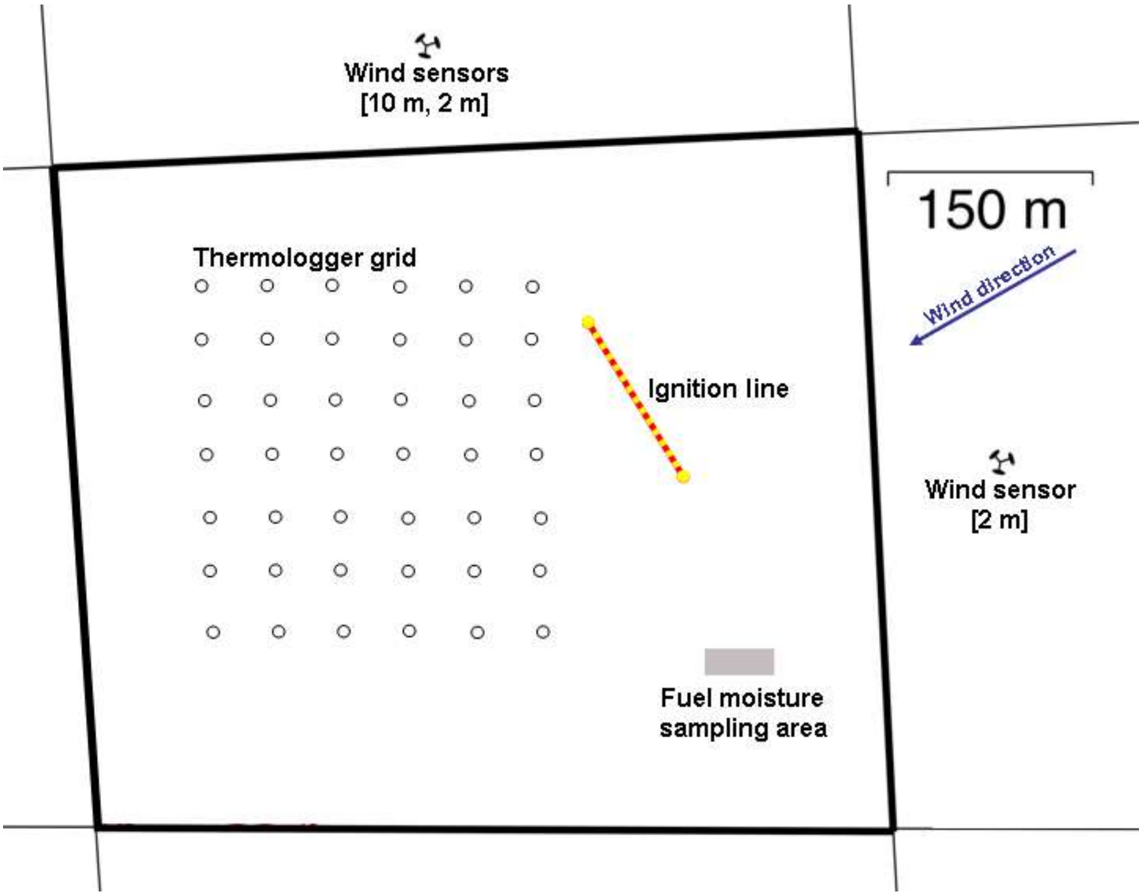


FIGURE 2.3. Experimental fire layout depicting pre-fire fuel moisture sampling area, wind sensor locations, ignition line and thermologger grid. Red lines depict fire growth isochrones extracted from infrared imagery (Pastor *et al*. In Press).

2.3.2) Fuel moisture

The moisture content of dead fine fuels was measured by destructive sampling. Two types of samples were collected. Surface litter was collected from the top 10 mm of the litter layer. At locations where the litter layer was less than 10 mm deep, the entire layer was sampled. Suspended dead fuel samples were taken from between 0.1 and 1.0 m height, depending on the vertical distribution of fuel at each sampling location. Fifteen minutes prior to each experimental fire five samples each (10 – 20 g) of litter and suspended fuel dead material of diameter < 6 mm were placed in a sealed tin. Dead fuel moisture samples were also collected after the completion of experimental fires. Samples were weighed, oven dried at 100°C for 24 hours, then reweighed to determine the fuel moisture content.

2.3.3) Ignition

Most of the experimental fires were ignited using lines with lengths between 220 and 250 m. Ignition lines were lit by two people with handheld drip torches. The ignition crew started in the centre of pre-marked ignition lines and moved to the ends at a fixed pace, ensuring the development of a solid flame front, less than 2 minutes. The ignition lines were oriented so that they were perpendicular to the wind direction, determined within the hour before lighting. Fire reached its pseudo-steady state rate of spread within the first 50-75 metres (Cruz *et al*. 2010).

2.3.4) Fire behaviour measurement

Fire behaviour was monitored using instrumentation installed prior to the burn and by direct observation from members of the researcher team. Thermologgers were buried or placed within insulated containers through a grid pattern within each burn plot. The grid sampling of fire spread characteristics yielded information on its variability. A thermologger consisted of a small datalogger (HOBO® U12, Onset, Massachusetts, USA) with a 200 mm long, 1.5-mm diameter, type K metal-sheathed thermocouple (Pyrosales, NSW, Australia). Thermocouple size and characteristics was a compromise between response time and durability. Loggers sample temperatures at 1 Hz (1-sec interval). A grid spacing of 50 m was used. (Figure 2.3) The thermologger registered the time the flame front arrived at each grid point. The time of fire arrival, assumed to coincide with a temperature of 320 C (Albini 1985) was used to determine fire-spread pattern and rate of fire spread through a triangulation method (Simard *et al*. 1984, McCaw 1997). Flame time-temperature profile, flame residence time and an estimate of flame depth were derived for each grid point. The grid was set up with compass and hip-chain, and grid points geo-referenced with a global positioning system (GPS, Trimble GeoXT).

Two groups made fire behaviour observations from close proximity to the flame front throughout each experiment. Fire behaviour quantities recorded at 2-minutes intervals were: fuel layers supporting fire spread, flame geometry (depth, height and angle), spotting activity (distance, quantity and density), overstorey canopy consumption and in-draughts.

2.3.5) Aerial suppression procedure

Each of the aerial suppression experimental fires had to be conducted on a separate day due to the logistical constraints required to conduct large controlled fire experiments and the limitation of working in the early afternoon to capture the peak burning conditions.

The air tankers were loaded at the start of each of the suppressant experiments and were airborne soon after ignition. The first suppressant drops were not made until they were called in by the research team leader who was on the ground. Subsequent drops were made after the aircraft had landed, refilled and taken off again. The drops ceased once the head fire had reached the end of the plot and drops had affected the majority of the remaining flanks.

Gel and foam drops did not start until the fires had progressed 150-250 metres and passed through the fire behaviour instruments. This method maximised the amount of perimeter boundary available for examination (fire perimeter 350-700 m). The fire in the retardant plot was ignited 250 metres upwind of the parallel retardant line.

Two fires were ignited for the foam drops in plot AS2 as there was a track that diagonally traversed this plot. The east and west halves of the plot AS2 are referred to as plot AS2E and AS2W respectively. The fire in plot AS2E was ignited from this track. The second fire was ignited from the western edge of plot AS2W after the fire in AS2E had been surrounded by drops on most of its perimeter.

After the completion of the suppression drops the remaining unburned parts of the plots were burnt out by the ground suppression crews. This was done as soon as possible so that the fires could be promptly extinguished and there would be minimal risk of escape.

2.3.6) Drop assessment

The effects of the drops on fire behaviour were determined using ground and aerial observation. Ground evaluation of drops occurred both during and after the experimental fire. Safe access to drops was limited during the fires. Ground observation teams walked in front of the head fire along each side of the plot fire break and made observations of suppressant drops and their effects on fire behaviour when possible. The ground observers recorded changes in fire behaviour and took photographs and video of the fire activity. Research teams were not permitted in the plot during burn-out operations, which limited the monitoring of long term drop effects on fire behaviour.

Each of the experimental fires was filmed from a helicopter with a standard video camera (visual spectrum) and an infrared camera. The cameras were positioned on top of a fixed tripod in the helicopter and were hand operated allowing focussing control. The infrared imagery was captured using an AGEMA Thermovision 570-Pro (FSI-FLIR Systems). This camera operated within the 7.5-13 μm range and was equipped with a frame grabber to control and store sequences of IR images (240 x 320 pixels) onto a laptop computer at a rate of 5 frames per second. Every IR image is a 240 x 320 cell temperature matrix which is represented by a colour map gradient. Further details of the infrared data capture method are available in Pastor *et al*. (2006b) and Perez *et al*. (In Press).

The helicopter was positioned so that the majority of the plot was in view for the duration of each fire, allowing for fire behaviour, drops and the fire behaviour around drops to be recorded and monitored. Hot reference control points were used to facilitate the geo-rectification of oblique infrared imagery. These were fires burning mallee roots and other coarse woody material contained within large drums and located on the corners and strategic perimeter points of the plots. A full explanation of the geo-rectification methodology is given in Perez *et al*. (In Press).

The dimensions and exact positions of all drops were recorded during post-fire assessments conducted in the week following the fires. Post-fire assessments also involved estimating drop length and width, fuel consumption, burn heights and scorch heights measured upwind, within and down wind of drop areas.

