



# **Aerial Suppression Experiment Cambridge, Tasmania, 21-23 February 2005**

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## Summary

A series of aerial suppression experiments on stubble fires were conducted near Cambridge, Tasmania, on 21 - 23 of February 2005. The main aim was to determine the effects of suppression drops on fire behaviour in stubble fuels. The experimental results were also used to develop and test methods for evaluating the effectiveness of aerial suppression.

The experimental site was part of the University of Tasmania's research farm, situated near Hobart and Cambridge airport. The suppression experiments were conducted in paddocks of barley stubble and drop pattern tests were done on a paddock of short grass. The stubble fuels were ideal for developing and testing methods for aerial suppression evaluation, and enabled experiments to be conducted in a short period of time.

We used a Bell 212 helicopter (Helitack 721) with both bellytank (1185L Isolair Eliminator II) and bucket (1430L Bambi bucket) delivery systems and applied water and foam drops.

There were four components of this study:

- 1) *Drop pattern tests*: to determine the ground distribution of suppressant from both the bellytank and bucket delivery systems.
- 2) *Head fire drop experiments*: to test the effectiveness of individual drops on different stubble fire intensities.
- 3) *Line length experiments*: test the effectiveness of single drops on different lengths of fire line.
- 4) *Multiple drop experiments*: to determine the effectiveness of repeated drops on larger fire perimeters.

Results showed that the helicopter was able to effectively suppress all fires in the light stubble fuels ( $3.4 \text{ t.ha}^{-1}$ ) under mild weather conditions (Grassland Fire Danger Index (GFDI) $<14$ ). Grassfires with intensities up to  $4000 \text{ kWm}^{-1}$  were effectively suppressed with both water and foam drops. Aircraft are unlikely to be deployed to fires burning in these conditions, as ground forces would be capable of dealing with them. The burning conditions did not generate fires more intense than could be suppressed by any of the suppressant and delivery combinations used.

The drop footprints from the drop tests were representative of the majority of drop footprints in the suppression experiments. The methods used for the head fire and multiple drop experiments are recommended for future aerial suppression experiments.

The cooperation and support of multiple dedicated agencies (Tasmania Fire Service, Ensis Bushfire Research (then known as CSIRO Forestry and Forest Products Bushfire Behaviour and Management Group), Bushfire CRC, Forestry Tasmania, and University of Tasmania) enabled the successful operation of this project.

## 1.0) Introduction

The report provides an account of the methods and results relating to the aerial suppression experiments conducted in February 2005 near Cambridge, Tasmania.

### 1.1) Aims

The main aim of this study was to determine the effects of suppression drops on fire behaviour in stubble (grassland) fuels. The secondary aim was to evaluate different methods for testing the effectiveness of aerial suppression on different intensity grassfires.

### 1.2) Background

This study consisted of four components:

- i) Drop pattern testing: to determine the ground distribution of suppressant from the delivery systems used in the fire suppression experiments;
- ii) Head fire drop experiments: to evaluate the effectiveness of individual drops on the most intense fire behaviour that could be attained;
- iii) Line length experiments: to test the effectiveness of single drops on different lengths of fire line;
- iv) Multiple drop experiments: to determine the effectiveness of repeated drops on larger fire perimeters.

### 1.3) Site characteristics

The experiments were conducted in the Coal River Valley near Cambridge, Tasmania (S 42° 47.982' E 147° 25.616') as shown in Figure 1. The site is located on the University of Tasmania's research farm. The suppression experiments were conducted in barley stubble paddocks and drop pattern tests on a nearby pasture paddock. The site was selected for its proximity to Cambridge Airport and Hobart, and its uniform fuels and terrain, and its nearby water sources.

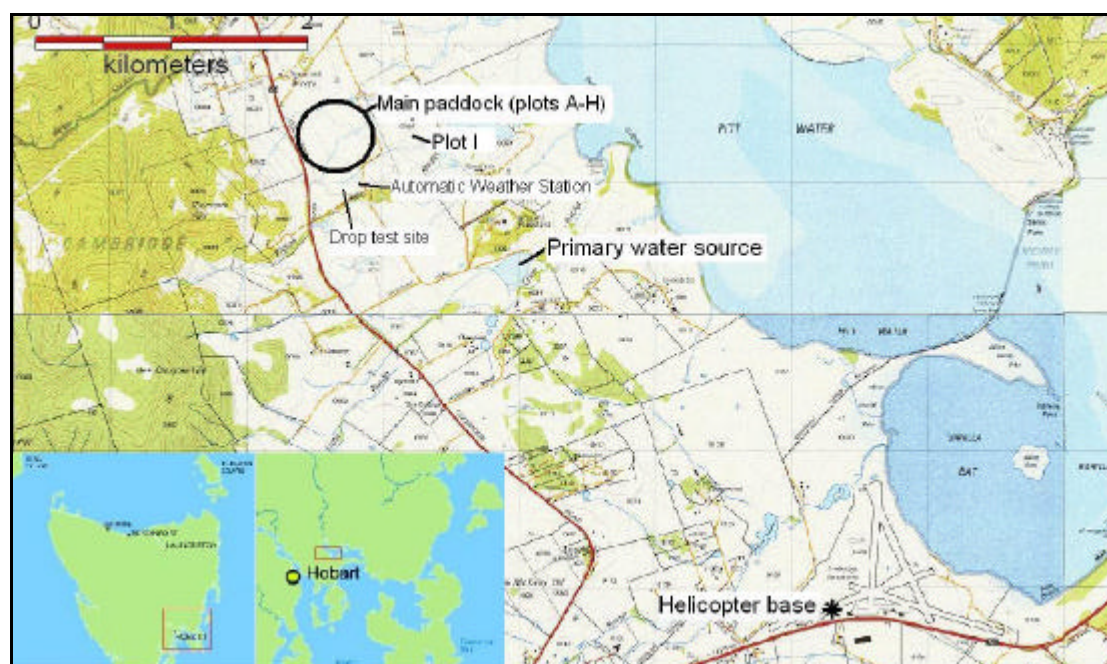
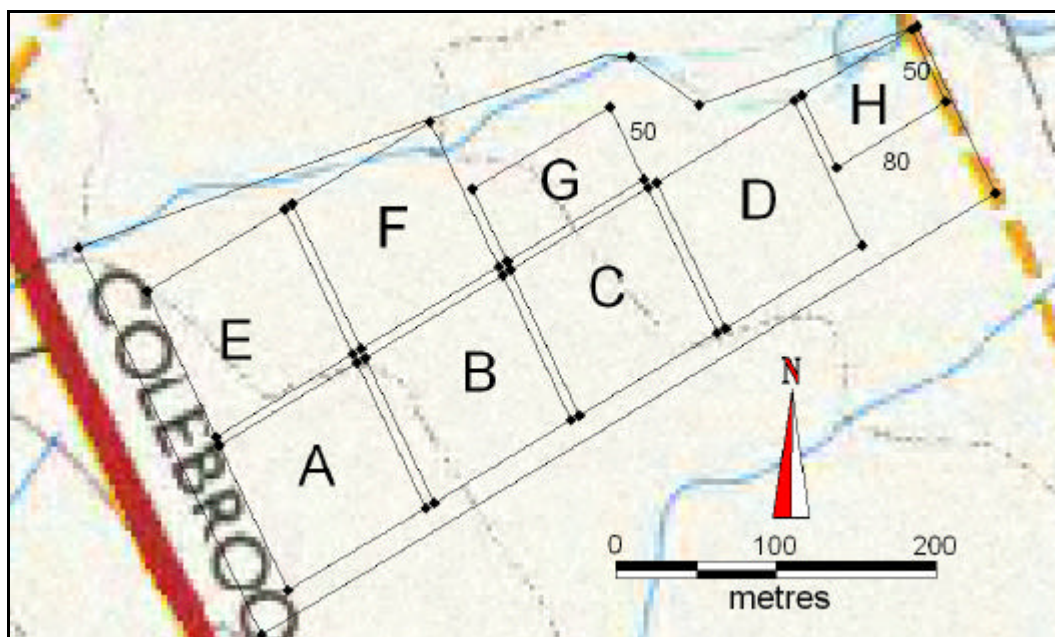


Figure 1: Location of experimental site (TasMap 5226)

The main stubble paddock was subdivided into 8 plots (Figure 2). Some areas in the paddocks were not suitable because of light fuels or the close proximity of trees. These areas were generally near the perimeter of the paddocks and limited the size of some of the plots. Six of the plots were 100x 100 metres and there were two smaller plots (100x 50m and 80x 50m). A second paddock had a single 160x 80 metre plot which was used for a multiple drop experiment. The plots were orientated with the prevailing wind directions, which are typically north-north west in the mornings and south-south east in the afternoons when there is a sea breeze. Burnt buffer strips were established around and between all plots before any experiments commenced.



**Figure 2: Plot layout** (TasMap 5226)

#### **1.4) Aircraft characteristics**

A Bell 212 helicopter (Helitack 721, VH-SYV), which was part of the fleet managed by the National Aerial Firefighting Centre and contracted to the Tasmania Fire Service for the 2005 fire season was used.

The helicopter has the capability to deliver suppressant using either a bellytank or bucket (Figure 3). The bellytank was an Isolair Eliminator II bellytank (Model 4600), modified to allow the bucket to be connected while the bellytank is fixed to the helicopter. This modification reduced the capacity from 1223 to 1185 litres. There was a problem with the foam pump on the bellytank which reduced and varied the proportion of foam injected during the experiments. The bucket used was a Bambi bucket (model 3542) and can hold 1589 L. The bucket is cinched to hold 90% (1430 L) of its full capacity when the bellytank is mounted on the helicopter. The bucket was on a 50 foot (15 m) long line. A mechanical problem with the hose connection for the foam injection in the bucket also caused variation in the foam proportions in the bucketed loads.



Figure 3: Helitack 721 showing bucket (left) and bellytank (right) drops

### 1.5) Previous aerial suppression research

There has been limited research investigating aerial suppression of fires through field experiments. Most research into aerial suppression has investigated drop patterns or the effectiveness of suppressants on small laboratory fires. Project Aquarius, conducted in Victoria in the mid 1980's (Loane and Gould, 1986) investigated aerial suppression effectiveness in field experiments. Research on aerial suppression effectiveness in the USA was mainly done through the Operational Retardant Evaluation (ORE) study (George, 1985, 1990). The ORE study collected data from large air tankers that were instrumented with recording devices to track the flying and delivery system characteristics while dropping on operational fires. There is no documentation of the fire behaviour affected by drops in the ORE literature.

The ORE study produced a list of recommended coverage levels of retardant for the different fuel models used in the 1978 National Fire Danger Rating System (Deeming et al., 1977). Coverage level 1 is given as the recommended level for annual and perennial grasses, which is the closest fuel type to the stubble fuels used here (George, 1985, 1990). Coverage level 1 is equivalent to 1 gallon per 100 square feet, which is  $0.5 \text{ Lm}^{-2}$  in metric units. The ORE recommended coverage levels are poorly defined in terms of fire behaviour, being listed for "average fire intensity conditions" (George, 1990). Loane and Gould's (1986) work for Project Aquarius suggested a coverage of  $0.65 \text{ Lm}^{-2}$  would be required for water to hold a grassfire up to  $2000 \text{ kWm}^{-1}$ . There is no recommendation for coverage level for foam solutions in the literature.

## 2.0) Methods

### 2.1) Weather observations

Weather data was obtained from three sources: a portable automatic weather station (AWS), measurements made with hand held instruments, and records from the Hobart Airport weather station. The AWS was used as the primary source of weather data during the suppression experiments. It was positioned at the eastern end of the drop grid, 350 metres south of the main stubble paddock. Unfortunately data from the AWS was unavailable during the drop pattern tests due to an error in the programming of the data logger. On site spot measurements were made by a person using hand held instruments. These measurements were made during experiments adjacent to the plots, and served as a back up to the AWS data. Additional weather

data was also obtained from the Bureau of Meteorology's weather station at Hobart airport, 7 kilometres to the southeast of the study site.

## 2.2) Fuel assessment

Fuel was sampled prior to the experiments. For this four 0.25 m<sup>2</sup> quadrats were cut in each of the 100m X 100m plot and two were cut in the smaller plots. The samples were cut 1 m in from each corner of the plots to eliminate bias (see Figure 4). The quadrats were harvested bare of all cured stubble fuel. Any green growth (limited to small shoots of grass) was left on site, as it would not have affected fire behaviour. The cured barley stubble was oven dried at 95°C for 96 hours.

## 2.3) Drop pattern tests

The drop pattern tests were conducted in a paddock 500m ESE of the paddock used for the stubble fire plots (Figure 1). The paddock was chosen for its proximity to the stubble paddocks and its short grass that allowed the containers to sit flat on the ground.

Plastic trays (length: 173mm, width: 117mm, depth 40mm) were used to collect samples of the drop. The containers were grouped into pairs, with one fixed to the ground with a roofing nail, with the other sitting inside. They were labelled and arranged into a 100 by 30 metre grid, with containers spaced 5 metres apart. The length of the grid was at a bearing 55 degrees and there was a 4 degree slope across the grid. After the drop, all trays with visible moisture in them were sealed with a lid and collected for weighing by a team of ten people to enable the next drop to be conducted soon after. Fresh trays for the next drop were placed out on the grid at the same time. The trays were weighed on electronic scales (accurate to 0.1 gram) inside a van. The method and materials selected for sampling the drop pattern were based on those described in Biggs (2004), Robertson *et al.* (1997) and Suter (2000). Two video cameras were used to film the drop pattern tests from the end and the side of the grid.

The six drop pattern tests are listed in Table 1. The first drop had one of the bellytank doors open and was repeated with two doors open in the other bellytank drops, with foam used during the second drop. The fourth drop was a repeat of the third because some of the trays were blown away when the helicopter landed too close to the grid. The helicopter was flying too low during the sixth drop, and many of the trays were either destroyed or washed away. The sixth drop was not repeated as the supply of trays had been exhausted.

**Table 1: Summary of drop characteristics**

Drop No.	Time	Delivery system	Suppressant
1	13:21:06	Bellytank (1 door)	Water
2	13:31:41	Bellytank (2 doors)	Foam
3	13:42:28	Bellytank (2 doors)	Water
4	14:02:11	Bellytank (2 doors)	Water
5	14:16:35	Bucket	Water
6	14:48:08	Bucket	Foam

## 2.4) Head fire drop experiment

The aim of this experiment was to test the effectiveness of drops from the helicopter on the most intense fire that could be generated in the experimental conditions. This was done by dropping a single load across the head of the fire and monitoring the effects in the drop zone.

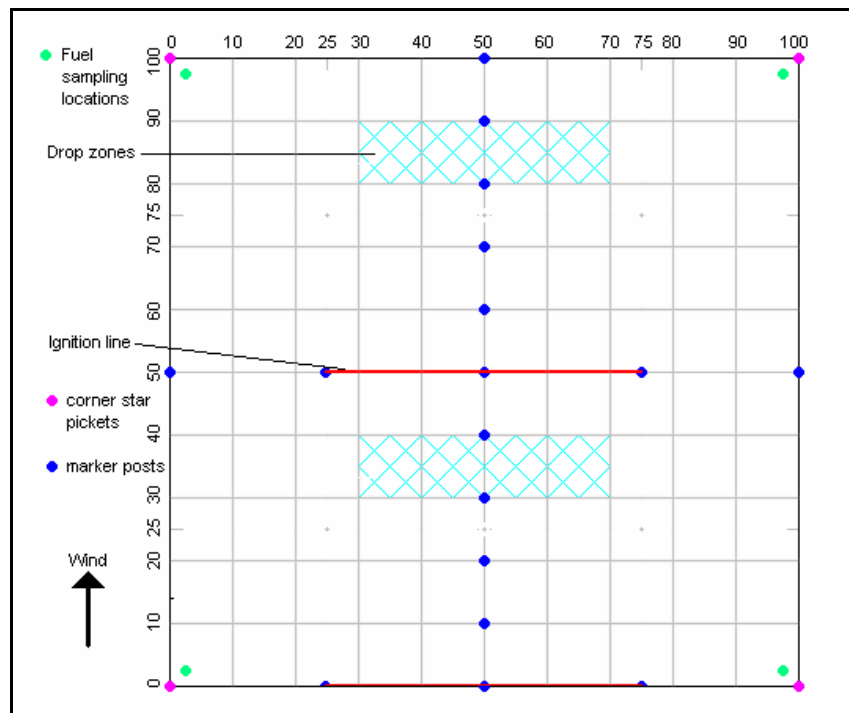
The main factors that were tested in this experiment were delivery system, suppressant type and fire behaviour. Both the bellytank and bucket delivery systems were used with both water and water with foam mix injected. Fire behaviour was relatively consistent for these experiments due to the stable fuel, terrain and weather conditions. The pilot was asked to fly at a consistent speed and height for all drops. All fires were ignited by a 50 metre line set perpendicular to the wind direction and were allowed to progress between 30-40 metres before they were suppressed by the helicopter. The schedule used for the head fire experiment is given in Table 2. All head fire drop experiments were conducted on Tuesday 22 February 2005.