The outcomes of all drops were assessed from the infrared footage. Drops were determined to have either held the fire or been breached by fire at the end of each experiment, defined by the ignition of the plot burn out. There are three potential mechanisms that can cause drops to be breached; spotting, burn around, or burn through. A drop can be breached by more than one of these. All drops were studied to determine if they were breached and how long they held before each breaching mechanism overcame them. A hold time was determined for each drop, defined as the difference in time between a drop being applied and breached.

2.3.7) Drop timing and tracking data

The exact timing of drops and other key events were determined from digital photographs and video synchronised with the time displayed on a GPS. Notes, footage, and photographs taken during the experiments were analysed to determine the exact placement of drops with respect to the fire and then evaluate the effectiveness of each suppressant drop. The airborne visual and infrared imagery were used to review the effects of drops during the experiments. This was usually the only means of monitoring drops and fire progression.

Tracking data was downloaded from the GPS installed in the aircraft after each fire when available. The flight characteristics, such as altitude, speed and direction, could be estimated for each drop by cross referencing the calculated drop times with the tracking data.

3) RESULTS

The aerial suppression experiments were conducted over three consecutive days (3-5 March 2008). The weather conditions varied during this period with different wind directions each day (northerly, southerly and westerly for 3, 4, 5, March respectively). A summary of the weather observations at the time of ignition obtained from the automatic weather station located in plot C (Figure 2.1) is given in Table 3.1.

TABLE 3.1. Weather observations at time of ignition for each experiment (weather station location given in Figure 2.1)

Ignition date and time	Plot	Temperature (˚C)	Relative humidity (%)	Wind speed (km/h)	Wind gust (km/h)	Forest Fire Danger Index
3/03/2008 14:35	AS1	35.4	8	15.3	24.7	44.2
4/03/2008 15:50	AS3	31.6	24	16.5	29.1	23.1
5/03/2008 15:00	AS2E	36.8	13	10.9	25.5	35.0
5/03/2008 16:10	AS2W	35.9	13	9.8	19.2	32.9

The fire behaviour observations made during the experiments are summarised in Table 3.2. More detailed descriptions of fire behaviour for the three plots are given in sections 3.1, 3.2, and 3.3. Fire behaviour instruments were not located in the plot AS2W. This fire experienced the most inconsistent wind direction and as a result had the most variable fire behaviour.

TABLE 3.2. Summary of fire behaviour observations made during each experiment (Cruz *et al.* 2010)

Plot	Run length (m)	Rate of fire spread (m/min)		Fireline intensity (kW/m)	Flame height (m)	
		Mean	Max		Mean	Max
AS1	300	40.0	169	6931	2.8	8-9
AS2E	300	46.6	100	6506	3.8	8-10
AS3	200	42.6	250	5013	3.8	6-8

The data associated with each of the drops made during the experiments is summarised in Tables 3.3 and 3.4. These tables contain information regarding the type, location, timing, flight characteristics, footprint dimensions, turn-around time, placement tactics and effect. Each drop has been given a reference code based on the suppression chemical (G= gel, R= long term retardant, F= foam) and a number referring to order of the drop in the experiment.

TABLE 3.3. Drop type, location, timing, flight characteristics, and footprint dimensions.

Drop Ref	Plot	Ignition date and time	Suppressant	Drop grid reference [GDA 94 Zone 54H]		Drop time (CST)	Aircraft call sign	Time fire impacted drop zone	Drop height (m above ground)	Aircraft speed (km/h)	Aircraft heading direction at time of drop (°)	Drop footprint	
				Easting	Northing							length (m)	Width (m)
G1	AS1	3 March 14:35	Gel	486177	6042442	14:42:18	B580	14:42:18	28	230	50	80	7
G2	AS1	3 March 14:35	Gel	486126	6042402	14:44:28	B583	14:44:28	-	-	90	80	15
G3	AS1	3 March 14:35	Gel	486290	6042349	14:50:27	B580	14:50:27	11	216	22	55	15
G4	AS1	3 March 14:35	Gel	486359	6042163	14:55:50	B583	14:55:50	-	-	90	-	-
G5	AS1	3 March 14:35	Gel	486444	6042167	15:03:54	B580	15:03:54	-	228	359	-	-
G6	AS1	3 March 14:35	Gel	486405	6042136	15:07:39	B583	15:07:39	-	-	270	-	-
G7	AS1	3 March 14:35	Gel	486453	6042449	15:13:26	B580	15:13:26	52	215	322	-	15
G8	AS1	3 March 14:35	Gel	485950	6042207	15:17:44	B583	15:17:44	-	-	0	80	15
G9	AS1	3 March 14:35	Gel	486423	6042505	15:20:25	B580	15:20:25	44	194	282	-	7
R1	AS3	4 March 15:50	Retardant	484765	6042902	14:54:21	B581	16:15:13	-	193	86	70	12
R2	AS3	4 March 15:50	Retardant	484877	6042856	14:56:56	B584	15:57:42	-	-	90	95	18
R3	AS3	4 March 15:50	Retardant	484966	6042861	15:04:25	B581	15:58:29	-	180	90	95	16
R4	AS3	4 March 15:50	Retardant	484794	6042911	15:10:20	B584	16:05:28	-	-	180	73	20
R5	AS3	4 March 15:50	Retardant	484796	6042856	15:18:42	B581	16:00:54	-	153	177	73	20
R6	AS3	4 March 15:50	Retardant	484801	6042773	15:20:33	B584	15:55:21	-	-	180	73	18
F1	AS2-E	5 March 15:00	Foam	485630	6042729	15:11:10	B583	15:11:10	37	207	157	-	-
F2	AS2-E	5 March 15:00	Foam	485670	6042687	15:12:32	B580	15:12:32	30	198	155	-	-
F3	AS2-E	5 March 15:00	Foam	485730	6042497	15:19:36	B583	15:19:36	25	213	261	-	-
F4	AS2-E	5 March 15:00	Foam	485371	6042703	15:23:16	B580	15:23:16	23	212	41	90	7
F5	AS2-E	5 March 15:00	Foam	485675	6042493	15:29:10	B583	15:29:10	25	187	262	-	-
F6	AS2-E	5 March 15:00	Foam	485431	6042764	15:33:11	B580	15:33:11	12	203	47	90	7
F7	AS2-E	5 March 15:00	Foam	485626	6042492	15:40:09	B583	15:40:09	33	194	274	-	-
F8	AS2-W	5 March 16:10	Foam	485185	6042341	16:13:14	B583	16:13:14	23	199	138	-	-
F9	AS2-W	5 March 16:10	Foam	485626	6042492	16:13:44	B580	16:13:44	31	202	166	-	-
F10	AS2-W	5 March 16:10	Foam	485136	6042488	16:21:14	B580	16:21:14	32	182	75	-	-
F11	AS2-W	5 March 16:10	Foam	485158	6042481	16:28:16	B583	16:28:16	16	199	168	-	-
F12	AS2-W	5 March 16:10	Foam	485168	6042267	16:31:03	B580	16:31:03	42	187	20	85	5

- indicates where data was not available or values could not be clearly determined.

TABLE 3.4. Drop tactical, turn-around time and effectiveness information

Drop Ref	Tactical placement	Percent length direct	Anchored	Linked to other drops	Fire type	Turnaround time (mm:ss) # air tankers		Breaching mechanism & timing			hold time (mm:ss)	Drop outcome
						1	2	Burnt through	Spotted over (mm:ss)	burnt around (mm:ss)		
G1	Direct	>50%	No	no	head	-		no	1:44	7:14	1:44	spotted over
G2	Direct	75%	No	no	head	8:09	2:10	no	6:23	11:42	6:23	spotted over
G3	Direct	>50%	No	no	flank	13:27	5:59	no	no	18:07	1:18	burnt around
G4	Direct	>50%	No	no	flank[+]	9:32	5:23	no	no	4:49	2:14	burnt around
G5	Direct	>50%	Yes	G6 (at 90°)	flank[+]	6:59	8:04	no	no	6:51	4:51	burnt around
G6	Direct		No	G5 (at 90°)	flank[+]	-	3:45	no		6:40	4:00	burnt around
G7	Direct	>50%	No	G9	flank	10:43	5:47	no		-	>30 min	held until burn-out
G8	Direct	>50%	Yes	no	flank	9:55	4:18	no		-	>20 min	held until burn-out
G9	Direct	>50%	No	G7	flank	-	2:41	no		-	>24 min	held until burn-out
R1	Indirect	0%	No	R4 (at 90°)	head	9:49		no	no	-	<30 min	burnt around
R2	Indirect	0%	No	R3, lightly to R5	head		2:35	yes	no	6:37	6:37	burnt through
R3	Indirect	0%	No	R23	head	10:04	7:29	no	no	-	3:19	burnt around
R4	Indirect	0%	No	R1 (at 90°), R5	flank	14:17	5:55	no	no	10:03	7:28	burnt around
R5	Indirect	0%	No	R6	flank		8:21	no	no	11:52	9:31	burnt around
R6	Indirect	0%	No	R5	flank		1:52	no	no	14:31	11:44	burnt around
F1	Direct	~50%	No	no	flank	10:05		eventually[*]	pre drop	6:27	0:00	burnt around
F2	Direct	>75%	No	no	head	-	1:22	eventually[*]		2:30	1:17	burnt around
F3	Direct	>75%	Yes	F5	flank	-	7:04	no	no	50:35	<50 min	burnt around
F4	Direct	>75%	No	F6	flank	8:26	3:40	eventually[*]	no	47:06	<45 min	burnt around
F5	Direct	>75%	No	F3 & F7	flank	9:34	5:54	no	no	41:01	<40 min	burnt around
F6	Direct	>75%	No	F4	flank	11:00	4:01	eventually[*]	no	37:12	>35 min	burnt around
F7	Direct	>75%	No	F5	flank	-	6:59	no	no	30:02	30 min	burnt around
F8	Direct	>75%	No	F9	head	-		<20min	no	no	<20 min	burnt through
F9	Direct	>75%	No	F8	head	-	0:30	no	no	no	>20 min	held until burn-out
F10	Direct	>75%	Yes	F11	head		7:30	no	no	no	>13 min	held until burn-out
F11	Direct	>75%	No	F10	flank	10:13	7:02	no	no	no	>10 min	held until burn-out
F12	Direct	>75%	No	F8	back	-	2:47	no	no	no	>5 min	held until burn-out

[*] These drops were initially burnt around and had been burnt through sometime afterwards
[+] The type of fire for these drops is assumed as they were not clearly visible on the infrared imagery.
- indicates where data was not available or values could not be clearly determined.