**Table 2: Schedule for head fire drop experiments**

Plot	Plot side	Delivery system	Suppressant	Ignition time	Drop time
A	west	bellytank	water	11:15:10	11:17:52
A	east	bellytank	foam	11:28:30	11:31:00
B	north	bucket	water	13:00:00	13:03:22
B	south	bucket	foam	13:15:30	13:18:51
E	north	bellytank	water	13:59:16	14:00:52
E	south	bellytank	foam	14:13:10	14:14:30
F	north	bucket	water	14:37:40	14:43:21
F	south	bucket	foam	15:09:10	15:10:41

### 2.4.1) Plot layout

Four of the 100 m X 100 m plots were used for these experiments (plots A, B, E, and F), with two experiments conducted in each plot. Plots A and E were used for the tests with the bellytank, as they were closer to obstacles that would have limited the manoeuvrability of the bucket. The plots were split perpendicular to the wind direction, with the up wind half of the plot burnt first, so the second fire would run into burnt ground if it wasn't stopped by the drop. The split plots were referred to by the location of their halves, e.g. plot A west and plot A east. The plots had been marked out with galvanised dropper posts every 10 metres along the central axis, with spread rates being calculated by noting the times that the fire reached each post (Gill and Knight, 1991). The marker posts were adjusted to be one metre tall, so they could be used as a photographic reference for flame height. Larger star pickets were used to mark the corners of each plot, with witch's hats placed on top of the pickets marking the active plot, to maximise visibility from the helicopter. The plot layout is illustrated in Figure 4. Metal tags were thrown to mark fire and drop locations during the experiments. These were numbered allowing the time of placement to be determined from the video footage. Fire intensity was calculated using Byram's (1959) equation, assuming that the heat yield of the stubble fuel was  $18,000 \text{ kJ.kg}^{-1}$ .



**Figure 4: Plot layout for head fire drop experiments**

## 2.4.2) Test procedure

The ignition line was usually centred along the plot axis. The ignition line was offset on some occasions when the wind was not perpendicular to the plot direction. In these cases the adjustment was made so that the tip of the head fire would be near the central axis when the drop was executed. The 50m lines were ignited by two people with drip torches walking from the centre point to the ends. These were clearly marked and the igniters were instructed to walk at a constant rate. The fires in plot A were burned under an easterly wind. The wind direction during the other fires was mainly from the south and south east. The first ignition in plot B commenced during an easterly wind, but the direction changed to the south as the line was being ignited, so it was quickly abandoned and extinguished, then later lit for the new southerly wind direction. Plots E and F were burnt under a southerly wind.

Once the line was ignited each flank was filmed by a by two staff with a video camera. They placed metal tags to mark positions of the fire and the suppression drop during the event. The cameras were focussed towards the head fire, and were operated so that verbal comments could be recorded. Video footage was also taken by a cameraman in a second helicopter, who was instructed to keep the entire plot (all four corners) in the field of view at all times. The aerial footage was used to reconstruct the spread of the fire. Still photographs were taken by another person, who moved around the fire to get the best view. Suppression crews and vehicles were stationed at the sides of the plot, inline with the ignition line. An incident controller coordinated communications between the ground personnel and helicopter. The incident controller directed the helicopter to the desired location for each drop once the research team had assessed the fire to have spread at least 25 metres from the ignition line. The helicopter operated its siren during drops to alert ground personnel.

After the firebombing helicopter had cleared the drop zone, the teams moved in to make close observations of the resultant fire behaviour, and to mark the ends of the drop and the length of fireline it had extinguished with marker tags. Drop zones were monitored until the effect was obvious, though this impact was generally immediately apparent. The suppression crew knocked down the flanks, starting from the ignition line, after the drop had occurred. Once the perimeter of the fire had been made safe, the researchers made a few basic measurements, as experiments were often done in fairly quick succession so that the helicopter did not have to shut down. The plots were comprehensively surveyed after all of the fires had been extinguished.

The footage recorded on the video cameras was reviewed and used to log events during each of these fires. The time stamp and filming of the global positioning system (GPS) time at the start of each tape allowed the times to be synchronised so that events could be logged to the exact second.

### 2.5) Fire line length experiment

The fire line length experiments were conducted in plots B, G, and H and consisted of lighting a line of a given length and allowing it to run for a few metres before being suppressed by a single drop. This was done to determine the effectiveness of drops on different lengths of fire. Twelve line length experiments were conducted, with lines of 5, 10, 15 and 20 metres ignited. Metal tags marked the location of the fire for measuring spread and the drop areas.

Both delivery systems and suppressant types were tested (Table 3). However foam was only used once in combination with the bellytank due to a malfunction in the foam injection system.

**Table 3: Schedule for line length experiments**

Plot	Delivery System	Suppressant	Ignition line length (m)	Date	Ignition time	Drop time
B	Bucket	Water	10	22-Feb	15:24:53	15:25:58
B	Bucket	Water	20	22-Feb	15:29:49	15:30:31
G	Bellytank	Water	5	23-Feb	12:43:15	12:43:58
G	Bellytank	Water	10	23-Feb	12:47:35	12:48:17
G	Bellytank	Water	15	23-Feb	12:51:45	12:52:21
G	Bellytank	Foam	5	23-Feb	12:58:11	12:59:49
G	Bellytank	Water <sup>1</sup>	10	23-Feb	13:03:40	13:04:33
G	Bellytank	Water <sup>1</sup>	15	23-Feb	13:10:00	13:10:57
H	Bucket	Water	10	23-Feb	14:07:00	14:07:45
H	Bucket	Water	15	23-Feb	14:13:16	14:14:01
H	Bucket	Foam	10	23-Feb	14:18:40	14:20:20
H	Bucket	Foam	15	23-Feb	14:27:50	14:28:49

<sup>1</sup> Scheduled to be foam but foam injector failed.

## **2.6) Multiple drop fire suppression experiment**

These experiments involved larger fires than the previous ones. Three plots, C, D and I, were used. Plots C and D were ignited by a 50 metre line, and plot I ignited with an 80 metre line. These fires were allowed to spread for 40 metres before suppression commenced. A small (5 metre) spot fire was also ignited in Plot I while the main fire was being attacked. These experiments were carried out in quick succession. The only delivery combination used was the bellytank loaded with water, as changing over to the bucket would have taken some time, with the pilot having to change seats and also shut the helicopter down. Additionally the helicopter foam injection system was still not operating correctly. The air attack supervisor determined what tactics were used to contain the fires.

## **2.7) Aircraft tracking with GPS**

Aircraft flying characteristics, such as speed and height above ground at the time of drops were collected using the track log from the Global Positioning System (GPS) mounted in the helicopter. The GPS track log contains coordinates, speed and altitude recorded at irregular time intervals ranging from 1 to 15 seconds. The point closest to the time of the drop was selected for analysis. This was investigated for all experiments.

## **3.0) Results**

### **3.1) Weather observations**

The weather observations during each of the experiments are presented in Tables 4 - 7 and graphically for the three experimental days in Appendix 1.

The weather recorded during the drop pattern tests is given in Table 4. This data comes from the Bureau of Meteorology's Hobart Airport weather station, as the on-site AWS data was unavailable due to a logging problem. Wind speeds on site, measured with a hand held anemometer, were considerably lower than that measured at the airport (see Appendix 1), with average speeds recorded on site being between 5 and 10 km.h<sup>-1</sup>, and gusts estimated to be about 15 km.h<sup>-1</sup>. This difference is much greater than the difference that would be associated with the heights that the measurements were made at (10 metres at the airport and two metres on site). The wind on site was also estimated to be coming from a direction between 100-105° (ESE) for the duration of the experiment. The differences in wind measurements between these two sites are probably due to the location of the airport on an open bay (to the south), and the experimental site having buffering from a line of trees about 100 metres south of and parallel to, the drop grid (see graphs in Appendix 1). The temperature was warmer at the site than at the airport as it was less exposed to the sea breeze.

**Table 4: Weather recorded at Hobart airport during the drop tests on 21 February 2005**

Drop No.	Time	Temp (°C)	Relative humidity (%)	Wind speed (km.h <sup>-1</sup> )	Wind gust speed (km.h <sup>-1</sup> )	Wind direction (°)
1	13:21	20.7	66	26	28	157
2	13:31	21.1	66	24	28	157
3	13:42	20.6	67	22	26	156
4	14:02	21.0	63	25	29	167
5	14:16	21.2	64	26	30	175
6	14:48	20.5	69	26	30	165

The weather was mild on 22 and 23 February 2005. The Grassland Fire Danger Index (GFDI) remained in the lowest part of the high range for the working parts of both days. The east and south easterly winds kept the humidity consistently high. The experiments would have benefited from having warmer and drier weather conditions in the afternoons, as this would have allowed for more intense fire behaviour and allowed the testing against mild fire behaviour experienced during the mornings. Higher fire intensity would have lowered the probability of successful suppression.

Tables 5 -7 show the weather observations from the on site AWS during the three different fire suppression experiments. The Grassland Fire Danger Index was calculated using Noble *et al.*'s (1980) equations with data from Hobart Airport, as this is the site of the regions fire weather forecasts. Fuel moisture content (FMC) was also calculated using Noble *et al.*'s (1980) equations for McArthur's meters, but using the on site AWS data.

**Table 5: Summary of weather during head fire drop experiments**

Plot/ side	Ignition time	Temp (°C)	Relative humidity (%)	Wind speed (km.h <sup>-1</sup> )	Wind direction (°)	Wind gust (km.h <sup>-1</sup> )	GFDI	FMC (%)
A W	11:15:10	21.8	68.0	9.4	100.5	14.7	10	12.9
A E	11:28:30	22.0	66.5	6.1	85.0	10.2	9	12.6
B N	13:00:00	22.8	66.5	8.7	83.0	15.1	10	12.2
B S	13:15:30	23.1	66.0	9.9	132.0	12.9	12	12.0
E N	13:59:16	23.3	67.0	10.6	154.5	15.7	12	12.1
E S	14:13:10	23.6	66.0	10.3	146.5	17.4	14	11.8
F N	14:37:40	23.5	66.5	11.8	142.0	19.1	10	11.9
F S	15:09:10	23.4	67.0	11.0	140.5	16.5	11	12.0



### 3.3) Drop pattern tests

Each of the drops investigated are described in detail in Sections 3.3.1-3.3.6. An oblique view of the drop pattern footprint and contour plot showing coverage levels is given for each drop. The oblique view indicates the three dimensional structure of the drop footprint, clearly defining peaks and consistency in coverage (Biggs, 2004). More graphical information, including down and cross range sections, and still images from video footage captured during each drop are given in Appendix 1.

#### 3.3.1) Drop 1: Bellytank with water: 1 door

The helicopter tracked along the line of containers 5m from the right (south eastern) edge for this drop. However, the greatest volumes of water were recorded on the 10m container line, due to the cross wind. There were three distinct peaks of coverage along the axis of this footprint (Figure 5). The greatest coverage level landed on the right side of the 10 metre line (Figure 6). This drop was the longest recorded, due to the pilot only opening 1 door. The length and width of the drop above  $0.5 \text{ Lm}^{-2}$ , recommended for grass fuels by the ORE project (George, 1985, 1990), are 80 and 12 metres respectively. The base of the bellytank was estimated to be about 14m above the ground during this drop from the video footage.

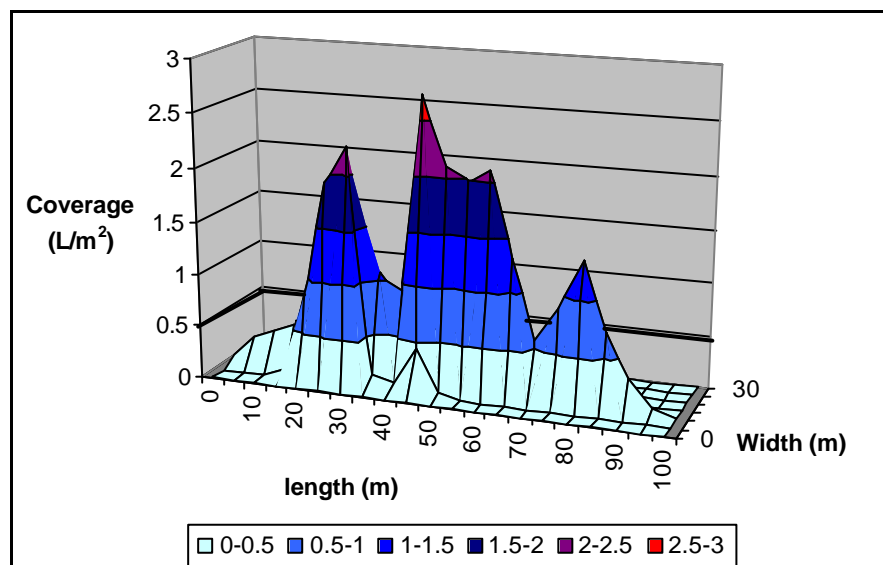


Figure 5: Oblique view of the drop pattern footprint for drop 1

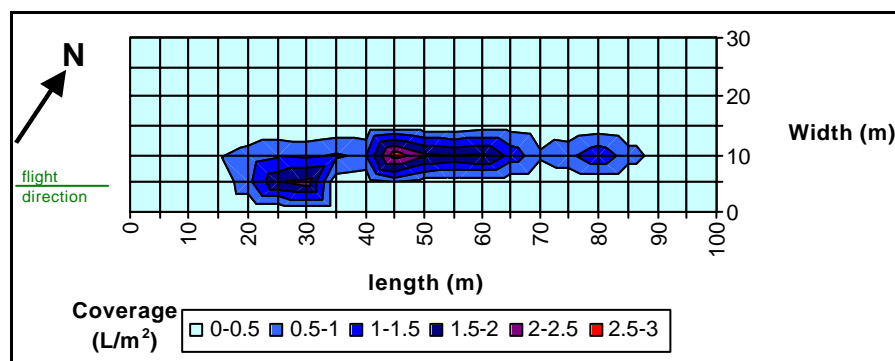


Figure 6: Drop 1 footprint coverage

### 3.3.2) Drop 2: Bellytank with foam mix: 2 door

The helicopter tracked along the line of containers 5m from the south eastern edge during this drop. However, much of the water landed along the line 5m to the northwest, with the highest coverage ( $4.66 \text{ Lm}^{-2}$ ) recorded 30m along the 5m line (Figure 7). This was the highest coverage recorded in all of the drop tests. The containers on either side of this point on the same axis were blown out of their holding container during the drop (Figure 8). The lighter parts of the drop were more affected by wind drift than the heavier parts. The width of this drop above  $0.5 \text{ Lm}^{-2}$ , was 14 metres. The length above this level was 53 metres, however this contained a two metre section with coverage below this level. The base of the bellytank was estimated to be about 11m above the ground during this drop.

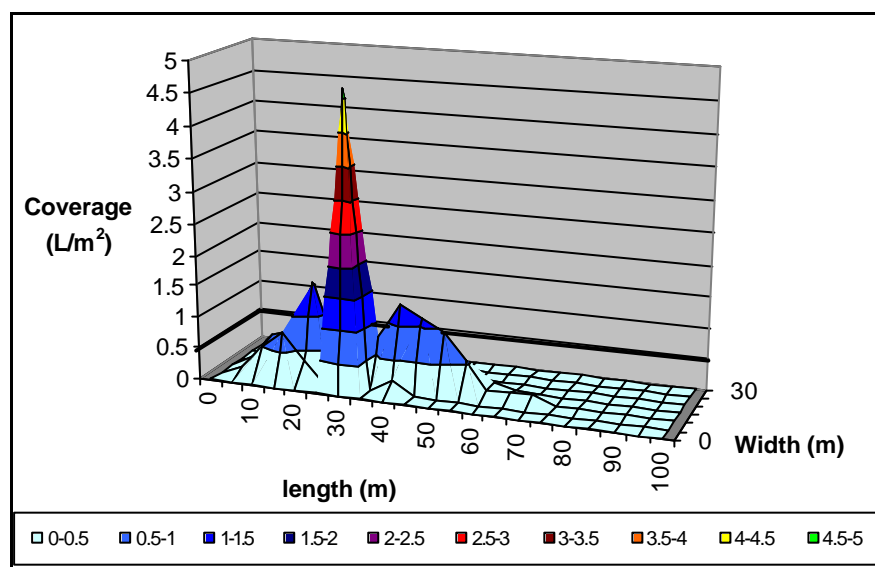


Figure 7: Oblique view of the drop pattern footprint for drop 2

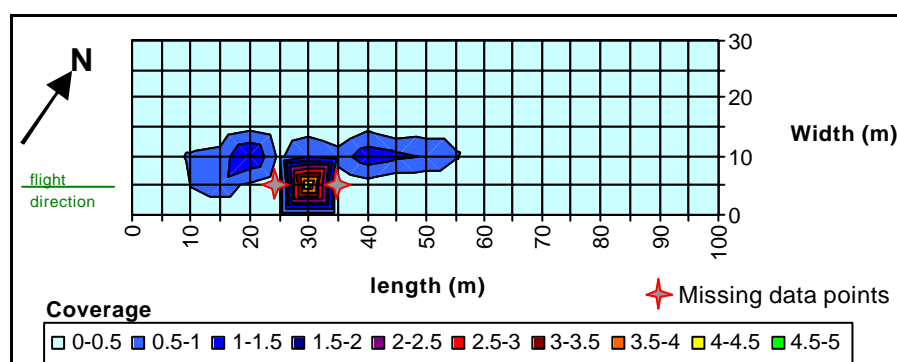


Figure 8: Drop 2 footprint coverage

### 3.3.3) Drop 3: Bellytank with water: 2 door

The helicopter tracked along the line of containers 20m from the south eastern edge of the grid during this drop (Figure 9 and Figure 10). The greatest coverage was recorded on the line 25m from the south eastern edge, due to the cross wind. This drop was very similar in dimensions to drop 2, but with only water. The length of this drop above  $0.5 \text{ Lm}^{-2}$ , was 53 metres, while the width was 13 metres. A large number of cups were blown away after this drop, when the helicopter landed nearby. The affected cups were in the most southerly lines, and were unlikely to have captured any

suppressant from this drop as they were located up wind. This drop combination was repeated in drop 4, in case any data had been lost. The base of the bellytank was estimated to be about 13m above the ground during this drop.