The aircraft tracking data collected from GPS units mounted in the bombing aircraft was of limited use. GPS tracks were not available for all aircraft used. The data that was collected had a logging rate that was too coarse (3-8 seconds) to determine the exact flying conditions at the times of most drops. Flight paths were very dynamic before and after each drop with rapid changes in altitude, direction and speed. The flight characteristics given in Table 3.3 are best estimates determined from GPS track files. Estimates of drop height were verified against photographs taken of each drop.

3.1) GEL SUPPRESSANT EXPERIMENT (PLOT AS1, 3 MARCH 2008)

The fire in plot AS1 was ignited by a 220 m east-west ignition line at 14:35. Light and variable winds initially lead to vertical flames and very little propagation. At 14:40 the fire was propagating with very high intensity, with rolling flames 6 m tall (flashing to 9 metres; flame angle 50 degrees) involving the mallee clumps. Multiple spot fires were observed to occur 15-20 metres ahead of the flame front, but typically were influenced by the main fire in-drafts and spread back towards the main front.

The first gel drops from the two air tankers were made on the head fire at 14:42 and 14:44 respectively. A spot fire ahead of these drops grew and spread in the south eastern side of the plot reaching the boundary at around 14:56. The first two drops had the effect of splitting the fire into two fronts which coalesced approximately 17 minutes later (15:02) when the western run reached the end of the plot. The majority of the subsequent drops occurred on different parts of the eastern flank. The second last drop was made on the western flank and anchored to Kirra road. All 9 gel drops were placed directly on the edge of the fire. The locations of the drops within the plot are shown in Figure 3.1.

The majority of gel drops in plot AS1 were breached by spotting or were burnt around (Table 3.4). The three last drops (G7-G9) held sections of flank fire until the plot was burnt out at 15:30. The exact holding times of these drops could not be determined because the plot was burnt out to reduce the risk of escaped fires.

A brief ground observation of the second drop (G2) found that a section of fire edge between the head and front part of the western flank had reduced head fire flames from 2 m high down to 0.2 m, with flaming combustion completely extinguished in sections of the drop zone with high gel coverage levels. This drop could not be monitored because of the surrounding fire behaviour and was burnt around soon after. Figure 3.2 illustrates the pre and post drop fire behaviour of this drop.

A close ground inspection was made of drop G8 which occurred on the southern extremity of the western flank. This drop extinguished flames that were up to 1 metre tall along the majority of its length (80 metres, Figure 3.3). Sections of litter fuels with small residual flames (0.1 m) remained under some clumps of mallee until the plot was burnt out. The final outcome of these residual flaming sections in the absence of the burn-out ignition could not be estimated with any confidence.

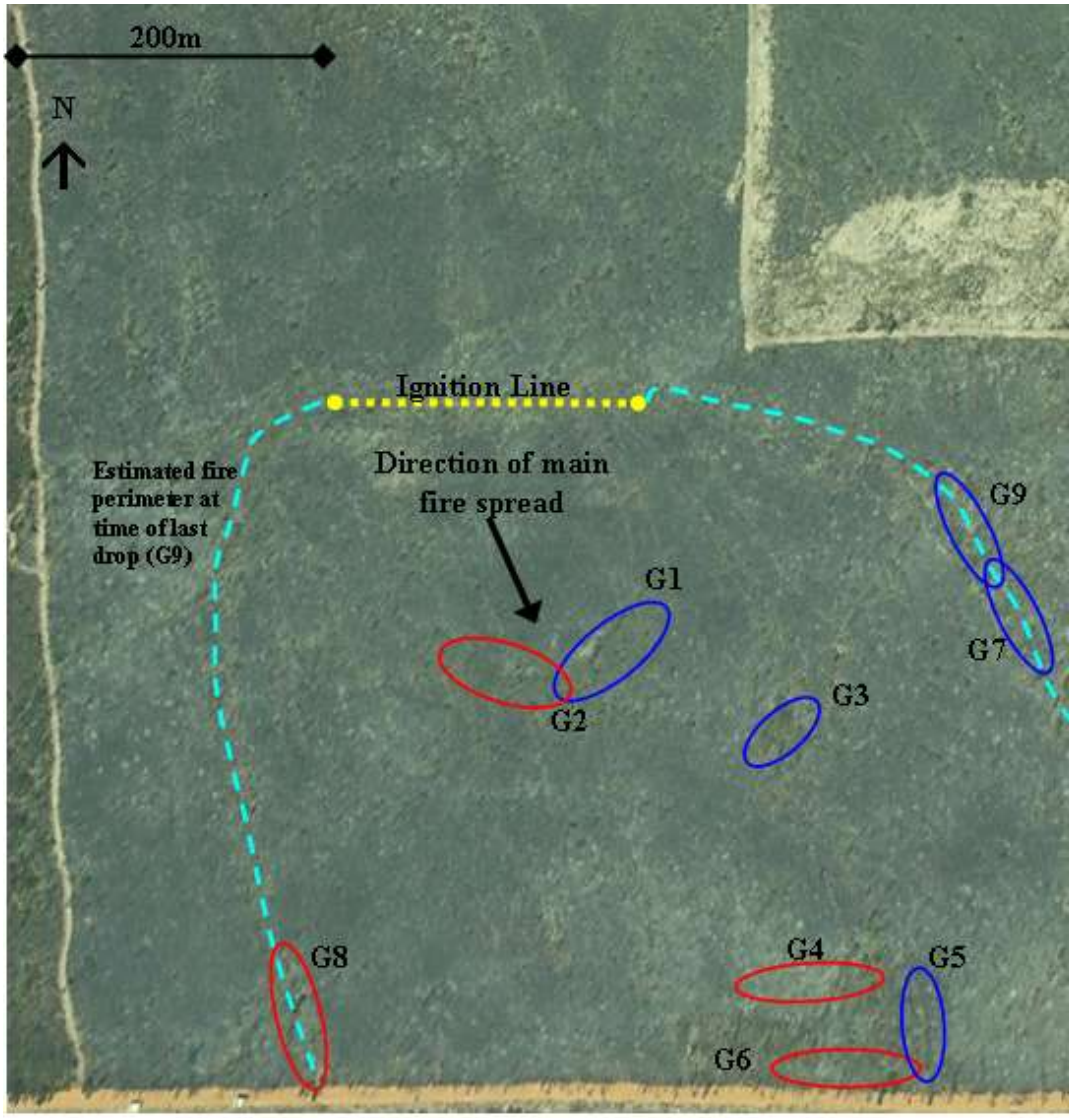


FIGURE 3.1. Plot AS1 – Gel suppression experiment superimposed over a post-fire geo-rectified aerial photograph. The blue and red ovals indicate approximate locations and orientations of drops from Bombers 580 and 583 respectively.

FIGURE 3.2. (a) Western head/flank corner of plot AS1 fire at 14:43:50 with flames up to 2 m. (b) Fire behaviour in drop G2 footprint at 14:47:44, 3 minutes after the gel suppressant drop, with residual flames around 0.2 m.

FIGURE 3.3. (a) Thick coverage of drop G8 with apparent full extinction of flank fire 7 minutes after drop. (b) Small residual flames (<0.1 m) in a section of lighter coverage 10 minutes after drop. (c) Aerial view of the drop being made on the western flank.

3.2) RETARDANT EXPERIMENT (PLOT AS3, 4 MARCH 2008)

Retardant drops in plot AS3 were made between 56 and 30 minutes prior to ignition (14:54 to 15:20). The drops were laid in an "L" shape, with three drops on each side of a right angle. Some of the drops were only lightly linked with others. The final pattern resulted in drop R1 not being adequately attached to the other east-west drops of R2 and R5 leaving a section of light coverage between R2 and R5 (see Figure 3.4).