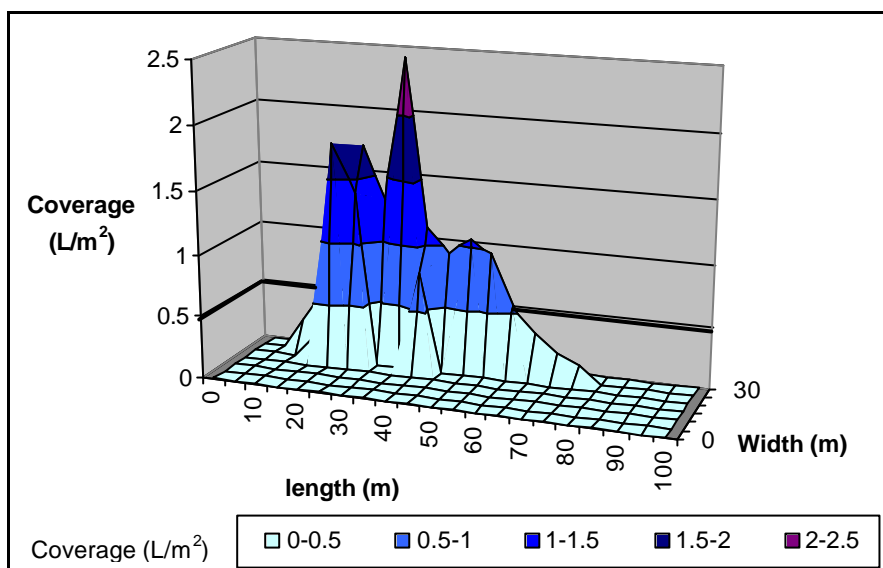


Figure 9: Oblique view of the drop pattern footprint for drop 3

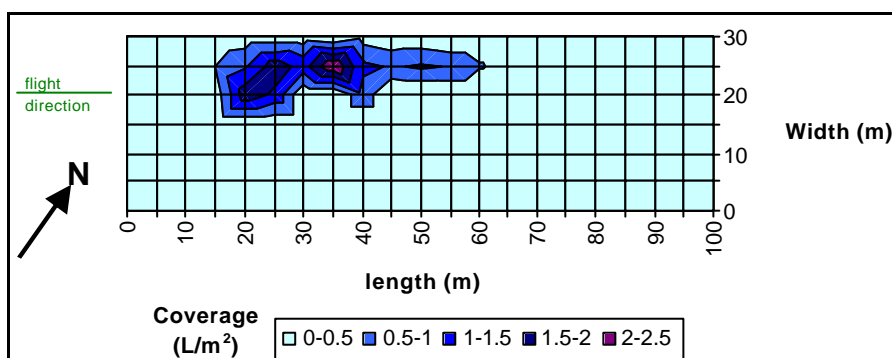


Figure 10: Drop 3 footprint coverage

### 3.3.4) Drop 4: Bellytank with water: 2 door

This drop was a repeat of drop 3. However it was not as successful as drop 3, as some containers in the main impact zone were blown over during the drop. The helicopter tracked along the line of containers 15m from the south eastern edge of the grid (Figures 11 and 12). The maximum coverage recorded for this drop were the lowest of all the bellytank drops. The main part of the drop was probably in the area where the containers were knocked out of their holding container. The length of the drop above  $0.5 \text{ Lm}^{-2}$ , was 40 metres, however this contained two major gaps due to the missing data points. The width above coverage level 1 was 14 metres. The base of the bellytank was estimated to be 11m above the ground during this drop.

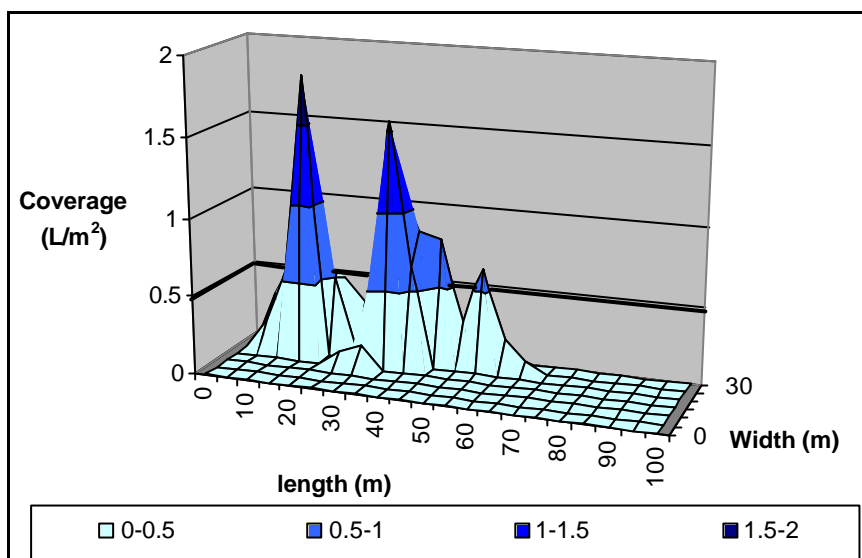


Figure 11: Oblique view of the drop pattern footprint for drop 4

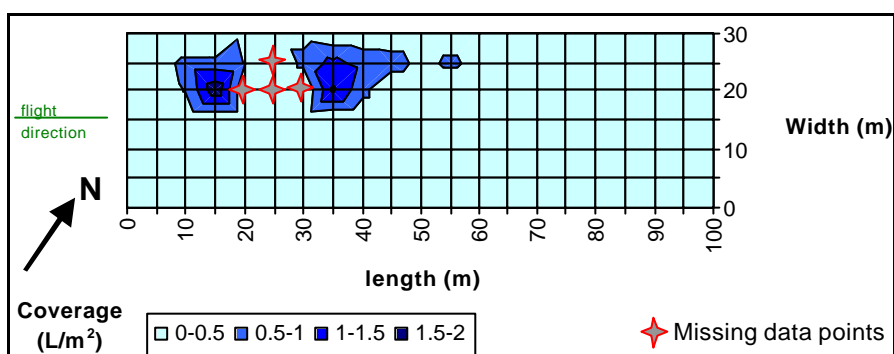


Figure 12: Drop 4 footprint coverage

### 3.3.5) Drop 5: Bucket with water

The bucket tracked along the south eastern edge of the grid during this drop, but veered slightly north (left) during the drop. This was due to the bucket swaying. It is likely that some of the drop missed the grid on the southern side (Figure 13). This drop was the widest of the drops undertaken, although only trace amounts ( $\sim 0.1 \text{ Lm}^{-2}$ ) of water were measured on the northern side of the drop. Two containers were blown over at the end of the drop (Figure 14). The length of this drop above  $0.5 \text{ Lm}^{-2}$ , was 59 metres, however would have been greater than this if no containers had been lost. The width above coverage level 1 was 14 metres. The base of the bucket was estimated to be 14m above the ground during this drop.

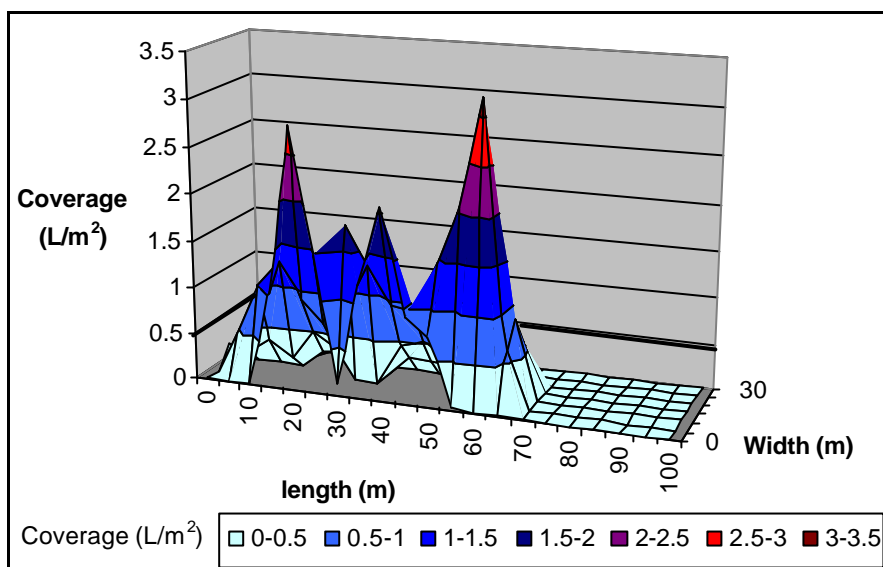


Figure 13: Oblique view of the drop pattern footprint for drop 5

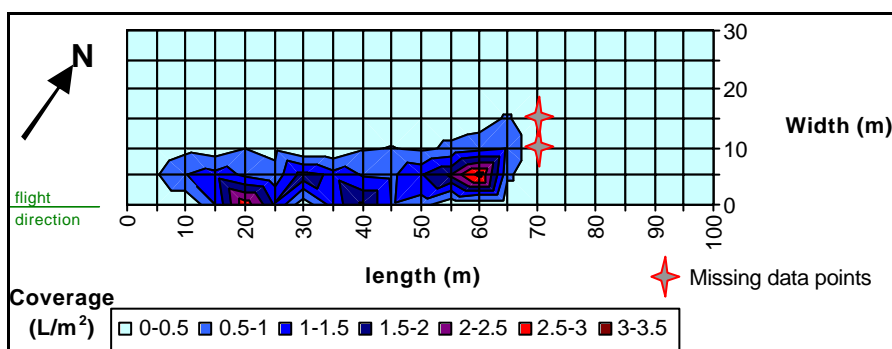


Figure 14: Drop 5 footprint coverage

### 3.3.6) Drop 6: Bucket with foam

The helicopter tracked along the line of containers 20m from the south eastern edge of the grid during this drop. Many containers were lost during this drop because the drop was too low, and the impact of suppressant knocked many of the containers out of their holding containers. This did not leave enough data points to estimate a reasonable drop pattern (Figures 15 and 16) or estimate the area above  $0.5 \text{ Lm}^{-2}$ . The base of the bucket was estimated to be only 4m above the ground during this drop.

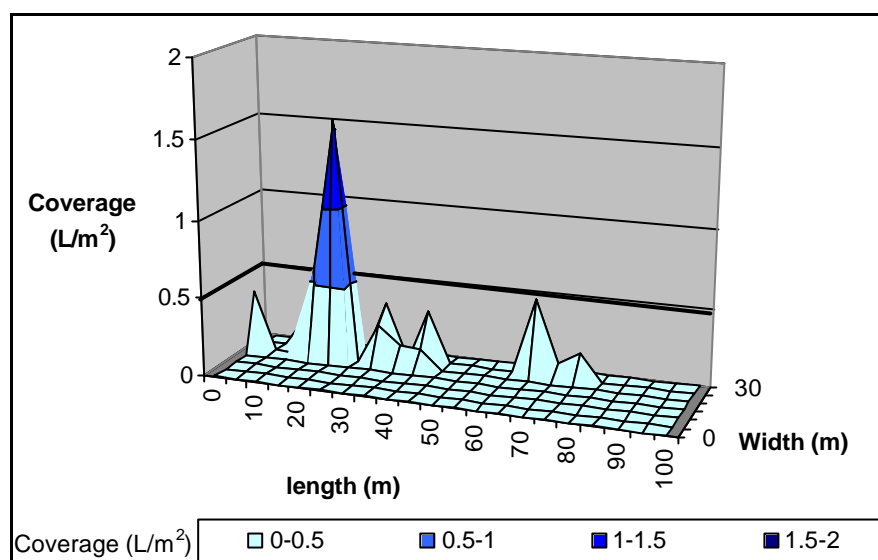


Figure 15: Oblique view of the drop pattern footprint for drop 6

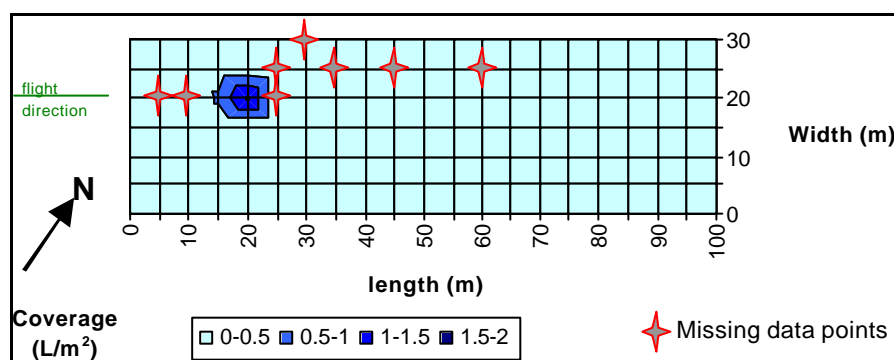
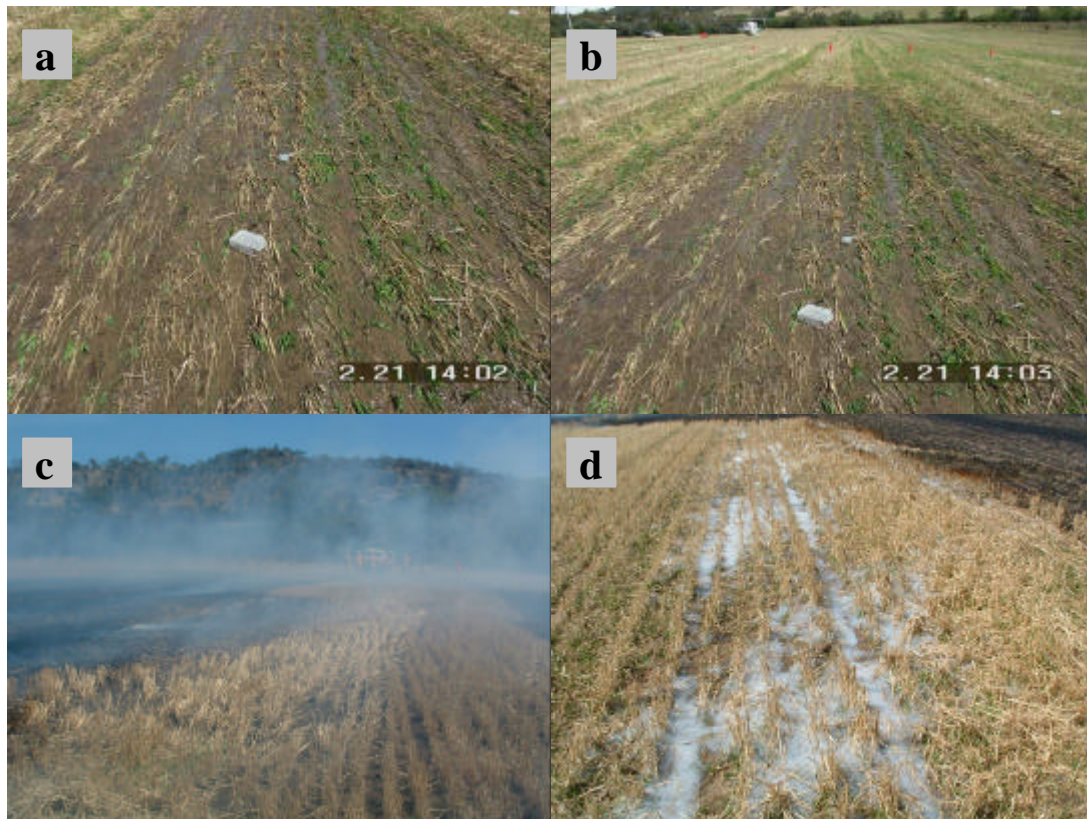


Figure 16: Drop 6 footprint coverage

### 3.3.7) Drop saturation zone quantification

The area of ground saturated by the drops has been termed “drop saturation zone” (DSZ) for these experiments. Most of the grass in this area was temporarily flattened by the of the drop (Figure 17a and b). The DSZs from foam drops were much easier to identify than those from water drops (Figure 17d). These areas could be easily identified during the drop tests and fire suppression experiments. The possibility of determining suppressant coverage levels across DSZs was explored using the DSZs determined during the drop tests and determining the spot coverage level samples from the containers within the area. An average coverage for DSZs would allow the estimation of the coverage being applied to fires during suppression experiments. The method for quantifying DSZs could also be used to calculate the proportion of the drop volume found within the m.



**Figure 17: Drop saturation zones** (a & b during drop pattern tests, c & d during fire experiments)

The dimensions of DSZs during the drop tests (Table 8) were used to determine an area, assuming a rectangular shape. The average coverage level of the drop, captured by the trays in the DSZ was calculated. The percent of the total load volume to fall within the DSZ was determined by calculating the volume of suppressant in the DSZ and determining what percentage of the drop volume this made.

**Table 8: Drop saturation zone characteristics during drop tests**

Drop*	Delivery system	Length (m)	Width (m)	Coverage level (Lm <sup>-2</sup> )		Percent of total load volume captured in DSZ
				Average	S.E.	
1	Bellytank (1 door)	65	5	1.54	0.19	42.3
2	Bellytank (2 doors)	40	6	1.73	0.60	35.0
3	Bellytank (2 doors)	40	5	1.42	0.19	24.0
4	Bellytank (2 doors)	35	6	1.41	0.21	25.0
5	Bucket	55	6	1.76	0.22	40.7

\*Drop 6 not used because too many trays were destroyed

The percentages of the load volumes calculated in the DSZ were low, with an average of only 33.4%. These results found the average coverage level in the drop areas to vary between 1.4 and 1.8  $\text{Lm}^{-2}$  in drops 1-5. These levels are low and too light to flatten grass, as are the recommended coverage level (0.5  $\text{Lm}^{-2}$ ). The spatial variability of coverage level within the drop zones probably led to poor estimates of average coverage levels. This problem is likely to have been exacerbated by the coarse grid (5m) used which may have missed many sections of high coverage. When making drops the helicopter tracked along the rows of trays. The dropping suppressant drifted to the side by the cross wind, which would have caused the heaviest coverage between the rows of containers, leading to the low reading. Because of this problem, the average coverage or proportion of load volume to fall in the DSZs cannot be confidently estimated.

### 3.4) Head fire drop experiment

A summary of the fire behaviour observed during each experiment is given in Table 9. Rates of spread differed because of temporal variations in wind speed and slight differences in fuel. Patches in the fuels in plot B north and plot F north, caused the head fire to split and lead to slower spread rates during both experiments. The fire intensity was calculated with Byram's (1959) equation, using average spread rate and assuming a heat yield of 18000  $\text{kJ.kg}^{-1}$  and the consumption of all cured stubble (3.4  $\text{t.ha}^{-1}$ ).

**Table 9: Summary of fire behaviour during head fire drop experiments**

Plot	Side	Ignition time	Drop time	Spread rate ( $\text{m.hr}^{-1}$ )	Intensity $\text{kW.m}^{-1}$	Max. flame height (m)	Max. flame depth (m)	Min. flame angle ( $^{\circ}$ )
A	West	11:15:10	11:17:52	1125	1900	1.3	1.5	30
A	East	11:28:30	11:31:00	1385	2338	1.3	2.0	30
B	North	13:00:00	13:03:22	679	1147	0.9	1.5	30
B	South	13:15:30	13:18:51	554	935	1.2	2.0	20
E	North	13:59:16	14:00:52	2400	4052	1.3	2.0	30
E	South	14:13:10	14:14:30	1895	3199	1.4	2.0	20
F	North	14:37:40	14:43:21	600	1013	0.9	1.5	30
F	South	15:09:10	15:10:41	1440	2431	0.9	3.0	20

The characteristics of the DSZs recorded for each of these experiments are given in Table 10. These drops are more variable than those recorded during the drop tests in length, while the drop widths are virtually the same. The bucket drops were considerably longer than the bellytank drops.

The estimated coverage given in Table 10 were calculated by using the visible foot print area, and assuming that 33.4% of the volume of the load fell in this area. 33.4% was the average recovery level calculated in section 3.3.7, and, as mentioned previously, this is likely to be an underestimate. The coverage level of every drop was enough to completely extinguish all of the running headfires that were generated in these experiments. The suppressant had an immediate extinguishing effect on all intensities of headfire. The remaining partially burnt fuel shows the angle and shape of the flames at the time of extinction (see Figure 18).

**Table 10: Summary of drop characteristics during head fire drop experiments**

Plot/ side	Delivery system	Suppressant	Drop length (m)	Drop width (m)	Estimated coverage level (Lm <sup>-2</sup> )
A W	Bellytank	Water	32	5.5	2.2
A E	Bellytank	Foam	42	6.5	1.4
B N	Bucket	Water	50	5.5	4.1
B S	Bucket	Foam	53	4.5	2.0
E N	Bellytank	Water	50	5.5	1.4
E S	Bellytank	Foam	40	6	1.6
F N	Bucket	Water	49	3.5	2.8
F S	Bucket	Foam	60	5	1.6

**Figure 18: Fuels extinguished after drop**

Maps of the fire growth showing the locations of the drops for each head fire drop experiment are given in Figures 19- 22. All of these fires were fully extinguished along the length of the drops, whether they were directly hit, or later spread to the drop areas. Some fires burned around the drop when they were not put out by ground crews. The fires in plot A were burned under an easterly breeze (Figure 19). The wind changed to a southerly during the first ignition in plot B (Figure 20). This ignition was abandoned, and the lighting pattern was changed so the ignition line was perpendicular to the new wind direction. The fires in plot E spread the fastest, as there was a slight positive slope ( $\sim 5^\circ$ , Figure 21). The fire in the north half of plot F split into two when the headfire reached patchy fuels and had to be relit. This caused the fire to have an unusual shape (Figure 22).

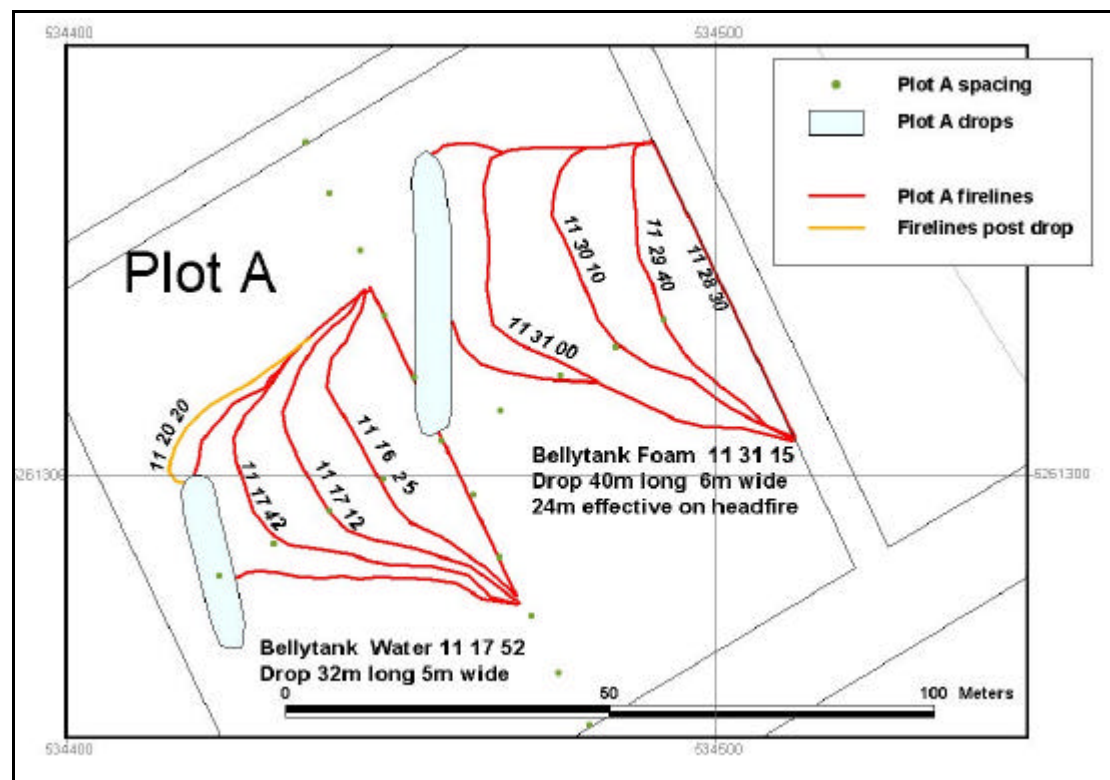


Figure 19: Fire growth map for plot A

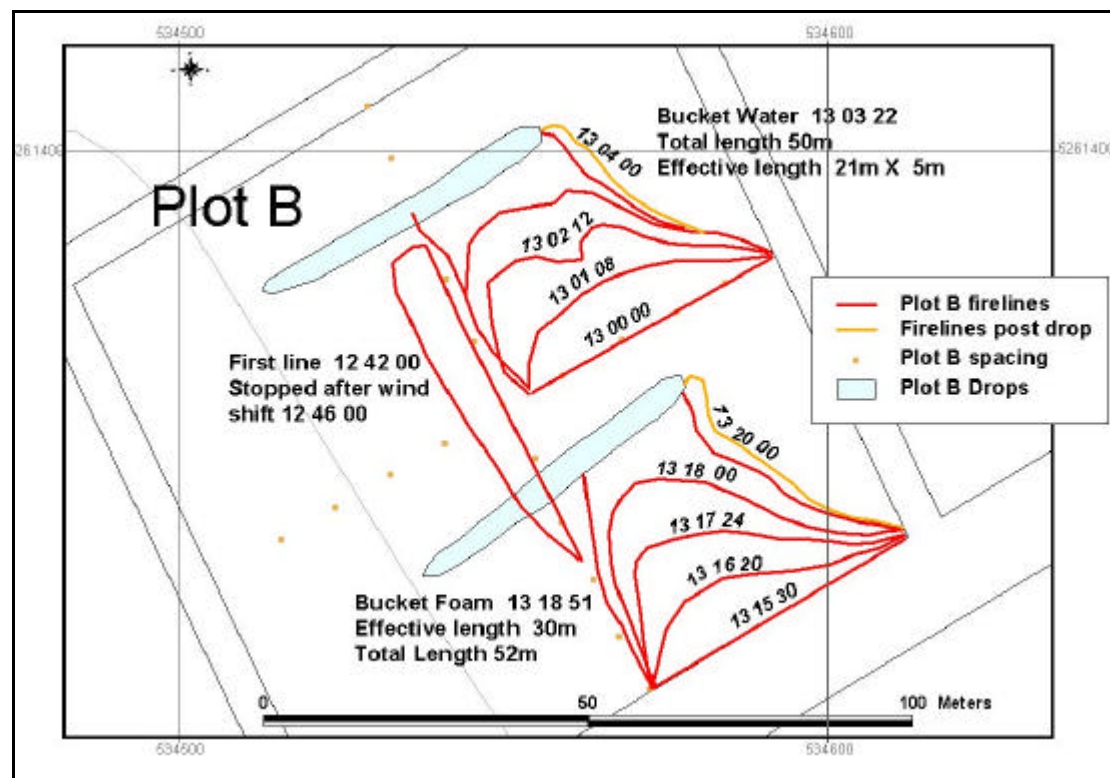


Figure 20: Fire growth map for plot B



### 3.5) Fire line length experiment

A summary of fire behaviour for line length experimental fires is given in Table 11, which shows the maximum fire line length ignited was 20 metres and the maximum distance travelled by the fires was 14 metres.

**Table 11: Summary of fire behaviour during line length experiments**

Plot	Date	Ignition line length	Ignition time	Drop time	Total distance fire travelled (m)	Spread rate (m.hr <sup>-1</sup> )	Intensity (kW.m <sup>-1</sup> )
B	22	10	15:24:53	15:25:58	14	77.5	1309
B	22	20	15:29:49	15:30:31	10	12.8	216
G	23	5	12:43:15	12:43:58	6	50.2	848
G	23	10	12:47:35	12:48:17	3	25.7	434
G	23	15	12:51:45	12:52:21	7	70.0	1182
G	23	5	12:58:11	12:59:49	6	22.0	372
G	23	10	13:03:40	13:04:33	9	61.1	1032
G	23	15	13:10:00	13:10:57	13	82.1	1386
H	23	10	14:07:00	14:07:45	5	40.0	675
H	23	15	14:13:16	14:14:01	5	40.0	675
H	23	10	14:18:40	14:20:20	7	25.2	426
H	23	15	14:27:50	14:28:49	8	48.8	824

The drop characteristics for these experiments are given in Table 12. All of the bellytank drops were much shorter than the drops from the bucket, with average lengths of 20 and 38 metres respectively. Both drop types were considerably shorter than those measured during the drop pattern tests and the head fire intensity experiments. The pilot flew slower during these drops to make the drops shorter in order to meet the smaller target size.

**Table 12: Summary of drop characteristics during line length experiments**

Plot	Delivery system	Suppressant	Ignition line length	Drop length (m)
B	Bucket	water	10	40
B	Bucket	water	20	50
G	Bellytank	water	5	19
G	Bellytank	water	10	22
G	Bellytank	water	15	21
G	Bellytank	foam	5	21
G	Bellytank	water	10	21
G	Bellytank	water	15	19
H	Bucket	water	10	35
H	Bucket	water	15	35
H	Bucket	foam	10	40
H	Bucket	foam	15	29

Fire maps for this experiment are given in Figures 23- 25. The aerial drops on all experimental fires stopped the forward spread of the fire in every case. Most fires had some sections of flank or backing fires that were still alight following the drops. These sections were extinguished by the ground crews soon after the drops, so that the



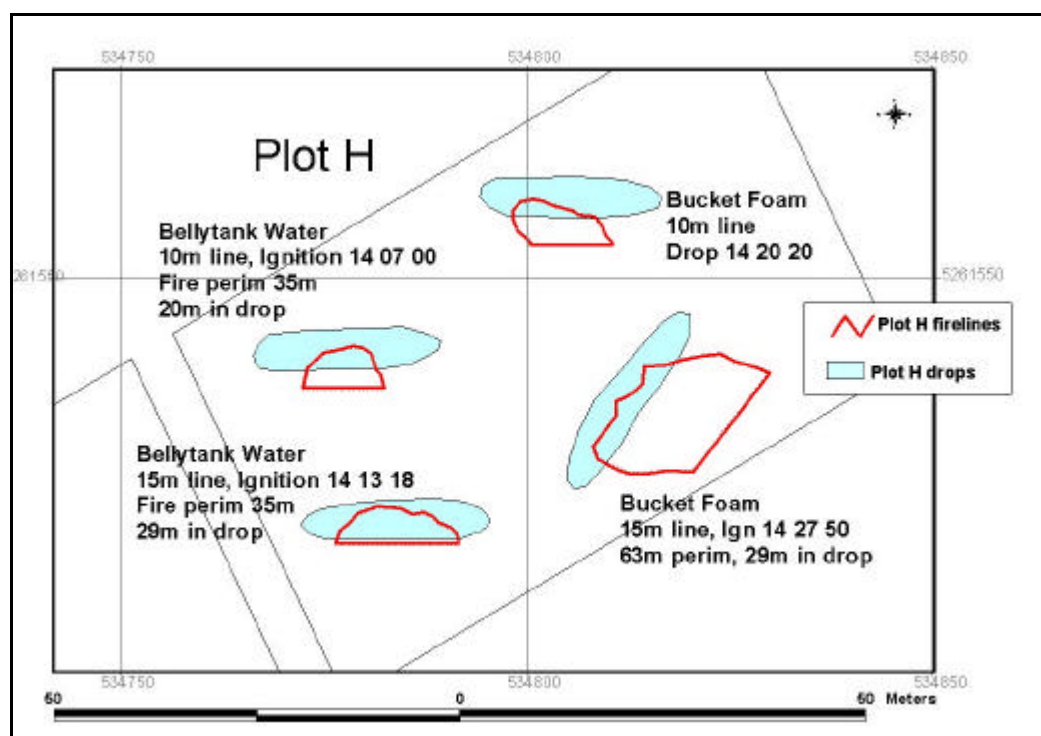


Figure 25: Fire maps for line length experiments conducted in Plot H

### 3.6) Multiple drop fire suppression experiment

The multiple drop suppression experiments involved the ignition of line fires that were allowed to spread for 30 to 40 metres before suppression commenced. The firebombing helicopter was the only suppression resource deployed on these fires, and was only tested with the bellytank and water combination.