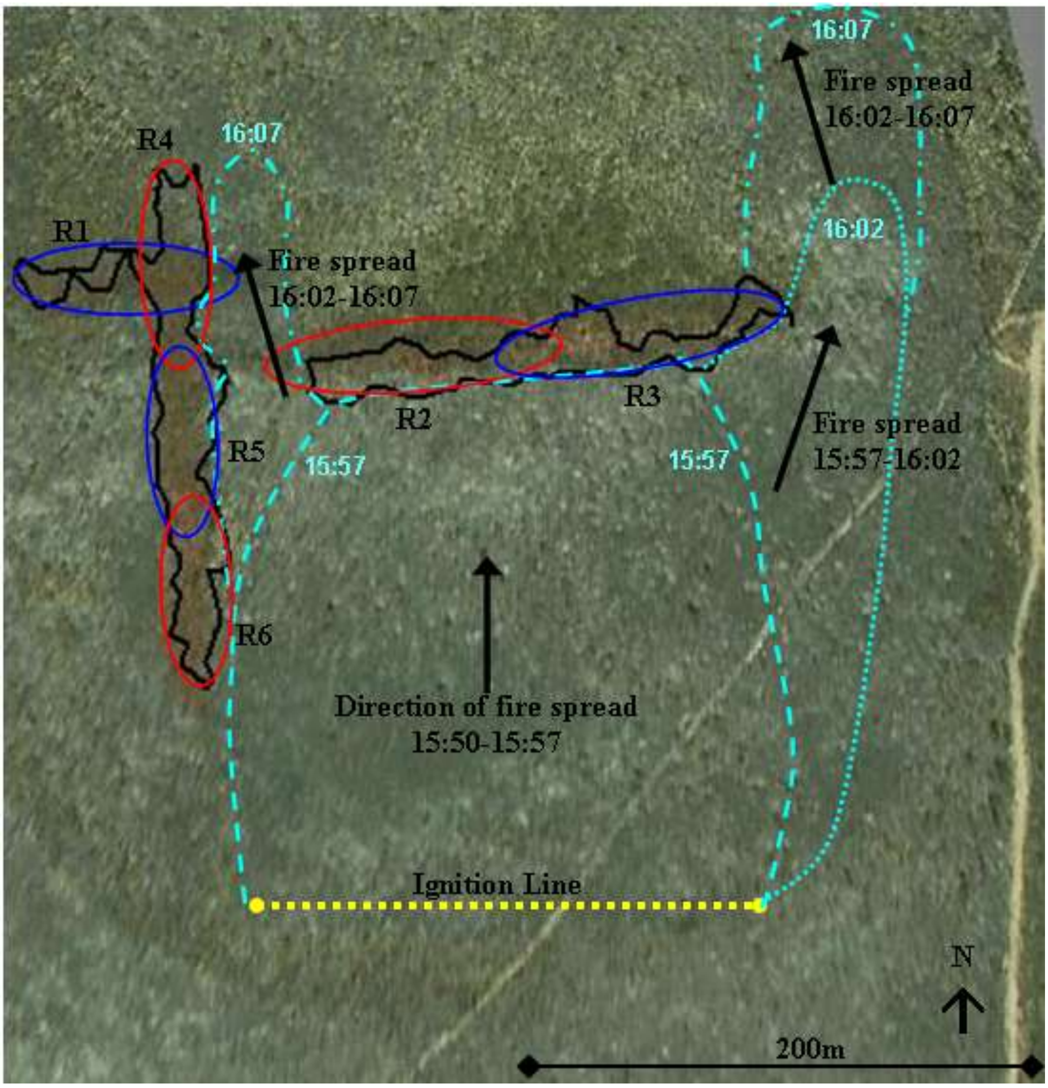


FIGURE 3.4. Retardant drop locations in plot AS3 superimposed over a post-fire geo-rectified aerial photograph. The blue and red ovals indicate approximate locations and orientations of drops from bombers 581 and 584 respectively. The black line shows the border of burnt and unburnt fuel around the retardant drops determined during post-fire drop evaluation. The green section north of drops R2 and R3 was burnt lightly as a backing fire after the fire had burnt around the drops.

The fire plot AS3 was ignited at 15:50 as a 220 m east-west ignition line in the southern section of the plot. Moderate south-south-westerly winds led to vigorous fire spread with the involvement of mallee canopy. Flame heights in the mallee clumps were peaking at 8-10 metres, but averaging 4 metres. Several spot fires were identified around the fire perimeter.

The western flank reached drop R6 at 15:55 and the tip of the head fire reached drop R2 at 15:57. In both cases the fire did not progress beyond the retardant line. The wind direction shifted to have more of a westerly influence for 3 minutes from 15:57 and the eastern flank burnt around drop R3. The wind returned to a southerly again at 16:00 and sections of the western flank were stopped by drops R6 and R5.

At 16:02 the wind developed more of a south-easterly influence. The north western section of the fire then picked up and started to burn into the western side of drop R2. The fire was observed to be spreading with high intensity in heath fuels and crowning in the occasional mallee clumps. Within 2 minutes the fire had passed through the tail (western end) of drop R2. The progression of the fire in plot AS3 is presented in Figure 3.5. After passing the east-west retardant line the fire progressed under the influence of a southerly wind in the form of two narrow fingers. The southern section of the western flank eventually burnt around the north-south retardant line. The reformed headfire reached the north plot boundary at 16:12.

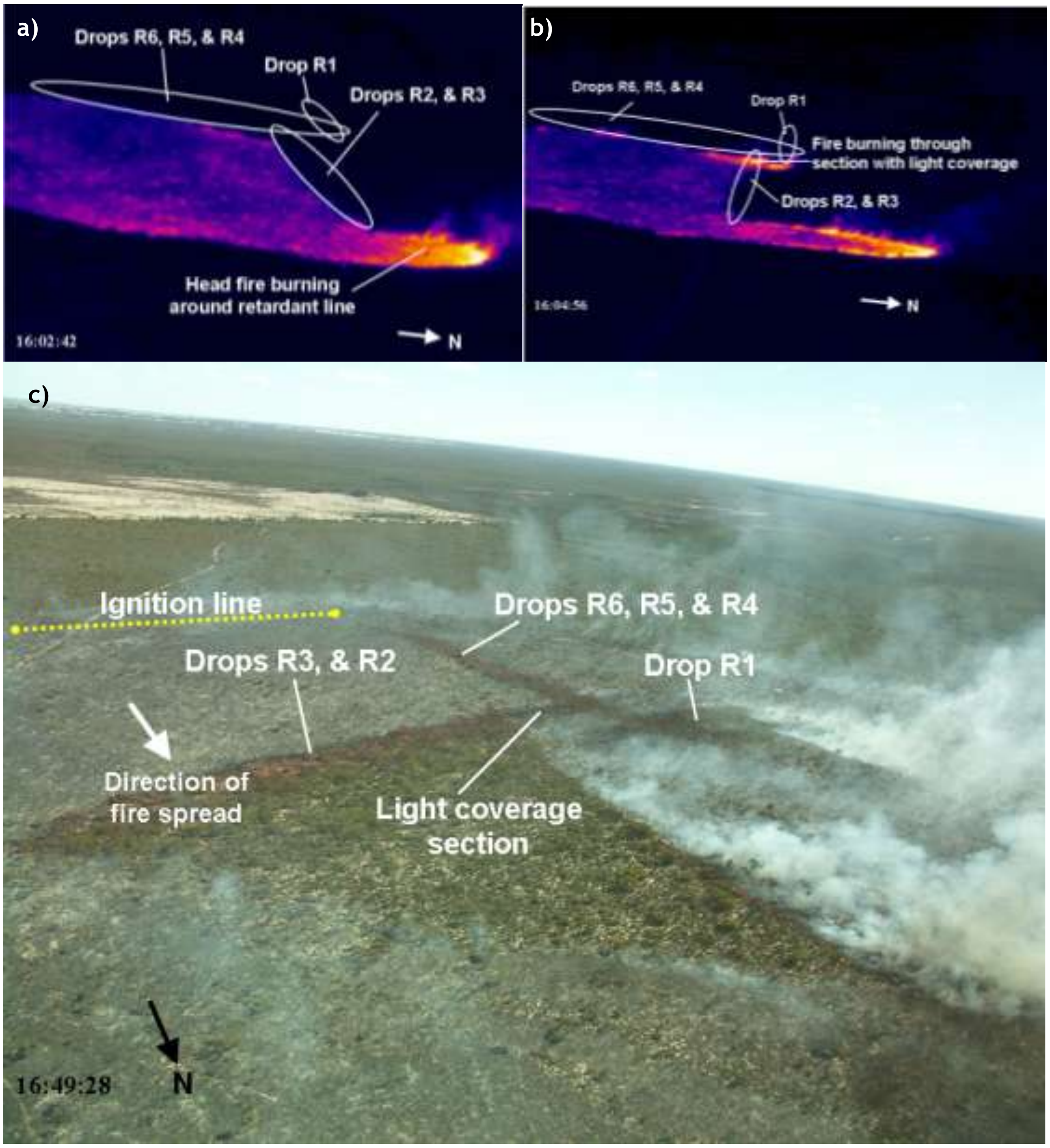


FIGURE 3.5. Sequence showing fire burning through section of light retardant coverage in drop R2. (a) Infrared image of the fire holding on east-west retardant line and burning around the eastern end. (b) Fire burning through section of light coverage in drop R2. c) Aerial view of the resulting burn pattern.

A post-fire inspection of the breached section of retardant line (drop R2) revealed that this was an area that had received only a light coverage of retardant. The weak section in coverage could not be discerned from other sections of the retardant line in the aerial video footage captured before ignition. However, it could be identified in the infrared footage (Figure 3.6).

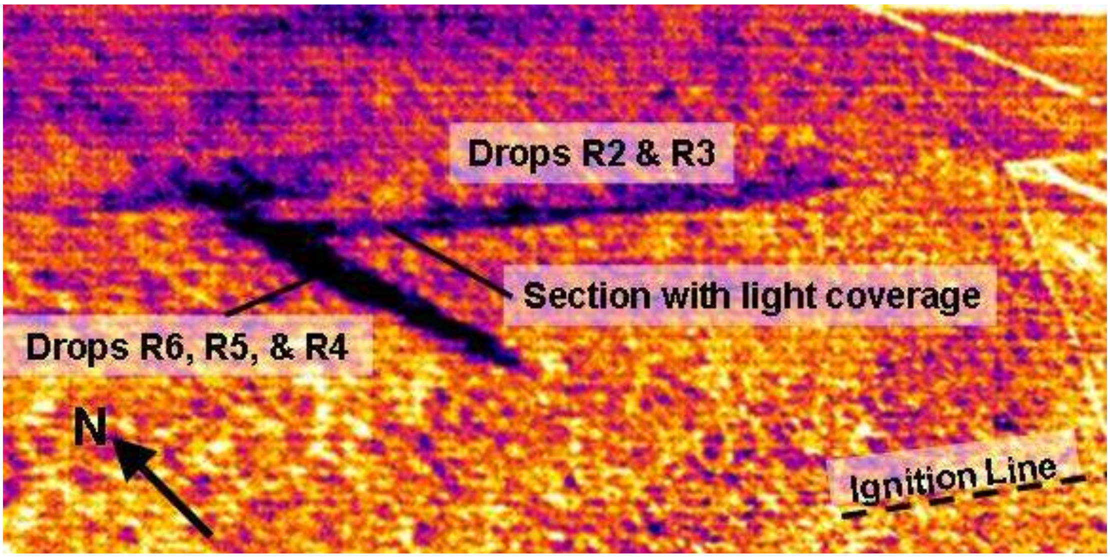


FIGURE 3.6. Infrared view of the plot AS3 retardant line prior to ignition, showing section of light coverage.

3.3) FOAM SUPPRESSANT EXPERIMENT (PLOTS AS2E & AS2W, 5 MARCH 2008)

Plot AS2 was burnt in two sections. The eastern portion of the plot was ignited at 15:00 from a track that diagonally traversed the plot, while south-western part of the plot (AS2W) was ignited at 16:10 along the western boundary of the plot (Figure 3.7).

This first fire (15:00) was ignited using a 250 m line and initially spread in heath vegetation, quickly gaining intensity with flames up to 4 metres. As the fire burnt into mallee vegetation, crowning ensued with flames up to 10 m. A short lull in wind speed five minutes after ignition slowed fire propagation and revealed multiple spot fires along the fire perimeter. As wind speed increased again the fire made a intense crown fire run in the mallee vegetation with flame heights between 8-10 m and spot fires developing 60 and 40 m ahead of the fire.

This fire spread faster than anticipated and had nearly reached the eastern boundary by the time of the first drops. The first two foam drops targeted the eastern end of the northern flank. A spot fire ahead of the first drop had nearly merged with the main fire by the time the second drop was made. Both of these drops were quickly burnt around by the rapidly spreading fire (Figure 3.8). Further drops in plot AS2E (F3-F7) were made on the flanks. These drops held until the fire burnt around them. The blue dye added to the foam drops did not aid their visibility on the ground.

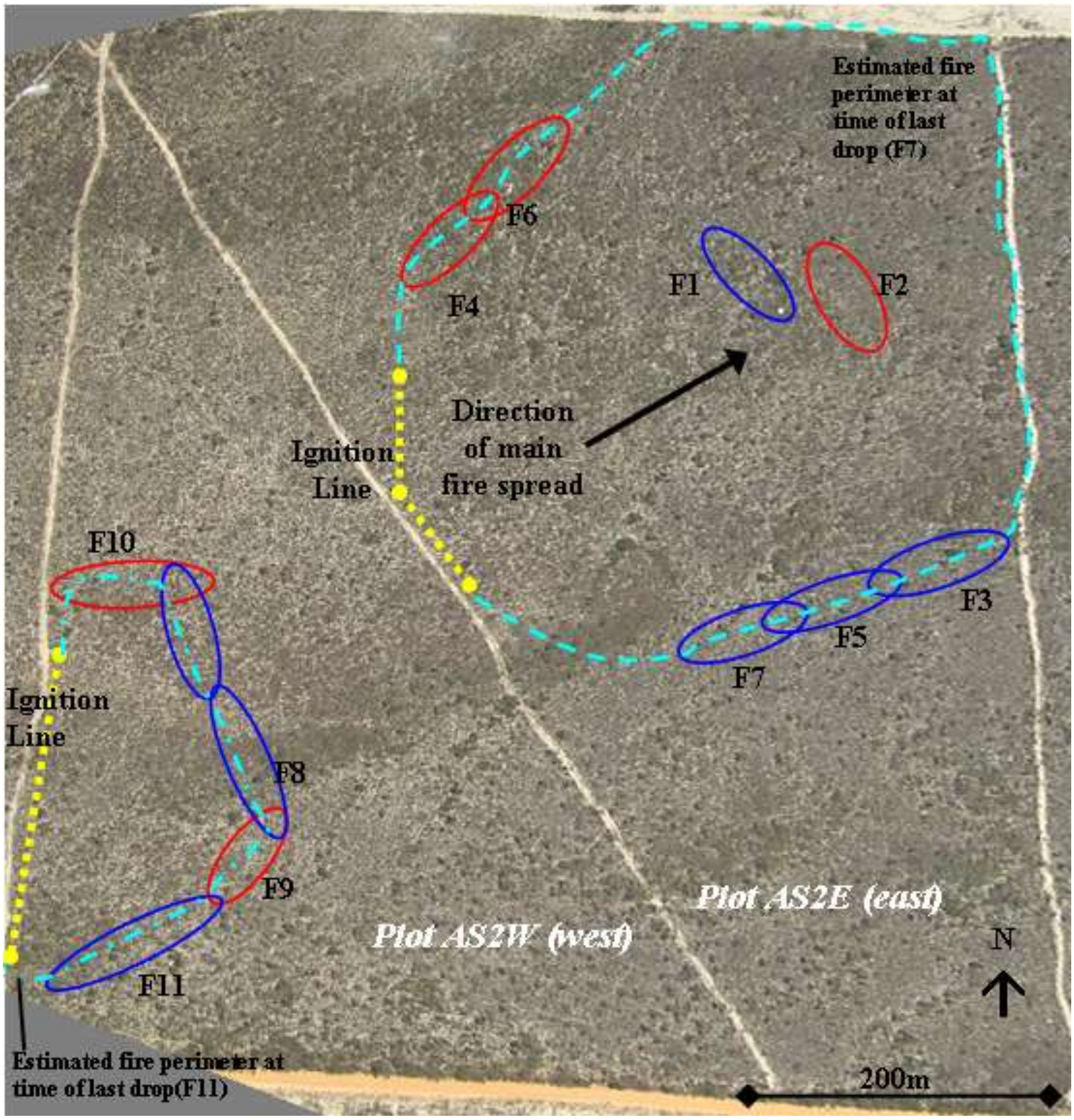


FIGURE 3.7. Foam drop locations in plot AS2 superimposed over a pre fire geo-rectified aerial photograph. The blue and red ovals indicate approximate locations and orientations of drops from bombers 580 and 583 respectively. [A post-fire aerial image was not available for this plot]

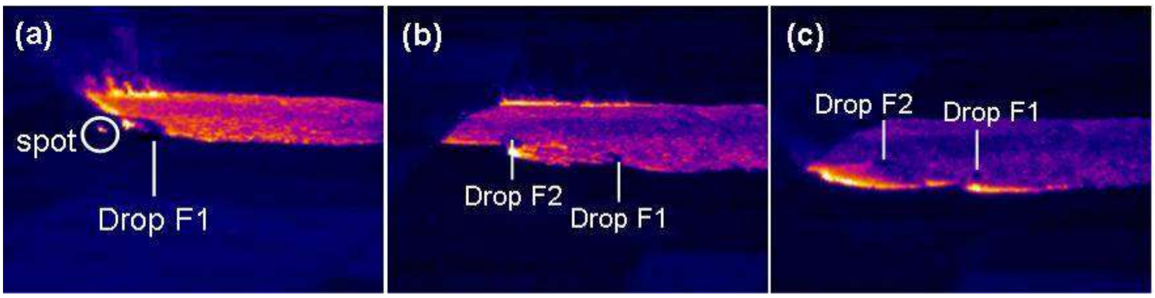


FIGURE 3.8. Infrared sequence showing drops F1 and F2 in plot AS2E. (a) spot fire ahead of drop F1 (15:11), (b) drop F2 being burnt around (15:14), (c) drops F1 and F2 completely burnt around (15:17).