General timing and fire behaviour information from these experiments is given in Table 13. The fire behaviour measurements were made before suppression commenced. The perimeter and area measurements were made after the fire had been extinguished. Coverage levels could not be estimated because most drops were split loads, and also overlapped with other drops.

Table 13: Summary of fire behaviour during line length experiments

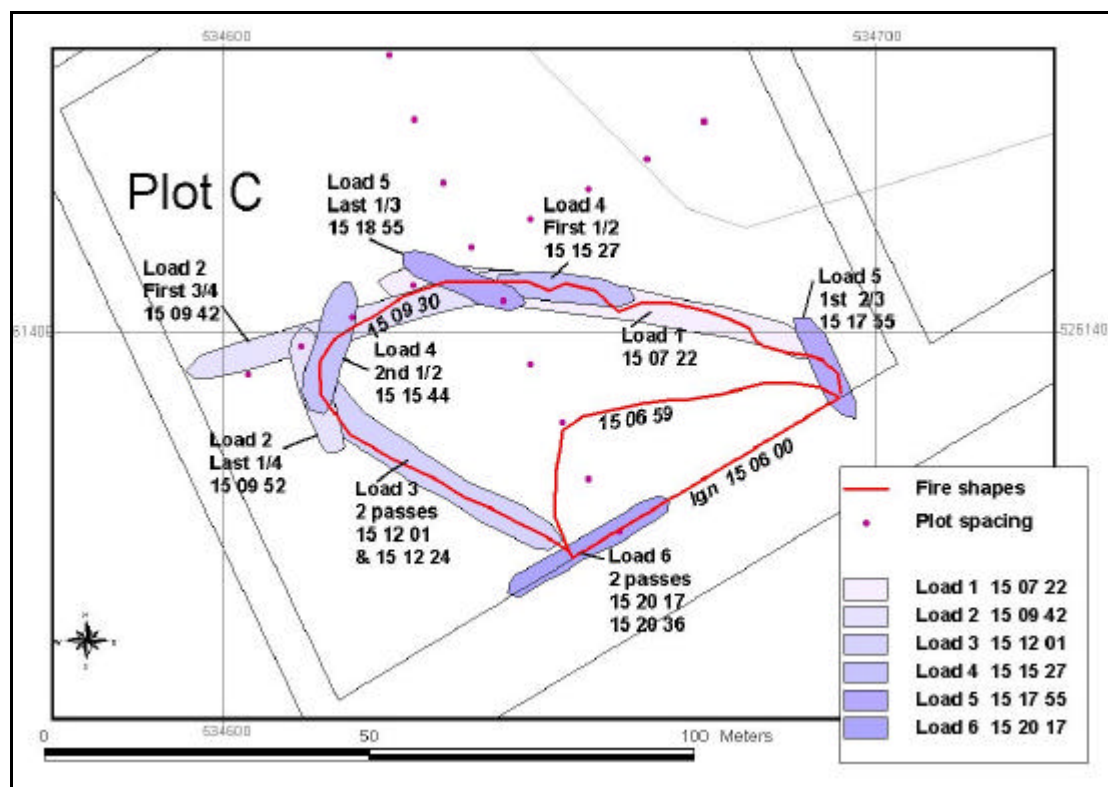
Plot	Ignition time	Ignition line length (m)	Time of first drop	Maximum spread rate (m.hr <sup>-1</sup> )	Max. Intensity kW.m <sup>-1</sup>	Max. flame height (m)	Perimeter (m)	Area (m <sup>2</sup> )
C	15:06:00	50	15:07:22	2000	1439	1.1	232	1639
D	15:21:02	50	15:23:17	1800	1319	1.3	220	2706
I	15:58:00	80	15:59:32	2250	1625	1.5	289	3302

A summary of drop times and locations for the Plot C fire is given in Table 14, and a fire growth map is given in Figure 26. This fire developed for 82 seconds and spread about 45 metres before the first drop. The first drop was made with the wind, which significantly increased its length and extinguished the majority of the right flank and tip of the head fire. The second and third loads were each split into two drops, and were used to extinguish the left flank. All forward spread of the fire was stopped by the first two loads (2min 30 sec), and the entire perimeter was contained by the first four drops (4min 40 sec), although the backing fire had burnt into the fuel break, so

the effective perimeter extinguished by the firebombing was 170 metres. The perimeter was blacked out by the fifth drop (8<sup>th</sup> drop, 10 min 30 sec). This equates to 21.25 metres of fire edge suppressed per drop or 970 metres of line constructed per hour ( $16 \text{ m min}^{-1}$ ) with an average turnaround time of 126 seconds.

**Table 14: Summary of drop times and locations during Plot C fire**

Drop	Load	Drop time	Turnaround time (s)	Drop location	Fire status
1	1	15:07:22		right flank and head tip	right flank checked
2	2	15:09:42	140	head side of right flank and head	head checked
3	2	15:09:52		left side of head & left flank	all forward spread checked
4	3	15:12:01	139	left flank	left flank checked (perimeter contained)
5	3	15:12:24		left flank	left flank black
6	4	15:15:27	206	right flank	head half of right flank black
7	4	15:15:44		head area	head fire black
8	5	15:17:55	148	base of right flank	all of right flank black (perimeter black)
9	5	15:18:15		middle of burnt area	
10	6	15:20:17	142	left flank, ignition line	
11	6	15:20:36		ignition line	

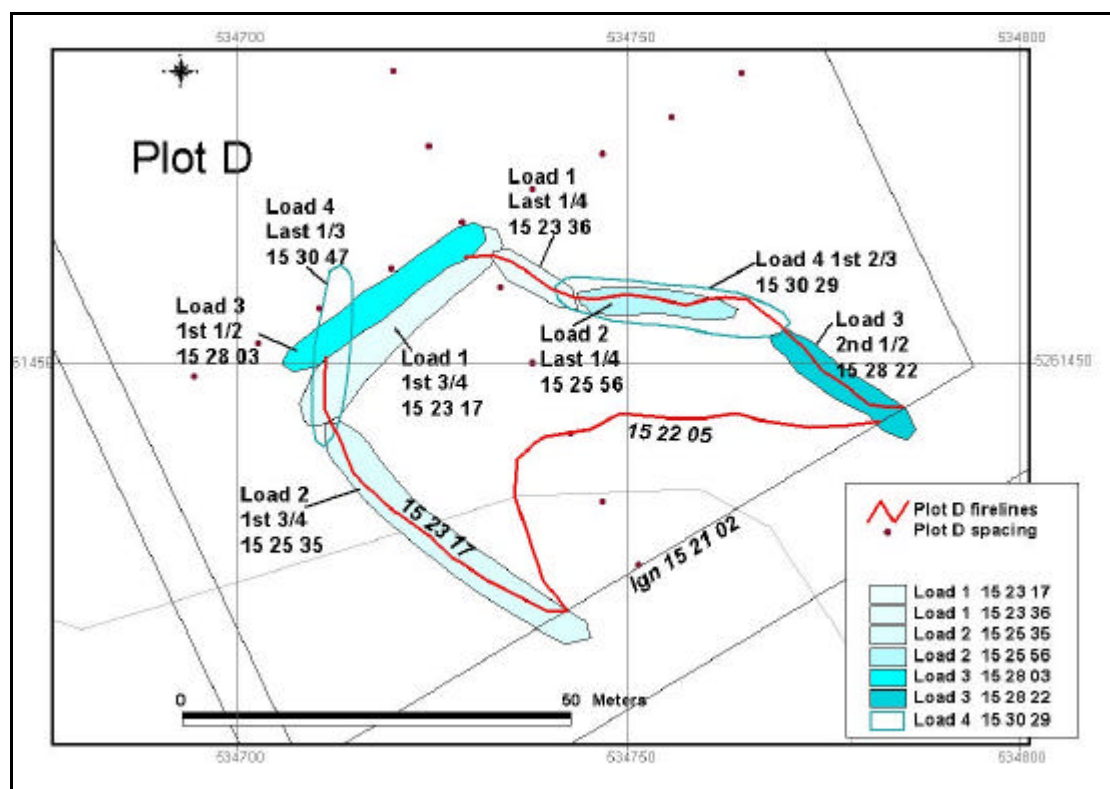


**Figure 26: Drop placement during Plot C fire**

The plot D fire was very similar to the plot C fire (Figure 27). This fire developed for 135 seconds before the first drop. The first drop checked the spread of the head fire, with a second drop from the same load used on the right flank, as listed in Table 15. The forward spread of the fire had been checked by the third drop (2min 20sec) and the head and flank perimeter (170m) was black before the 6<sup>th</sup> drop (5 min 5 sec). This is equal to 28.3 metres of fire edge suppressed per drop or 2000 metres of line constructed per hour ( $33.4 \text{ m.min}^{-1}$ ) with an average turnaround time of 102 seconds.

**Table 15: Summary of drop times and locations during Plot D fire**

Drop	Load	Drop time	Turnaround time (s)	Drop location	Fire status
1	1	15:23:17		across head	left side of head fire checked
2	1	15:23:36		head half of right flank	right side of head and head half of right side checked
3	2	15:25:35	138	tip two thirds of left flank	left flank black (perimeter checked)
4	2	15:25:56		right flank	all but 5m of right flank black
5	3	15:28:03	148	across head	head black
6	3	15:28:22		back third of right flank	Whole perimeter black
7	4	15:30:29	146	mid third of right flank in black	
8	4	15:30:47		across head	



**Figure 27: Drop placement during Plot D fire**

Plot I was ignited by an 80 metre line (Figure 28). This fire spread about 40 metres in 90 seconds, before the first drop took place (Table 16). The first drop was elongated by a following wind and fast helicopter ground speed and extinguished the majority of the right flank and the head of the fire. The second drop extinguished the left flank of the fire. A spot fire was ignited with a 5 metre line, on the western side of the main fire, immediately after the second drop. The third load was split into three drops which effectively extinguished this spot fire. The first half of the fourth load was used to extinguish the remaining left flank. This plot had a lower fuel load than the other plots ( $2.7 \text{ t.ha}^{-1}$ ) and the lighter fuels were observed to be more easily extinguished by light spray from the drops. Line construction rates for this fire were affected by the third load being dedicated to the spot fire. Excluding this load, the 240 metres of fire perimeter was extinguished in four loads, which is equivalent to 60 metres per load and a production rate of 2400 metres per hour ( $40 \text{ mmin}^{-1}$ ). This extra distance per load was achieved because the stretched out drops were able to extinguish flames with a much lower coverage than in the other plot and because the much of the backing fire self extinguished low fuel load.

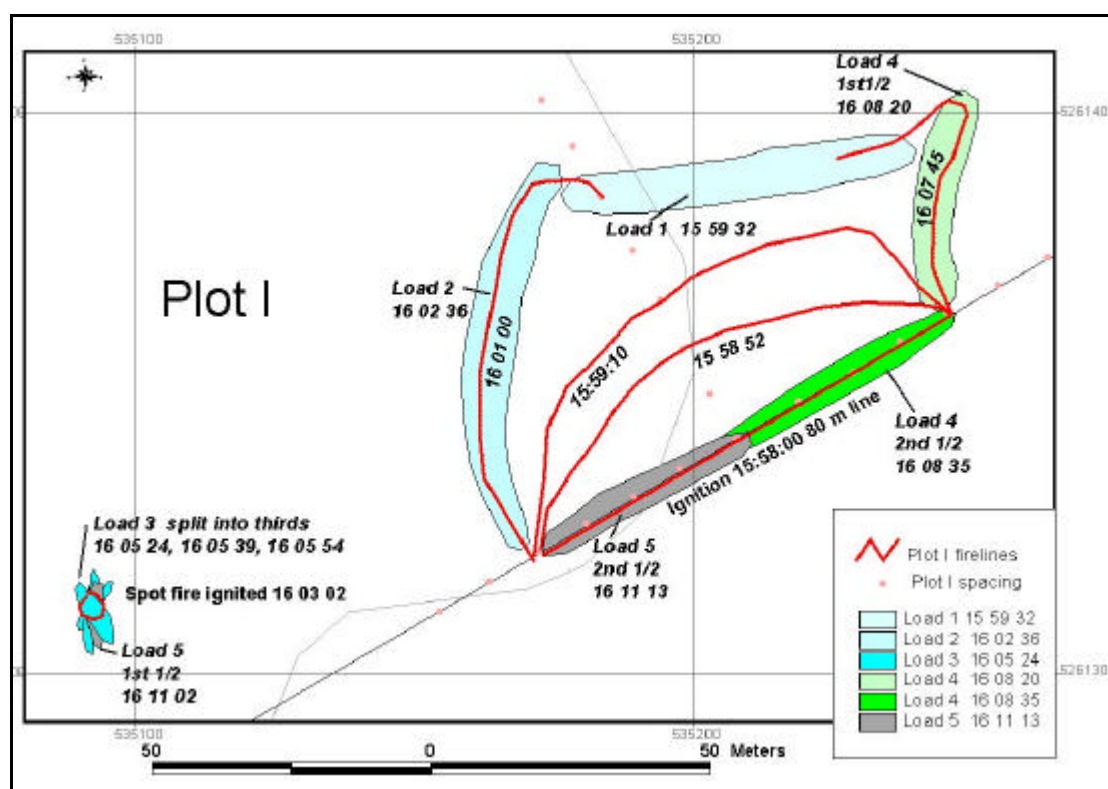


Figure 28: Drop placement during Plot I fire

**Table 16: Summary of drop times and locations during Plot I fire**

Drop	Load	Drop time	Turnaround time (s)	Drop location	Fire status
1	1	15:59:32		right flank and right half of head	head and 2/3 right side stopped
2	2	16:02:36	184	whole left flank	left flank black
3	3	16:05:24	168	right side of spot fire	half spot out
4	3	16:05:39		left side of spot fire	spread stopped on spot fire
5	3	16:05:54		on small remainder of spot	spot blacked out
6	4	16:08:20	176	remainder of right flank	all spread of fire checked
7	4	16:08:35		backfire/ ignition line	backfire flames extinguished
8	5	16:11:13	173	backfire/ ignition line	backfire black (perimeter black)
9	5	16:11:20		ahead of fire area (accidental)	

### 3.7) Helicopter GPS tracking results

The aircraft GPS was found to be of limited value because of the interval and irregularity of the points in the track log (1-15 seconds). The speed and altitude recorded for the drops can only be used as a guide, as the logging rate of the GPS did not allow measurement at the exact (calculated) second that the drop was made and the speed and direction of travel usually change within a few seconds of the drop. The GPS was not available for all drops as it was not always switched on at the start of each flight.

The GPS track was only available for the fifth and sixth drops during the drop pattern tests. The track for these two drops is illustrated in the Figure 29. From the tracks the speed (68, 64 km.h<sup>-1</sup>) and altitude of the helicopter (instrument panel 134, 96 ft (41, 29 m)) above the ground were determined from the nearest points to the drop location. The aircraft speed would be fairly accurate for these two drops as the helicopter was flying in a straight line at the time the points were logged. The speed of the helicopter was unable to be determined from the video footage as the witches hats identifying the ends of the 100m grid could not be identified clearly. The height of the delivery system could also be estimated at the beginning of each drop using still frames taken from the video footage, using a person as a reference. The calculated helicopter altitudes were about 10 metres (30 ft) higher than what was estimated from the video footage. The bellytank was estimated to between 10 and 15m above the ground in drops 1-4. Unfortunately the lack of GPS data on the first four drops prevented the comparison of aircraft speed and height with drop dimensions.

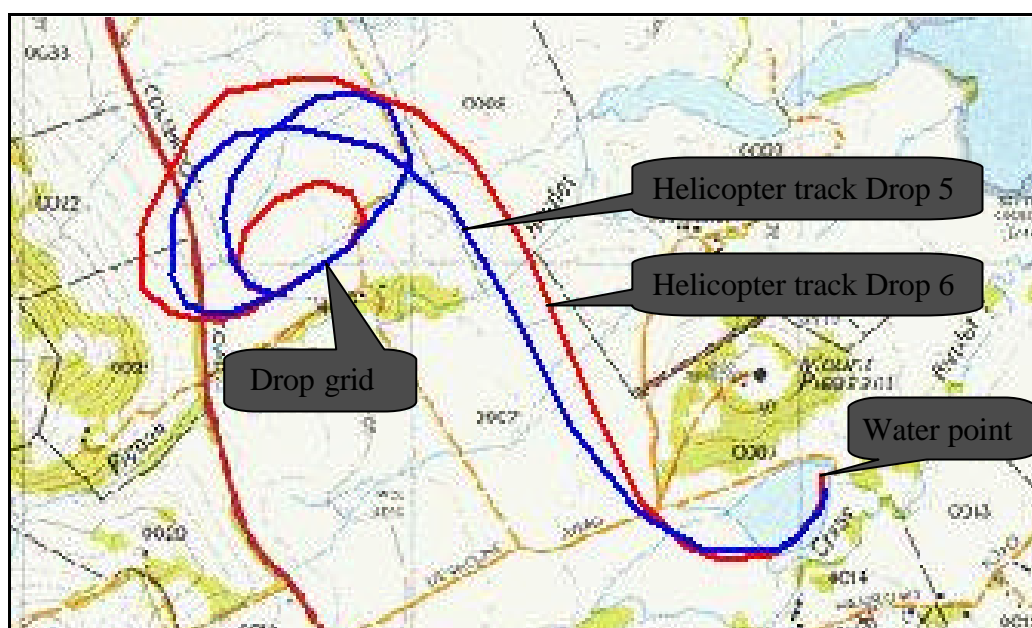


Figure 29: GPS track of aircraft movements for drops 5 and 6

The helicopter speed and delivery heights estimated from the GPS during the head fire intensity experiments are given in Table 17. The aircraft speed varied between 62 and 95 km.h<sup>-1</sup>, and were generally faster for the bellytank drops. The height was adjusted for the base of the delivery system by subtracting 1 metre for the bellytank, or 33 metres for the bucket. The differences between the nearest point in the track file, generated by the helicopter's GPS, and the time that the delivery commenced, varied between 1 and 6 seconds (Table 17). Since the helicopter's speed and direction usually changed around the time of the drop, the accuracy of the estimated speeds are limited. There were no significant correlations between the dimensions of the drops and the flight characteristics. Similar issues were found with the GPS data from the line length experiments (Table 18). The GPS was not turned on for the 6 drops made in plot G. Drop speeds and heights were not determined for the multiple drop experiments as the flight pattern had too many rapid changes in direction (Figure 30). The GPS could be used to collect data on turnaround times between drops for this experiment, and operationally.

Table 17: Summary of drop characteristics during head fire drop experiments

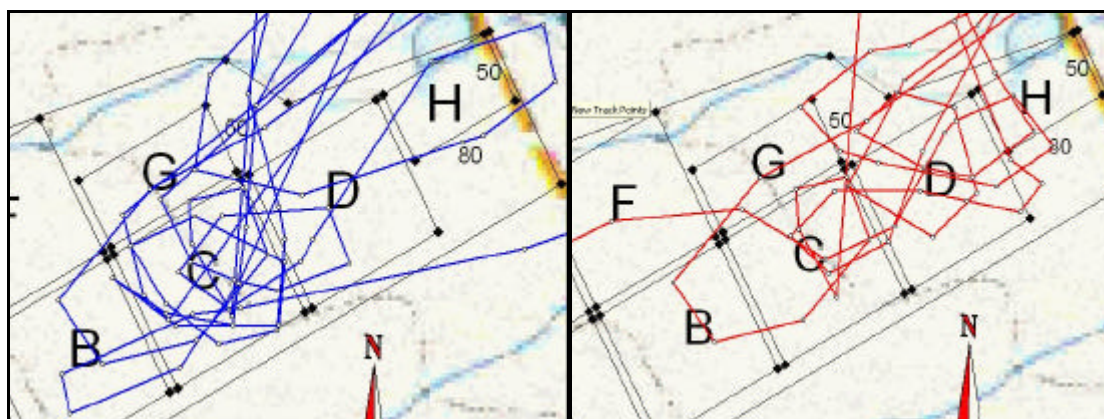
Plot/ side	Delivery system	Aircraft speed (km.h <sup>-1</sup> )	Delivery height <sup>1</sup> (m)	Time difference (sec)	Suppressant	Drop length (m)	Drop width (m)	Estimated coverage level (Lm <sup>2</sup> )
A w	Bellytank	94	17	1	Water	32	5.5	2.2
A e	Bellytank	95	9	3	Foam	42	6.5	1.4
B n	Bucket	84	28	4	water	50	5.5	4.1
B s	Bucket	70	27	6	Foam	53	4.5	2.0
E n	Bellytank	85	27	3	water	50	5.5	1.4
E s	Bellytank	94	25	3	Foam	40	6	1.6
F n	Bucket	62	30	-4	water	49	3.5	2.8
F s	Bucket	92	33	-2	Foam	60	5	1.6

<sup>1</sup> Delivery height has been adjusted for the base of the bellytank or bucket.

**Table 18: Summary of drop characteristics during line length experiments**

Plot	Delivery system	Aircraft speed (km.h <sup>-1</sup> )	Delivery height <sup>1</sup> (m)	Drop time	Time difference (sec)	Suppressant	Drop length (m)
B	Bucket	83.2	30.4	15:25:58	1	water	40
B	Bucket	68.9	19.4	15:30:31	8	water	50
H	Bucket	56.6	32.9	14:07:45	3	water	35
H	Bucket	70.4	38.0	14:14:01	1	water	35
H	Bucket	70.6	39.3	14:20:20	-1	foam	40
H	Bucket	78.3	36.8	14:28:49	-1	foam	29

<sup>1</sup> Delivery height has been adjusted for the base of the bellytank or bucket.

**Figure 30: Helicopter track during plot C and D fires**

#### 4.0) Discussion

The stubble fuels in the plots were simple to quantify, and were relatively uniform in comparison to other fuel types. The fires could only generate a limited amount of heat due to the low fuel load (3.4 t.ha<sup>-1</sup>). The fuel arrangement, with low to moderate density stubble to a maximum 30cm tall, gave short fire residence times and narrow flame depths. Fires were easily extinguished in this fuel type, as the fine light fuel particles were quickly consumed by flame fronts, with no lingering flaming or smouldering combustion to provide sources of reignition.

The open treeless paddock was easily surveyed for the experiments. Buffer zones were able to be burned around each plot, and provided effective fuel breaks and increased accessibility. The absence of a canopy and other obstacles in this fuel type allowed the entire volume of the drops (minus evaporative loss) to reach the surface without having any significant gaps in coverage. Similar experiments conducted in fuel types with trees or shrubs would have patchy coverage on surface fuels. Drops through canopies would not be as well represented by drop pattern tests conducted in open fuels, as they were for the stubble fires. Experiments in more complex fuels could also investigate the time required for fires to burn through drop zones.

The fire behaviour in the stubble fuels was relatively consistent, and simple to quantify. The fire shapes were usually uniform. There were three occasions where fires burned into patchy or green fuels, causing them to stall or split. This was rectified by relighting with drip torches, but this flame discontinuity still disrupted the

spread of the fires. The methods employed to measure fire behaviour worked well. The video footage of the fires proved essential for determining accurate spread rates, as the fires were too fast for adequate notes to be taken during the experiments. The marker posts, located along the central access of the plots, were sometimes difficult to see in the footage, and would have benefited from brighter or larger markings.

The weather conditions were relatively stable for the duration of the experiments. This enabled the fire behaviour in the experiments to be fairly consistent, and the drops to be affected by a similar amount of wind in the fire experiments and drop pattern tests. The consistent weather prevented fire behaviour from being tested as a factor in any of the experiments and prevented the fire behaviour from exceeding any suppression scenarios that were tested.

### *Drop pattern tests*

Four of the six drop pattern tests gave useful data for determining ground distribution patterns. These were drops 1, 2, 3, and 5. These drops were representative of drops that were made on the stubble fires during the suppression experiments on the following days. The third drop test was similar to the second. This was expected, given that the only difference was the suppressant used. The combination of bucket with foam mix (not tested), would probably have given a similar footprint to drop 5 (bucket with water). Too many containers were lost in drops 4 and 6 to characterise their drop patterns. The drop pattern tests were not continued after the 6th drop, as the supply of fresh containers was low, and also the helicopter needed to be refuelled.

The method used on these drop tests worked reasonably well. The team of people enabled a smooth and efficient transition between drops. The weather conditions experienced during the drops were very similar to those during the fire suppression experiments. The main problem experienced during the drop tests was the loss of data due to containers being lost. Some containers were dislodged or blown away, by the rotor wash. Fewer trays would have been lost if the site used for the grid had been smoother or flatter or if the trays were more firmly fixed to the ground.

The precision of the drop test measurements would have been higher if a finer scale sampling grid had been used. The five metre spacing of the containers was used because it was a manageable sample size for the available resources. The precision obtained from this grid was adequate for determining the general information on drop patterns, such as coverage level across the drop, but was limited when trying to determine the proportion of the drop that fell within the DSZs. It is likely that the highest coverage of suppressant often fell between the rows of containers with the five metre spacing. Some studies of drop patterns (eg: Grigel, 1970) have used grids with a higher density of cup spacing around the main drop area to balance precision and sample size. This method would improve the quantification of the DSZ. Other problems with drop recapture may have resulted from suppressant splashing out of the trays. Trays with higher sides would have limited this problem, and should be investigated to quantify this error and determine if they are more suitable.

### *Head fire drop experiment*

The procedure used to conduct the head fire drop experiments worked well. However the value of the experiments to meet the objective of testing the effectiveness of individual drops on different stubble fire intensities was restricted by the limits and range of weather and fuel conditions. Head fires were used for these experiments because they had the maximum intensity that could be generated under the conditions. Unfortunately these were not enough to challenge the extinguishing capabilities of the drops.

Experiments designed to test the effectiveness of aerial suppression drops would ideally determine the critical limits of direct extinction of flaming. Establishing this limit would require data from fires that were not successfully extinguished by aerial suppression, as well as data from those that were. This objective would need to compare ranges of suppressant types, coverage levels, delivery systems, and fire intensities. Since all of the drops conducted during this experiment successfully extinguished the flame front, the upper limit of stubble fire intensity able to be extinguished by this helicopter and its delivery systems and suppressant combinations could not be determined. An experiment that included unsuccessful drops would involve using resources when they may be required elsewhere for fire fighting operations, as well as an increase in the risk of fire escape. Fire agencies would normally have suppression resources available for a quick response from their bases during the weather conditions when such an experiment would be conducted, thereby limiting their availability for other tasks. The risk of fire escape is minimised by having quality buffer areas downwind of experimental plots. Larger buffers are required for higher intensity fires than would be for fires of moderate intensity.

The methodology used to conduct this experiment can be recommended for future experiments, with the inclusion of fire intensities that would test the suppression capability of the resource. Suppression experiments in which the tested fire intensity is varied could potentially be used as a basis for a detailed study of holding times and sources of reignition in heavier and more complex fuels. They could also be used to test ground support as a factor in drop success.

### *Fire line length experiment*

The fire line length experiment was limited in its output. The helicopter, with both delivery systems, was easily able to effectively check all 12 of the ignitions lit. This experiment did, however, clearly show that lines of fire up to 20 metres in length can be significantly extinguished by a single aerial drop from the aircraft and delivery system combinations used. This was achieved by direct extinction, and in some cases, also by leaving a wet line ahead of some small remaining burning sections, thereby halting their forward spread. There were some ignitions that had burning sections which may have trickled around the drop areas with time and continued the spread. In a real fire fighting situation, fires of these restricted dimensions (most likely spotfires) are more likely to be attacked using a split load strategy, as was used effectively on the spotfire in the multiple drop experiment in plot I.

The effective length of suppressed edge from a single drop can be determined from the other aerial suppression experiments. The multiple drop experiments showed the helicopter was able to extend the length of fireline suppressed with a single drop, by increasing the flying speed and opening one door on the bellytank.

### *Multiple drop fire suppression experiment*

The multiple drop experiments demonstrated the advantages of splitting loads and the tactics that could be used by a highly manoeuvrable aircraft when executing successive drops in the absence of ground support. The suppression tactics used in this experiment were more characteristic of those used during wildfire operations than those used in the other experiments. The main data that can be collected by this sort of experiment is line building rates. This can be expressed in terms of length of fire perimeter suppressed in a period of time, or by a number of drops. The length of perimeter suppressed in a given time period is inversely proportional to the turnaround time between the fire and the aircraft fill point.

All drops made on running flames during these experiments were effective, including the stretched out drops. The first drop made in each of the three multiple drop fire experiments extinguished the majority of the largest flank and the tip of the head fire. This had the effect of limiting fire growth to some minor flank and backing spread. Subsequent drops were used to extinguish flames that were only moving slowly. Fire growth would not have been much different if the helicopter's turnaround times had been longer, as the fastest spreading sections of the fire had effectively been stopped. Fire in the lower fuel loads in plot I were able to be extinguished with lower coverage levels in the stretched out drops.

Multiple drop suppression experiments unsupported by ground forces, would be an important inclusion in any future aerial suppression experimental programs. This type of experiment would be valuable in more challenging, fuel, weather or fire conditions. Under such conditions, fire perimeter growth rates may be closer to line construction rates and repeated drops over sections of fireline may be required to halt fire spread. Multiple drop experiments in forest and woodland fuel types would enable an investigation into the importance of breaks in drop coverage to line failure. They may also improved data on holding times and also impacts of sequential drops on fire behaviour.

### *Aircraft GPS tracking*

The use of a standard GPS for tracking the helicopters flying characteristics at the time of drops was limited due to the logging rates of the track files. Specialised aircraft tracking systems, such as those used in agricultural spraying planes would be more suited to this application. The standard GPS would still be of considerable value for determining aircraft flying patterns and calculating drop times during wildfire suppression.

### *Limitations and future improvements*

The results of this study were limited by the fuel and weather conditions experienced during the experiments. As previously discussed, the mild conditions significantly restricted the type and intensity of fire that could be generated. The light stubble fuel particles were easily and quickly extinguished. The logistics and costs associated with running the helicopter favoured a schedule of a quick succession of drops of the same type. This was able to be factored into the experimental program. This could have been a constraining factor had the weather conditions been less stable.

The video footage taken from the observing helicopter provided an excellent record of the fire shapes and effect of drops. The footage would have been better if the

observing helicopter maintained a higher altitude to limit angular distortion. Future application of aerial video capture to suppression experiments should include a briefing to the cameraman and pilot, particularly instructing them of the preferred filming altitude or angle. Also general instructions should include: activation of the video time stamp, allowing the time to be synchronised by filming an operating GPS; filming for the entire duration of the fire; filming the fire at all times (rather than the helicopter), and keeping the entire plot in view.

The ground video footage was a very effective way of recording the events during the experiments. Similar instructions should be given to the operators of these cameras. The audio records on the video tapes were also useful, and could have been used to greater advantage, particularly for verification of events that are difficult to view on the footage, such as fire arriving at marker posts. Making the marker posts more visible would have helped the determination of fire spread rates, and would be necessary in other fuel types, where there are more visual obstructions. The majority of methods applied to this experiment could be applied to other fuel types.

Experiments similar to the headfire intensity and multiple drop experiments conducted here would be worthwhile repeating in other fuel types, and in higher fire danger conditions. The stubble fuel was a simple fuel type to work in and was a useful environment to develop and test methods. Experiments in forest, woodlands or shrublands would likely require a longer preparation time, notably for buffer zone establishment, plot preparation, and fuel assessment, as the preparation of plots and buffer zones would be much more involved, as would fuel quantification. These fuel types would pose a greater challenge to effective fire suppression and would enable investigation into other aspects of suppression effectiveness, such as drop holding times and canopy interception of drops.

## **5.0) Conclusions**

We found that the medium helicopter to effectively suppress fires in light stubble fuels and under mild weather conditions ( $GFDI < 14$ ).

The stubble paddock was useful for developing and testing methods for aerial suppression evaluation and was able to be prepared in a short period of time.

Both water and foam suppressants were equally effective in extinguishing fires in this fuel type and the fire intensity range tested ( $\sim 1000$ - $4000 \text{ kW.m}^{-1}$ ).

The 1185 L Isolair bellytank delivery system was better suited to fire fighting in these conditions than the Bambi bucket, because it allowed the helicopter to be more manoeuvrable, fly closer to obstacles, and split loads. The 1430 L Bambi bucket was also effective. The choice of delivery system used operationally should be made with consideration of available water sources.

Experiments similar to the headfire intensity and multiple drop experiments conducted here would be worthwhile repeating in other types of vegetation. Investigating drop holding times and the effectiveness of aerial suppression in combination with ground suppression, would be useful further developments to the methodology used, and suitable for more complex fuel types.

## **6.0) Acknowledgements**

The cooperation of multiple dedicated agencies was essential for the smooth running of this experiment in the short lead time.

This experiment would not have proceeded without the outstanding work of Ken Burns and Marcus Skelly of the Tasmania Fire Service, who were invaluable in finding a site, organising the aircraft, and providing practical support. This experiment was planned in a short amount of time, and the site was assessed and prepared in the four days prior to the experiments. This would not have been possible without the high level of practical and logistical support received, or if the experiments had been conducted in more complex fuel types, or at less accessible sites.

Tasmania Fire Service's support for these experiments was in the form of: assistance in research tasks during site assessment; assistance with site preparation, and assistance with conducting the experiments. Support during experiments included filling organisational roles and arranging resources such as the firebombing helicopter, ground suppression teams, aerial video footage, fire permits, safety officers, operational communications, and catering, as well as managing the media.

The support on days of experimental work involved a large number of personnel and equipment. We are grateful for the support received from a large number of staff and volunteers from the Tasmania Fire Service. Forestry Tasmania also provided some research assistance, including providing an automatic weather station. The University of Tasmania's farm management loaned some equipment and rearranged their schedule to allow the experiment and site preparation to go ahead smoothly.