The fire in the south-western part of the plot (AS2W) was ignited at 16:10 along the western boundary. This fire had a shorter ignition line (~100 m) and was smaller than the other fires. It was not instrumented for fire behaviour measurements. The fire behaviour was strongly affected by changes in wind direction, with sections of fire perimeter alternating between head and flank fire behaviour. Drops F8 and F9 were made directly on the head fire 3 minutes after ignition when the wind was from the west. Drop 10 was made on the northern section of fire 7 minutes later when the wind was from the south. Sections of drop 8, which originally appeared to have been extinguished, were observed to re-flame 20 minutes after the drop was made. Unfortunately this drop could not be monitored as the block was burnt out soon after and the helicopter had to land to be refuelled.

4) DISCUSSION

The experimental aim to demonstrate the effectiveness of different wildfire suppressants could not be achieved to the desired level as there was insufficient data to make direct comparisons between suppression chemicals. The main reasons for this were the limited number of drop holding time observations and the lack of replicate experiments. Holding time data was difficult to obtain because many of the drops were burnt around, or had been spotted over. Other drops could not be observed for a long enough time to collect evidence of fire burning through them because of the requirement to have the plots burnt out soon after the last drop had been made.

Holding time is the best available measure for comparing the effectiveness of different drop types. Holding time can be defined as the time between a drop impacting a fire (or fire impacting a drop) and a drop being burnt through. Most of the drops observed during these experiments were either burnt around or had been spotted over before they were burnt through. Fires burnt around most drops that were not anchored to other drops or fuel breaks. All of the foam and most of the gel drops had been burnt through prior to post-fire surveys. Only the sections of gel drops with the heaviest coverage contained unburnt fuels.

Plots could not be monitored while suppression crews burnt the remaining unburnt sections. Burn-out operations were conducted because the incident control team wanted to minimise the chance of fires escaping the plots. Burn-out took place soon after the last drops were made to minimise the amount of time that suppression crews had to work at the site. Once plots had been burnt out the mechanisms for drops being breached could not be determined. Future aerial suppression experiments should use a methodology that maximises opportunities for determining drop holding times, including the delay of burn-out operations.

Airborne infrared imagery proved to be a very effective method of monitoring suppressant drops and fire behaviour during these experiments. It was often the only method available for monitoring drop effectiveness. The effectiveness of all drops in each plot could not be practically and safely monitored by ground observers. The airborne infrared footage allowed the mechanism and timing for each breached drop to be determined. This footage also enabled clear monitoring of fire progression, including the presence and location of developing spot fires.

The fire behaviour varied on the three experimental days, mainly due to differences in weather (Tables 3.1 and 3.2). Changes in wind speed and direction after ignition caused surges and lulls in fire behaviour. Comparisons between fire suppression chemicals would have been difficult to make even if different chemicals were applied on the same fire. Linked drops made within a short period of time on the same section of fire may have been the only way of minimising this source of error, however operating mixing facilities for two suppressants at the same time may have required extra resources at the airbase.

Comparisons between gel and foam suppressants are of greater interest than comparisons with retardant, as both gel and foam are designed to be used for direct attack. Post-fire drop assessments tended to find greater portions of unburnt fuel in gel drops than in foam drops. However these observations cannot be adequately quantified and there would be variation in the fire intensity experienced by each drop. Tests involving repeatable experimental fires with different suppressants are required to make such a direct comparison.

The longevity of gel drops laid indirectly is also of interest. Commercial suppliers of gels have suggested that their slow evaporation rates make them suitable for indirect attack application in situations where fire may impact drops within a few hours, such as parallel attack or protection of structures in the path of fire. Such claims warrant investigation. The utility of gel drops for indirect attack would require an understanding of evaporation rates, as drop areas are able to be burnt once the fuel moisture content dries to an ignitable level. Taylor *et al.* (2005) conducted some preliminary drying tests on a gel suppressant and found it to have greater moisture retention than foam solutions and plain water. Similar tests should be conducted in wildfire representative weather conditions and could involve the frequent application of a standardised ignition source to determine the duration until flaming reoccurs. Running comparable experiments in a laboratory environment would allow the replication of burning conditions that would allow direct comparison of suppression chemicals with a high level of confidence.

The experiments presented here have enabled a methodology of aerial suppression drop assessment to be refined. The data collected from these experiments can be used to develop material used for training fire fighters who work with aircraft. Footage and images captured with the airborne infrared camera illustrates important aerial suppression tactical issues, such as drop coverage, drop accuracy and drop placement. An example of such training material is given in the appendix in the form of a guide used to educate fire fighters on assessing aerial suppression drops.

5) CONCLUSIONS

The results from these experiments indicate that the tactical placement of drops is the most important requirement for aerial suppression to effective. Drops that are not placed appropriately will be ineffective regardless of the suppression chemical used.

The experiments were unable to directly compare suppression chemicals because holding times could not be determined for most drops. Comparisons of the suppression capabilities of these chemicals would be best made in laboratory fire experiments where differences in tactics, fire behaviour, weather and fuels can be minimised and there is no risk of fire escape or need for imminent burn out operations.

The methodologies used and tested here are able to provide meaningful assessments of aerial suppression effectiveness at a tactical level. Airborne infrared imagery was shown to be the most effective method for monitoring drops and fire behaviour. The analysis of this imagery was often the only method able to quantify drop outcomes during these experiments. This method would be well suited for the assessment of aerial suppression drops made on operational wildfires.

The data produced from these experiments would be of great value for use in training material for wildfire aviation specialists. This data highlights the tactical importance of drop placement with regard to fire behaviour and location. It also illustrates the importance of having adequate coverage levels within drops for stopping fire propagation.

REFERENCES

Àgueda A, Pastor E, Planas E (2008) Different scales for studying the effectiveness of long-term forest fire retardants. *Progress in Energy and Combustion Science* **34**, 782-796.

Albini FA (1985) A model for spread in wildland fuels by radiation. *Combustion Science and technology* **42**, 229-258.

Cruz M.G., Matthews S, Gould J, Ellis P, Henderson M, Knight I, Watters J (2010) Fire dynamics in mallee-heath; fuel weather and fire behaviour prediction in South Australian semi-arid shrublands, Bushfire Cooperative Research Centre Technical Report A.10.01. East Melbourne, Victoria.

Dando M, Cheney NP, Hutchings PT (1988) 'An evaluation of synthetic foam as a bushfire suppressant.' National Bushfire Research Unit, Canberra.

George CW (1985) An operational retardant effectiveness study. Fire Management Notes. Vol. 46, Issue 2, pp 18-23.

George CW (1990) An update on the Operational Retardant Effectiveness (ORE) program. In: Alexander, M.E.; Bisgrove, G.F. (technical coordinators). The Art and Science of Fire Management. Proceedings of the First Interior West Fire Council Annual Meeting and Workshop. Forestry Canada, Northwest Region, Northern Forestry Centre, Edmonton, Alberta. Information Report NOR-X-309, pp 123-136.

Keetch JJ, Byram GM (1968) A drought index for forest fire control. USDA Forest Service, Southeastern Forest Experiment Station, SE-38, Asheville, North Carolina, USA.

Loane IT, Gould JS (1986) 'Aerial suppression of bushfires: cost-benefit study for Victoria.' (CSIRO Publishing)

McCaw WL (1997) Predicting fire spread in Western Australian mallee-heath shrubland. PhD thesis, University of New South Wales (Australian Defence Force Academy).

Pastor E, Planas E, Ribeiro LM, Viegas DX (2006a) Modelling the effectiveness of long-term forest fire retardants. In 'Proceedings of the 5th International Conference on Forest Fire Research'. 27–30 November, Figueira da Foz, Portugal

Pastor E, Agueda A, Andrade-Cetto J, Munoz M, Perez Y, Planas E (2006b) Computing the rate of spread of linear flame fronts by thermal image processing. *Fire Safety Journal* **41**, 569-579.

Pastor, E., Pérez, Y., Cubells M., Planas, E., Plucinski, P., Gould J., (submitted) Quantifiable assessment of aerial suppression tactics in wildland fires by IR monitoring. Submitted to 6th International Conference on Forest Fire Research.

Pérez, Y., Pastor, E., Planas, E., Plucinski, M., Gould, J., (In Press) Computing aerial suppression effectiveness by IR monitoring, *Fire Safety Journal*. (manuscript FISJ-D-09-00156R1)

Plucinski, M., Gould, J., McCarthy, G., and Hollis, J. 2007. The effectiveness and efficency of aerial firefighting in Australia, Part 1. Bushfire Cooperative Research Centre Technical Report A0701. East Melbourne, Victoria.

Plucinski M, McCarthy G, Gould J (2006) 'Aerial Suppression Experiment, Cambridge Tasmania, 21-23 February 2005.' Ensis Technical Report No. 153. Canberra, Australian Capital Territory.

Schlobohm P, Rochna R (1988) An evaluation of foam as a fire suppressant. *Fire Management Notes* **49**, 16-20.

Simard AJ, Eenigenburg JE, Adams KB, Nissen RL, Deacon AG (1984) A general procedure for sampling and analyzing wildland fire spread. *Forest Science* **30**, 51-64.

Solarz P, Jordan C (2000) 'Ground pattern performance of the Snow Air Tractor with constant flow tank.' USDA Forest Service, 0057-2852-MTDC, Missoula, Montana.

Specht RL (1966) The growth and distribution of mallee broombush (*Eucalyptus incrassata- Melaleuca unciata* asscociation) and heath vegetation near Dark Island Soak, Ninety Mile Plain, South Australia. *Australian Journal of Botany* **14**, 361-371.