The authors would also like to thank Hayden Biggs (Victorian Department of Sustainability and Environment) for valuable advice regarding setting up the drop pattern tests.

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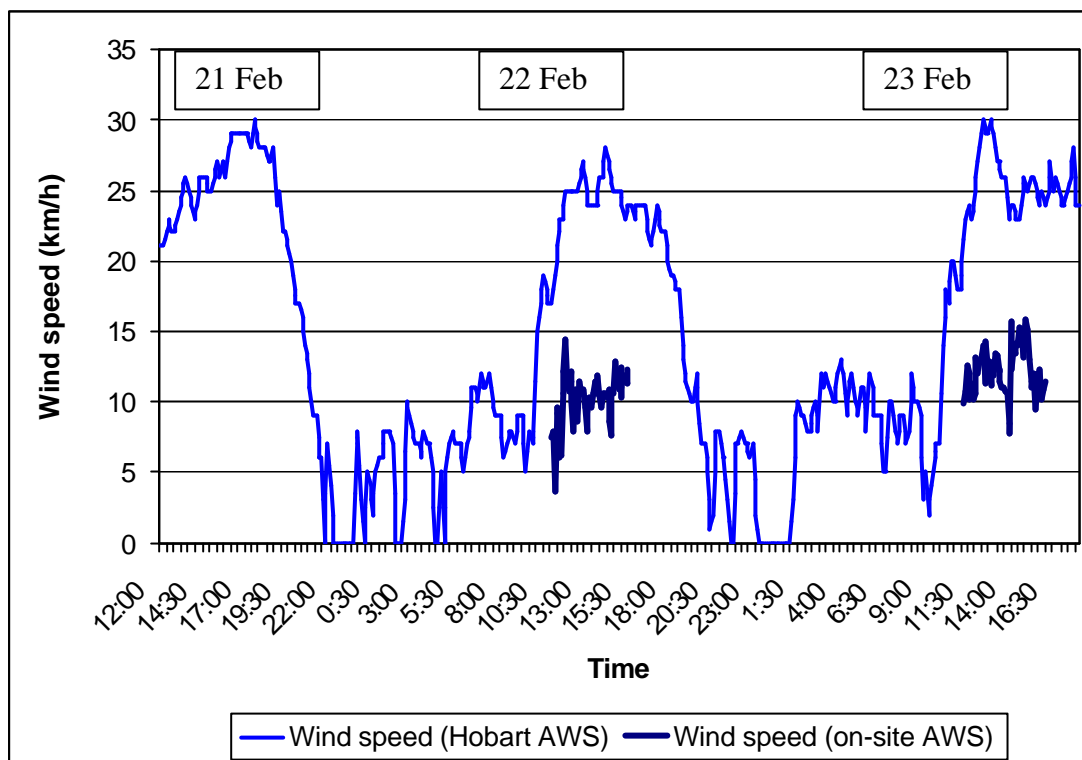