Specht RL, Rayson P (1957) Dark Island Heath (Ninety-Mile Plain South Australia). I. Definition of the ecosystem. *Australian Journal of Botany* **5**, 52-85.

Stechishen, E.; Murray, W.G. (1990) Effectiveness of foam as a fire suppressant. In: Alexander, M.E.; Bisgrove, G.F. (technical coordinators). The Art and Science of Fire Management. Proceedings of the First Interior West Fire Council Annual Meeting and Workshop. Forestry Canada, Northwest Region, Northern Forestry Centre, Edmonton, Alberta. Information Report NOR-X-309, pp 123-136.

Taylor D, Swift S, Roach K (2005) 'A preliminary trial of Phos-Check AquaGel-K for aerial and ground application by DPI Forestry in exotic pine plantation fire management.' Queensland Government, Department of Primary Industries and Fisheries, Brisbane.

USDA Forest Service (2010) Wildland Fire Chemical Systems, Available online at: http://www.fs.fed.us/rm/fire/index.htm (last accessed 5 May 2010)

Vega JA, Cuíñas P, Fonturbel T, Pérez JR, Vega DJ, Pérez-Gorostiaga P, Fernández C, Jiménez E (2007) Comparing The Effect Of Polyphosphate And Foam Addition To Water On Fire Propagation In Shrubland.In Proceedings of the 4th International Wildland Fire Coference, Sevilla, Spain, 13-17 May, 2007.

APPENDIX:

BUSHFIRE CRC FIRENOTE 38: "ASSESSING AERIAL SUPPRESSION DROP EFFECTIVENESS"

Background briefings on emerging issues for
fire managers from AFAC and Bushfire CRC.

FIRE NOTE

ISSUE 38 SEPTEMBER 2009

ASSESSING AERIAL SUPPRESSION DROP EFFECTIVENESS

Aerial suppression can be an important part of bushfire containment operations. It requires significant logistical support and can be expensive. It is important that aerial suppression drops are carried out in a safe and effective manner. The purpose of this Fire Note is to outline key criteria for assessing aerial suppression drops so that this can be achieved.

There are a large number of factors that influence the effectiveness of aerial suppression operations. These vary considerably depending on the conditions and resources available for a particular fire. This Fire Note concentrates on the main considerations for assessing single and multiple linked drops, which are: placement; coverage; and effect on fire behaviour. These aspects need to be considered in relation to the suppressant agents being used, the fire fighting tactics and strategies being employed, and the aircraft and delivery systems that are available. These issues are discussed in detail in this document and are used as the key topics in the list of considerations for drop assessment.

Aerial suppression drops should be directed in a way that is consistent with the overall fire fighting strategy. In nearly all cases, aerial suppression drops are of limited value without timely follow up from ground suppression resources. Unsupported drops that are quickly burnt around or spotted over are ineffective and will have a very limited influence on slowing the fire. Suppressant drops are often used to knock down flames ahead of ground resources that follow behind extinguishing residual flames and mopping up. This tactic can enable faster rates

ABOUT THIS PROJECT

Bushfire CRC Project A3.1 – Evaluation of Air Suppression Techniques and Guidelines.

The author: Dr Matt Plucinski, CSIRO Sustainable Ecosystems

MAJOR CONSIDERATIONS FOR DROP ASSESSMENT

PLACEMENT

- On target — Yes → was this the most appropriate target?
  No → what is the likely reason for poor placement? (e.g. wind, visibility etc)
- Is the drop anchored and well linked?

COVERAGE

- Did the drop penetrate through the canopy and into fuels?
- Is there adequate coating of surface and near surface fuel layers?
- Are there gaps in the coverage?
- Is there enough coverage between linked drops?
- If the answer to any of these questions is no, provide a reason

EFFECTS ON FIRE BEHAVIOUR

- Is there a significant reduction in fire activity?
- Is the post-drop fire behaviour reduced to the level required?
- Is the drop holding? — Yes → monitor and note the duration
  No → Give reason(s) why (e.g. spotting, burn around, burn through)

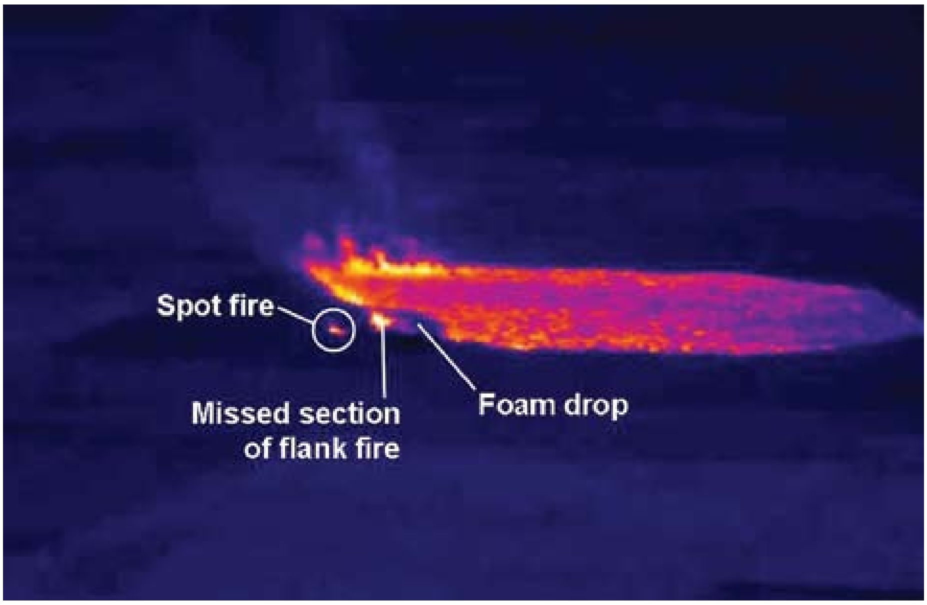
of line construction than either resource type working alone and may allow ground crews to work on sections of fire edge that would be too intense for them to safely suppress alone, though they should not rely on aircraft for safety. In the absence of ground crews, drops may slow fire spread but will not stop it. Aerial suppression cannot provide the detailed attention required to mop up burning and smouldering fuels, which can cause containment lines to fail. This task can only be achieved from the ground.

UNDERTAKING A DROP ASSESSMENT

A drop assessment needs to consider the drop objectives and whether it is part of a direct or indirect tactic. The objective for a drop may be to slow or stop fire spread, or reduce fire intensity for ground crews. The tactics used to achieve the objectives should be compatible with those being used by other resources.

Suppression drops are best assessed on the ground. This allows for detailed observation and monitoring at the site of impact. Drop assessment from aircraft is limited, especially when there is a canopy present, because drop areas can be difficult to identify and close inspection of the drop areas is usually not possible. Infrared cameras, which allow fire to be seen through smoke and light canopies, can greatly assist evaluation of drops. Some infrared images from the Project FuSE aerial suppression experiments are used as examples here.

Ground crews can advise when drops are being ineffective or could be improved. However ground observers need to be aware of hazards, such as falling limbs and slippery ground when working in and around drop areas and should be away from the drop area as it impacts. It is not always possible to get drops assessed at ground level, as crews may not be available or conditions may not be safe for drop areas to be accessed. Air operations need to be clear when communicating requests for information. Ground crews should clearly describe the location, drop time, and aircraft responsible as well as other drop effects including limb dislodgement and adverse rotor wash effects when relaying information on drop effectiveness.



▲ **Figure 1:** Infrared image of a misplaced foam drop, Project FuSE Aerial Suppression Experiments. A section of flank fire and a spot fire are located in front of the drop. This drop had a very minimal effect on slowing that section of fire edge and was therefore ineffective.

FURTHER READING

Plucinski M., Gould J., McCarthy G., Hollis J. (2007) *The Effectiveness and Efficiency of Aerial Firefighting in Australia*, Part 1. Bushfire Cooperative Research Centre, Australia. Report A.07.01.

MAIN CONSIDERATIONS

1) Drop placement

During assessment, drop placement should be considered both in terms of the intended target and the best target. If the intended target is not the best place for a drop the reasons for this should be relayed to air operations personnel and pilots. Drops may not reach their intended target if they are affected by unexpected wind drift, made in poor visibility conditions, or have been dropped from too high due to difficult terrain.

Suppressant drops

The location of the drop with respect to the fire edge is critical for direct attack. Direct attack drops should have their area of highest coverage impact along the intended section of fire edge. Suppressant drops that land in areas that are already burnt are wasted (Figure 1, above).

Suppressant drops that land ahead of the fire in unburned fuels may eventually slow the fire, but have a high risk of being burnt around or spotted over when the fire reaches them.

The placement of suppressant drops should be part of the overall strategy for the fire, with sequences of drops linked together and with breaks in the fuel. Fire will spread through gaps between drops and areas of light coverage.

Retardant drops

Retardant drops are normally laid ahead of fires with the intention of stopping their spread or protecting assets in their path. They are often laid in areas with limited ground access. The placement of retardant drops also benefit from alignment with and anchorage to existing features. Retardant is often laid in lines of multiple drops. These need to have a consistent coverage along their whole length (Figure 2, next page).

SUPPRESSION CHEMICALS

Most aerial suppression drops contain chemical additives. Drops containing only water are occasionally used for direct attack, particularly when fires are near waterways or there are concerns about the environmental impacts of chemicals.

Suppression chemical additives can make drops more effective. They fit into three classes: foam surfactants, water enhancers and long term retardants. Foam surfactants and water enhancers are primarily designed for direct attack and are only effective while wet. These are termed suppressants and are sometimes called short term retardants. Foams aid the wetting of fuels by lowering the surface tension of the water and assisting saturation. The proportion of foam concentrate in aerial suppression drops has a large influence on the drop characteristics and the ability to penetrate through dense canopies. Water enhancing gels contain substances that slow evaporation and increase adherence to fuels. Gels are currently being trialled in some parts of Australia, and are coloured with a blue dye.

Long-term retardants are designed to be laid ahead of the fire as they remain effective after the water they originally contained has evaporated. They are usually coloured red. Retardants work by inhibiting flaming combustion.

2) Drop coverage

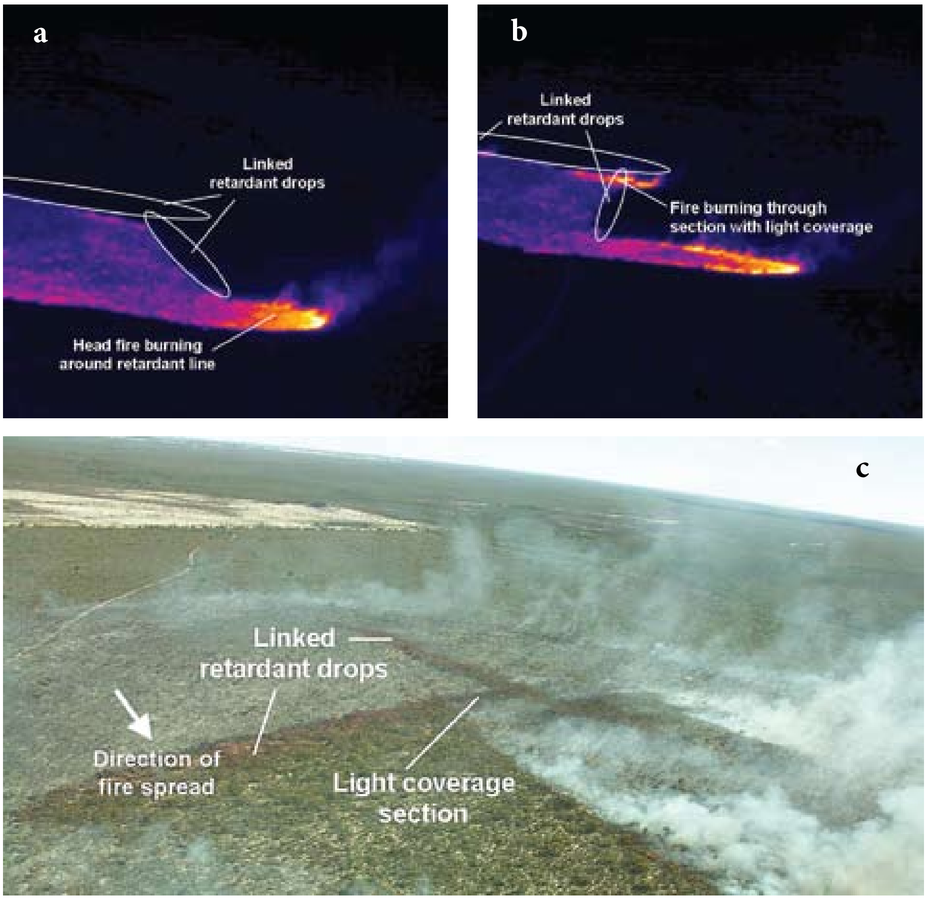
Assessors need to determine if there is a sufficient amount of suppressant or retardant reaching the fuels. Coverage levels will vary across drop patterns. The highest coverage level is usually located in the centre of the drop, with areas of lighter coverage surrounding. The coverage level required to extinguish flames increases with fuel load and fire intensity. High intensity fires burning in heavy fuels may require coverage levels beyond what can be delivered with even the largest aircraft. Drops on such fires will only temporarily subdue flames.

It is important that drops coat fuels on and just above the ground and penetrate them. It is also important that a consistent coverage is achieved within the drop and where drops overlap. Breaks in coverage can be caused by shadowing from overlying vegetation and other obstacles such as logs and rocks (Figure 3, below right). Generally, drops that rain down vertically are less affected by shadowing. To achieve this, drops need to be made at a height that allows the drop mass to lose forward momentum at or above the top of the canopy. A disadvantage of this is that drops may be exposed to wind drift and may have a wider footprint with a lower coverage level. Drops made during peaks of fire activity are particularly prone to this problem. When possible, drops of retardant for strategic lines ahead of the fire edge should be made at times when wind speeds are low.

The ability of a drop to penetrate a canopy can be affected by its viscosity and surface tension. Thick or highly viscous mixes of suppressants

AIRCRAFT AND DELIVERY SYSTEMS

A large range of aircraft and delivery systems are used for aerial suppression in Australia. These have evolved through operational experience and are selected for a range of reasons including cost, carrying capacity, ability to access water, travelling speed and drop patterns. Not all suppression chemicals can be used in all delivery systems. Drop patterns are influenced by a number of properties related to aircraft and delivery systems. Crucial factors include the speed and height of the drop and environmental variables, such as wind speed and canopy interception. The most important attributes of drop patterns are coverage levels on surface fuels and the consistency and dimensions. Different levels of coverage are required for different fuel types and fire intensities.



▲ **Figure 2:** Sequence showing fire burning through section of light retardant coverage from the Project FuSE Aerial Suppression Experiments. a) Fire holding on retardant line and burning around one end. b) Fire burning through section of light coverage in retardant drop. c) The resulting burn pattern.

▲ **Figure 3:** This retardant drop held the fire despite being penetrated in some sections that were shadowed by the trees. Drops can be breached by fires trickling through sections of light coverage like this.

END USER STATEMENT

"Accurate assessment of drops is absolutely fundamental to ensuring that aerial firefighting resources are used effectively and that fire agencies are properly accountable for the delivery of a vital but high-cost, highly specialised capability. Consistent, accurate drop assessment will ensure that collectively we can continue to improve the efficiency and effectiveness of aerial firefighting. As well as providing a valuable consolidation of relevant information, this work represents a very significant advance on the topic and provides a solid foundation for more rigorous approaches to assessing drop effectiveness and improving performance."

– Richard Alder, General Manager, National Aerial Firefighting Centre Ltd

▲ **Figure 4:** High foam concentration drop adhering to a tree canopy. Drops like this will not penetrate thick canopies.

and retardants hold together well when dropping and are more resistant to wind drift. However, they have a high adherence to the canopy and limit the proportion of the drop that drips through. Such drops may also have difficulty penetrating into litter layers. Similarly, foam drops with high proportions of foam concentrate (>0.04%) may adhere to canopies due to the high surface tension (Figure 4, above). High concentration foam drops also mix with air when dropping and are more prone to wind drift.

The table (above right) outlines some of the compromises that should be considered when balancing drop coverage and effectiveness. The effects listed are generic and the range of the effects will vary depending on products and delivery systems. Finding an optimal balance between these effects may require some assessment of effect and adjustments within a given operation.

3) Effects on fire behaviour

The ultimate test of drop effectiveness is the effect on fire behaviour. The best way of assessing this is to compare pre- and post-drop fire behaviour (Figure 5, above right) and determine how long the drop impedes fire spread. When drops are breached the reasons should be investigated and fed back to those determining the tactics.

Drop success depends on the availability of ground suppression support. If ground crews are present, drops may only need to reduce fire behaviour to manageable levels to be effective. If ground support is delayed, then drops need to hold fire spread until ground resources arrive.

There are three causes of drop failure: spotting; burn around; or burn through. Drops can be breached by more than one of these causes.

Embers that carry for distances greater than the effective drop width will prevent the drop from holding fire spread. If the density of spot fires beyond the drop is high, or spots develop quickly, then drop effectiveness is greatly reduced.

Drops can be burnt around if there is a problem with their placement. This can occur when turnaround times are too slow for the rate of perimeter growth. Such a result should prompt a revision of tactics.

If drops are burnt through then their coverage may be inadequate for the fire intensity and hold time required. All suppressant drops are at risk of eventually being burnt through, as the duration of their effectiveness is always determined by the rate of evaporation of their water content. For this reason, when possible, the duration of drop holding time should be estimated for suppression drops that are burnt through.

BALANCING DROP COVERAGE AND EFFECTIVENESS

	Too high	Too low
Drop height	More prone to wind drift	Intercept canopy at an angle resulting in shadowing
Foam concentration	More prone to wind drift Low penetration of canopies and fuel layers	Low adherence to fuels
Retardant / gel viscosity	Low penetration of canopies and fuel layers	More prone to wind drift Lower concentration of retardant salts

▲ **Figure 5:** The effect of a direct suppressant drop on fire behaviour as indicated by pre (a) and post drop (b) images taken during the Project FuSE Aerial Suppression experiments. Flames that were up to 2 metres were knocked down to less than half a metre and extinguished in some places. Although this drop had a large influence on this section of fire perimeter, it was not anchored and the fire quickly burnt around it, making it ineffective.

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