Figure A1-3: Winds peed during experimental days

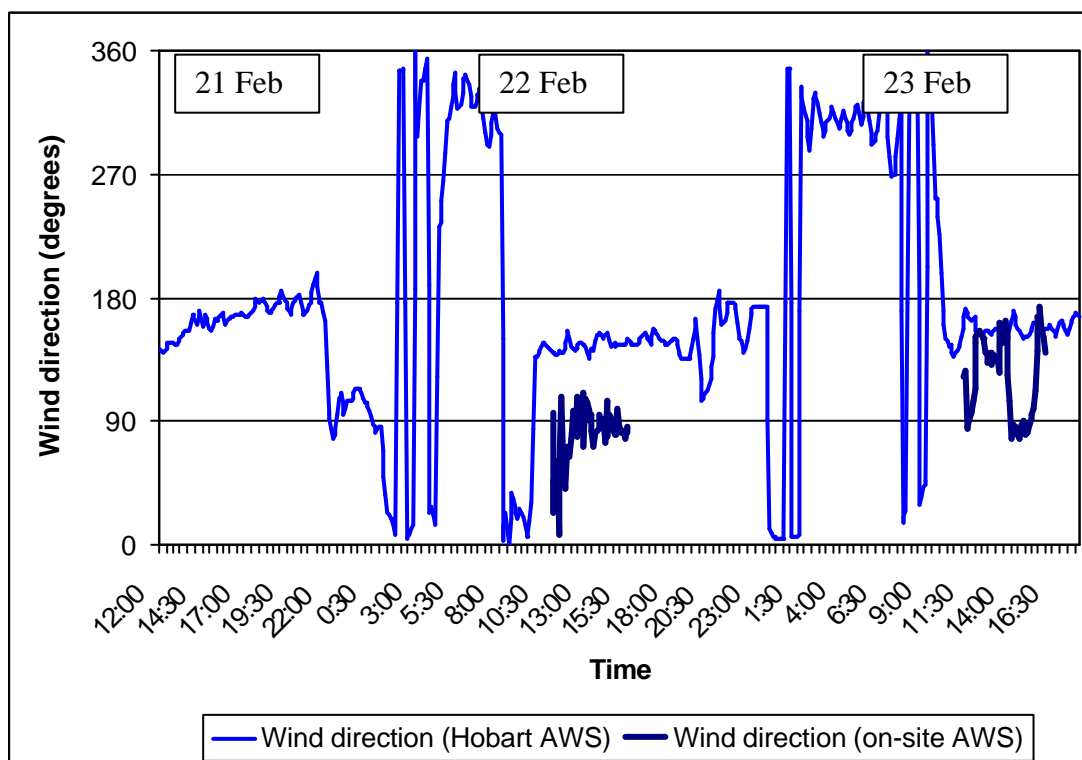


Figure A1-4: Wind direction during experimental days

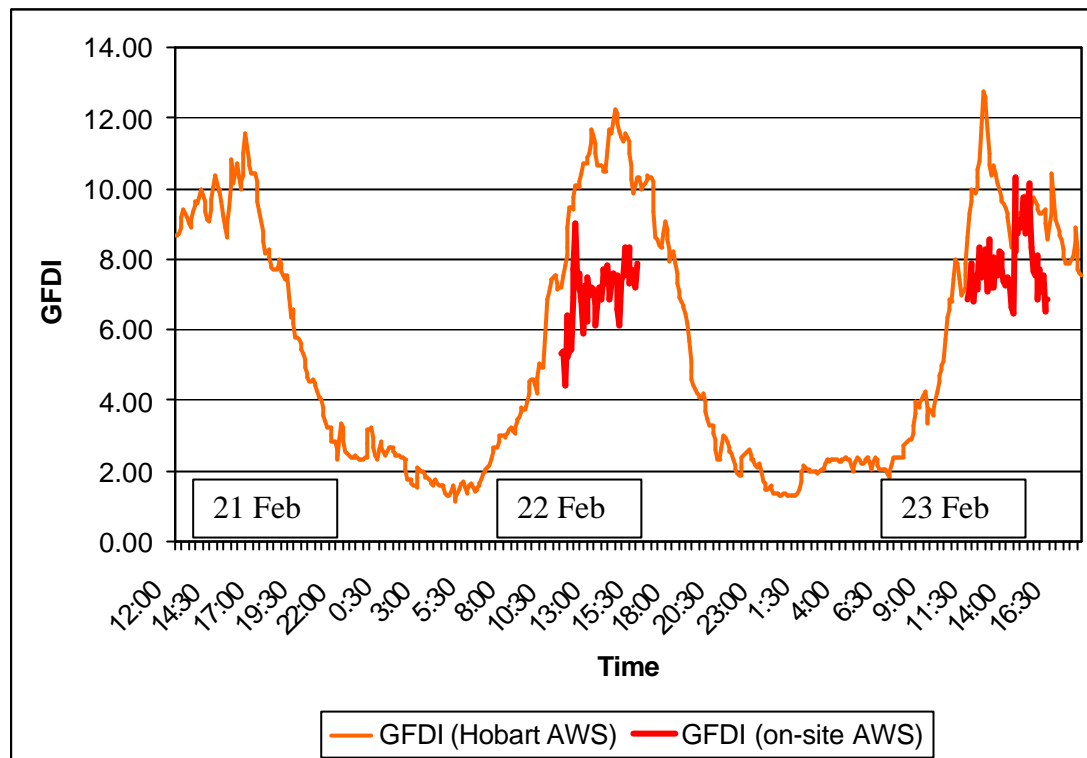


Figure A1-5: Grassland Fire Danger Index during experimental days

## Appendix 2: Cross sections and still images from drop pattern tests

### A2-1) Drop 1: Bellytank with water: 1 door

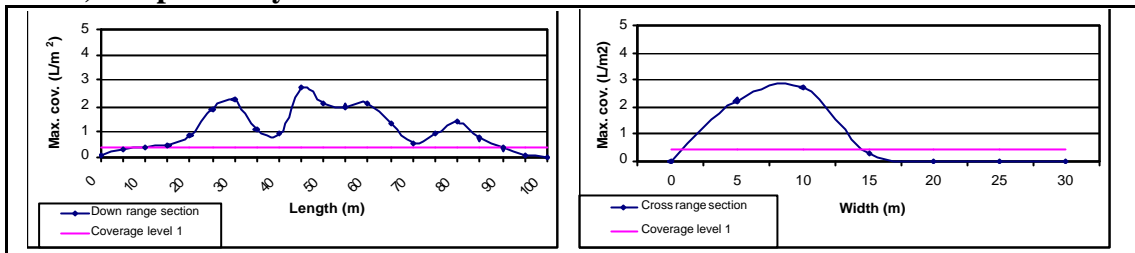


Figure A2-1: Down range and cross range sections of drop 1

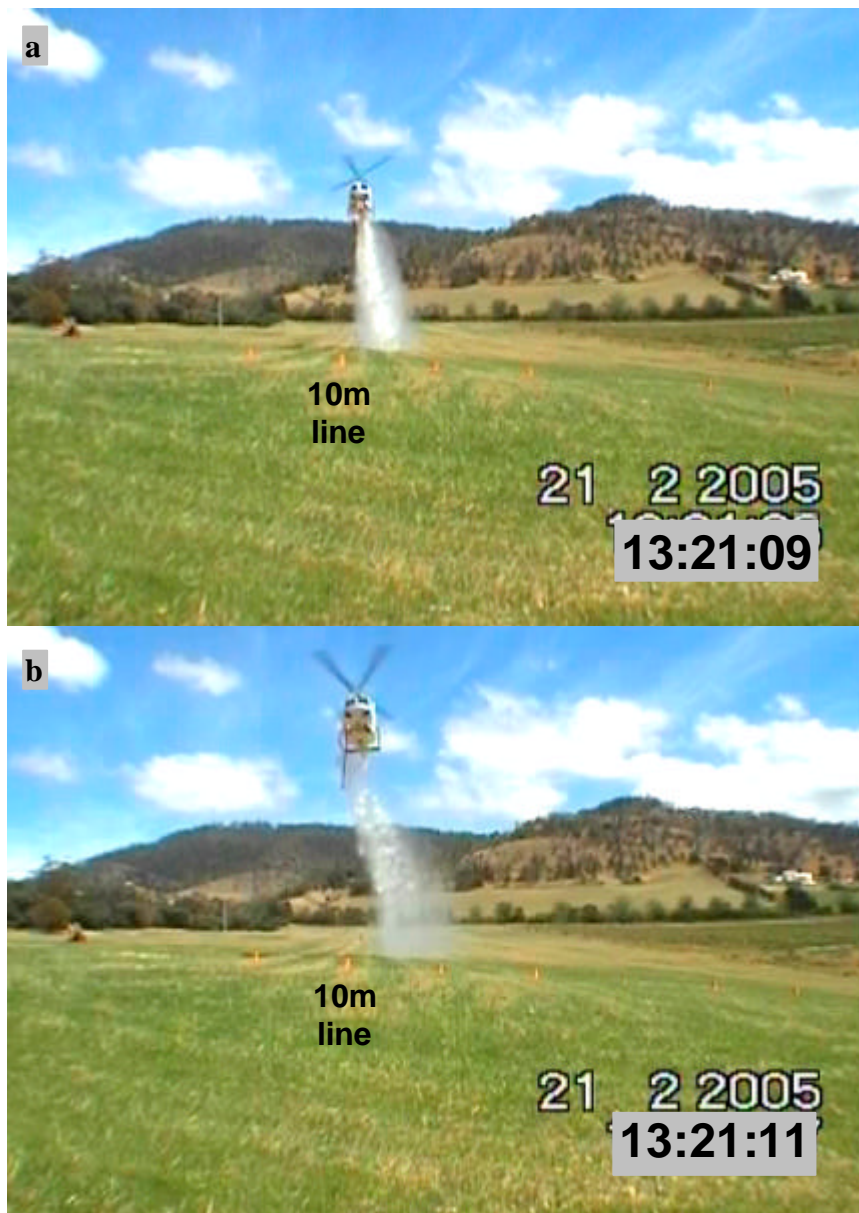


Figure A2-2: Images from drop 1

## A2-2) Drop 2: Bellytank with foam mix: 2 door

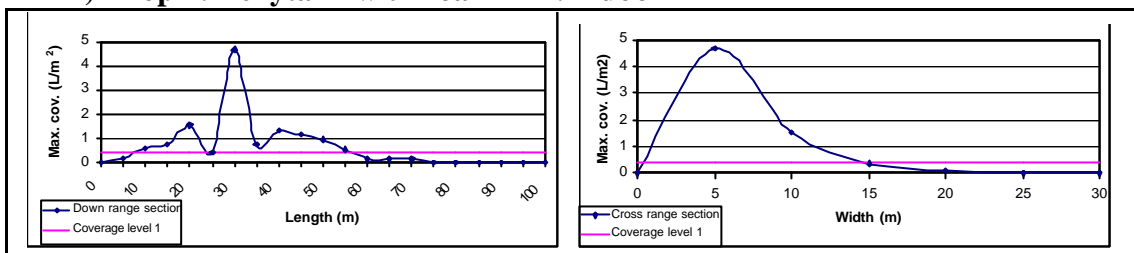


Figure A2-3: Down range and cross range sections of drop 2

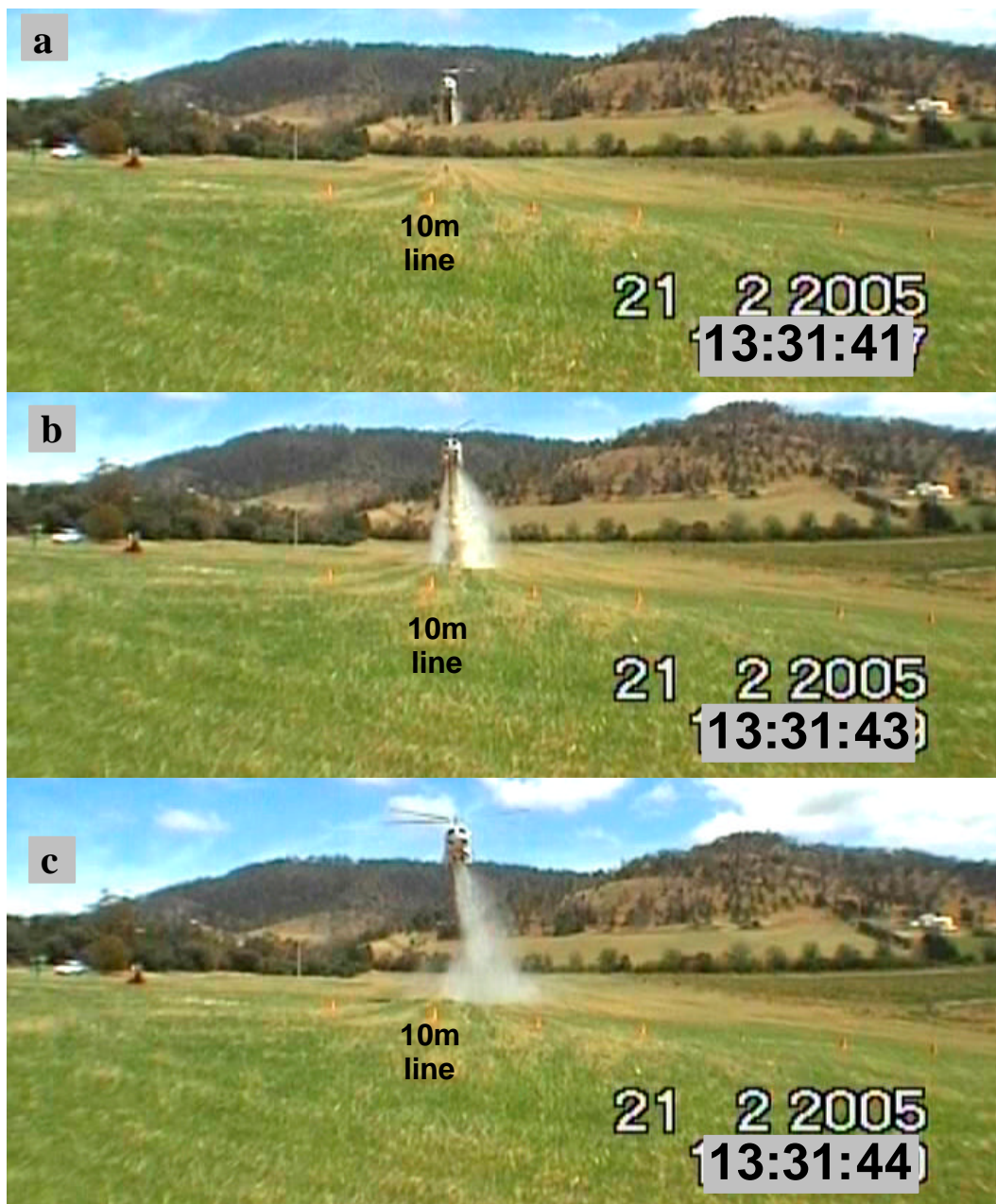


Figure A2-4: Images from drop 2

### A2-3) Drop 3: Bellytank with water: 2 door

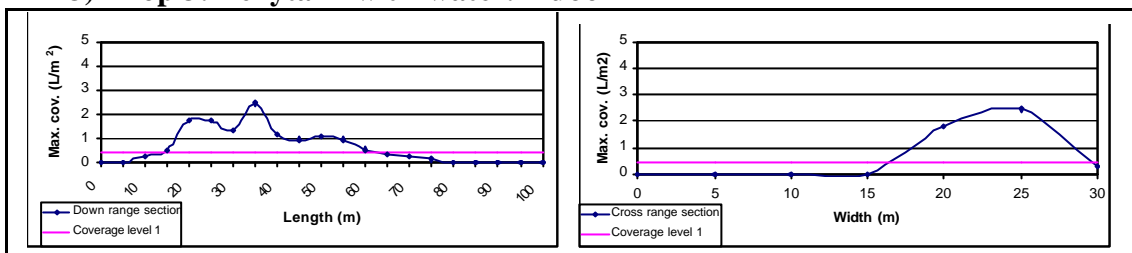


Figure A2-5: Down range and cross range sections of drop 3

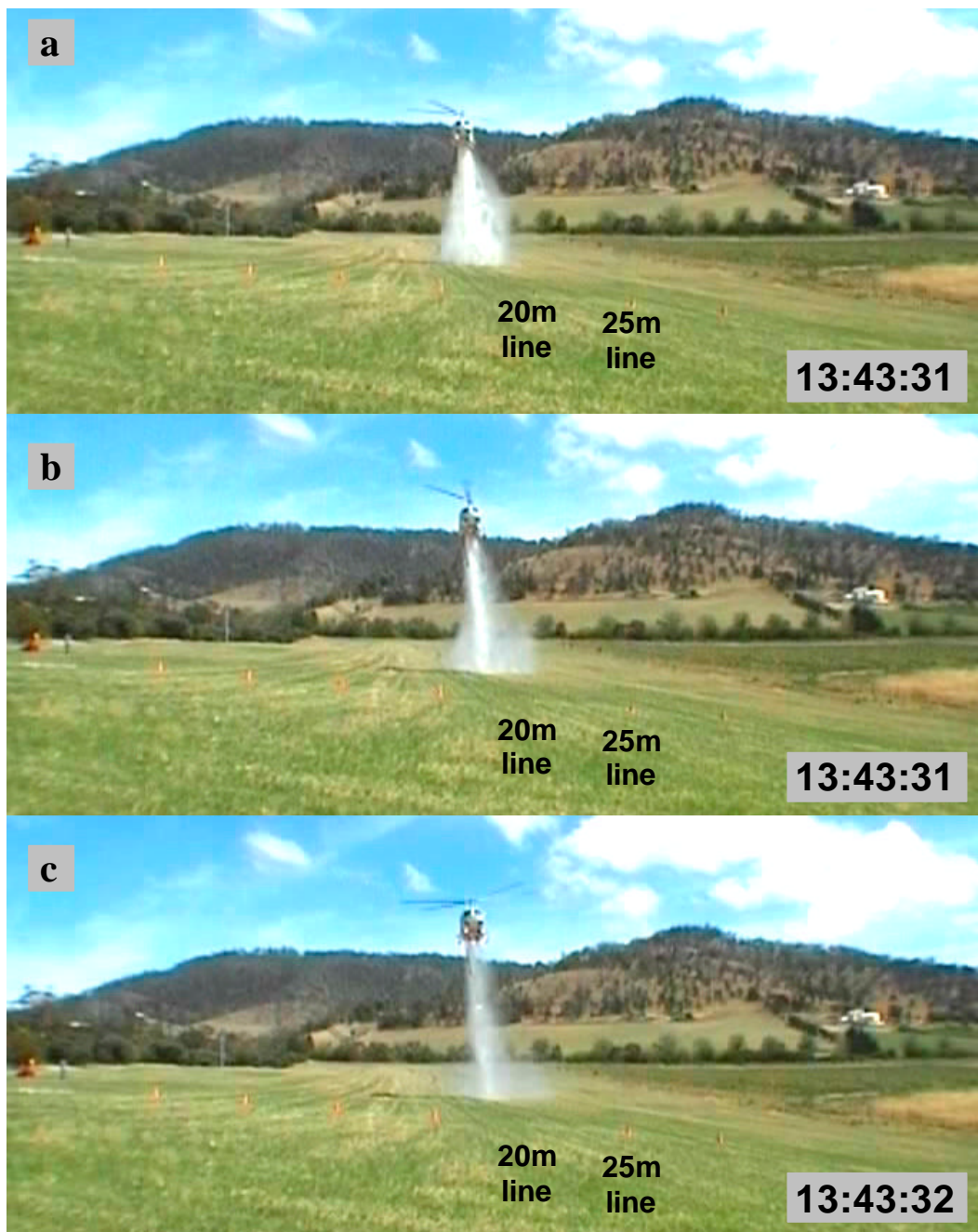


Figure A2-6: Images from drop 3

#### A2-4) Drop 4: Bellytank with water: 2 door

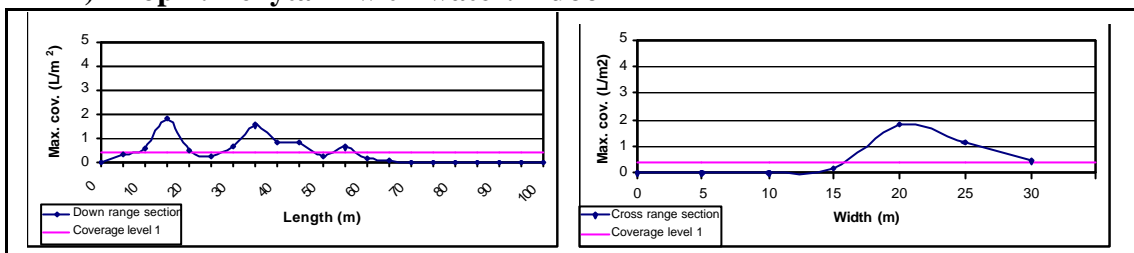


Figure A2-7: Down range and cross range sections of drop 4

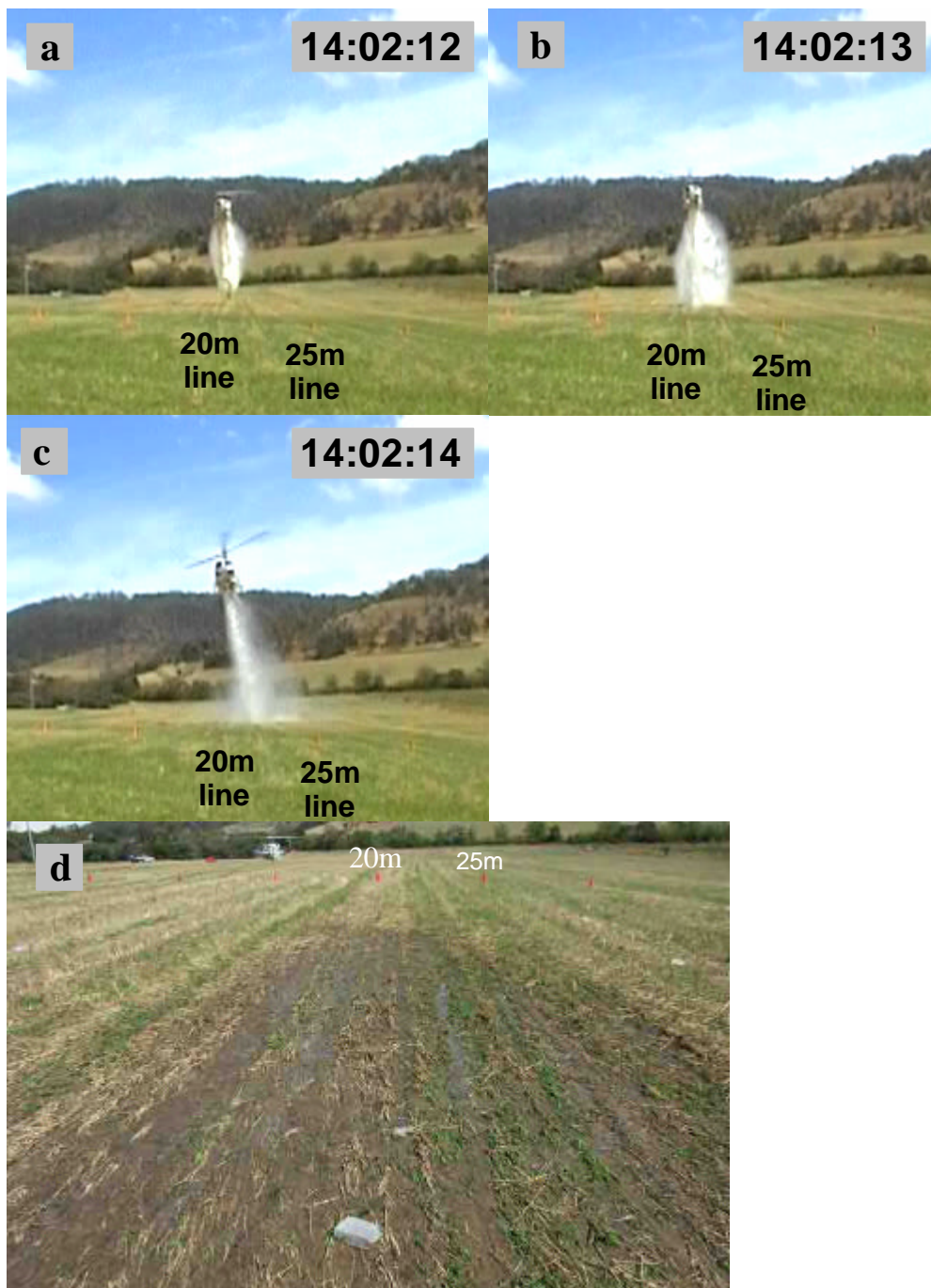


Figure A2-8: Images from drop 4

### A2-5) Drop 5: Bucket with water

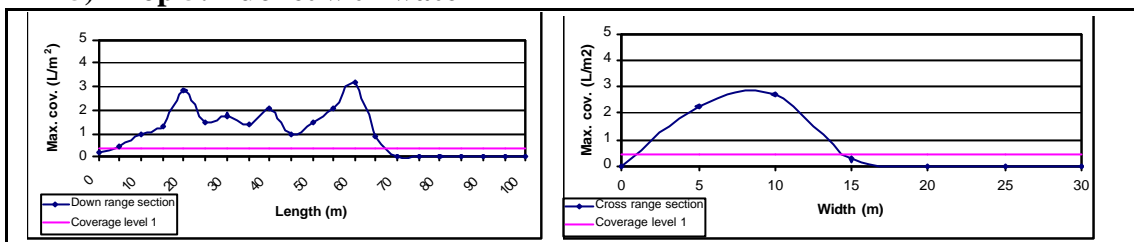


Figure A2-9: Down range and cross range sections of drop 5

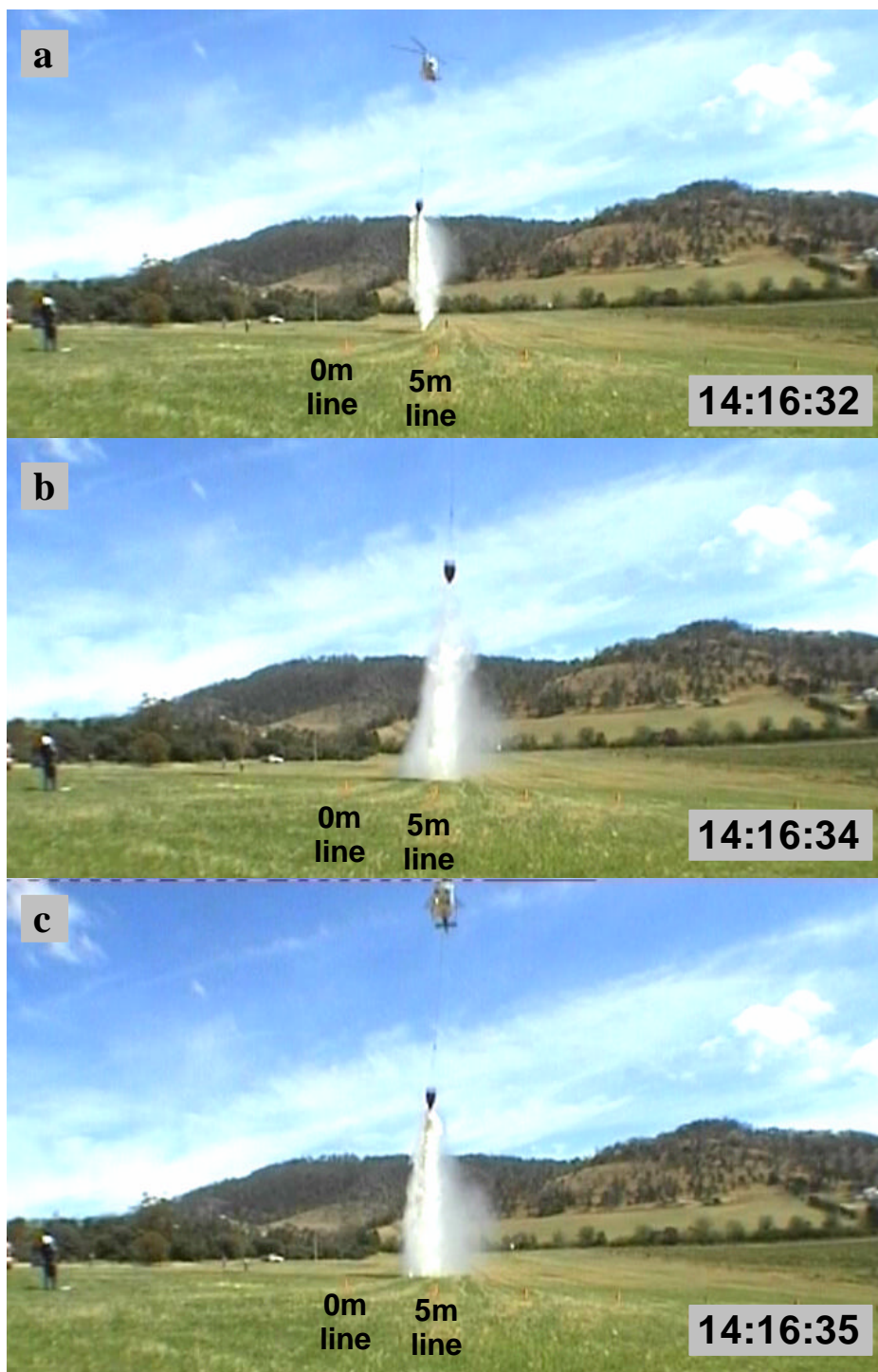


Figure A2-10: Images from drop 5

## A2-6) Drop 6: Bucket with foam

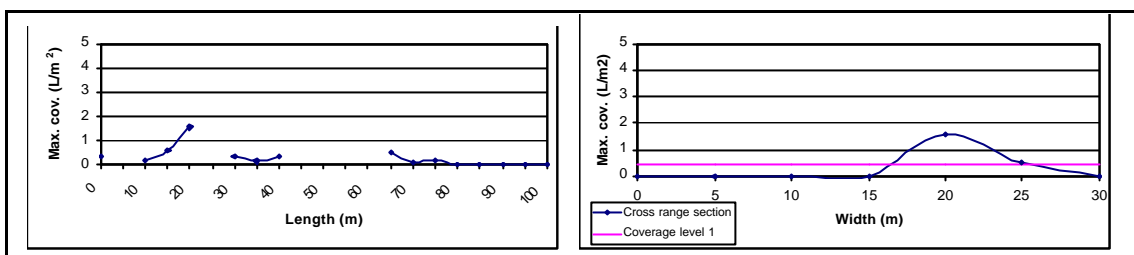


Figure A2-11: Down range and cross range sections of drop 6

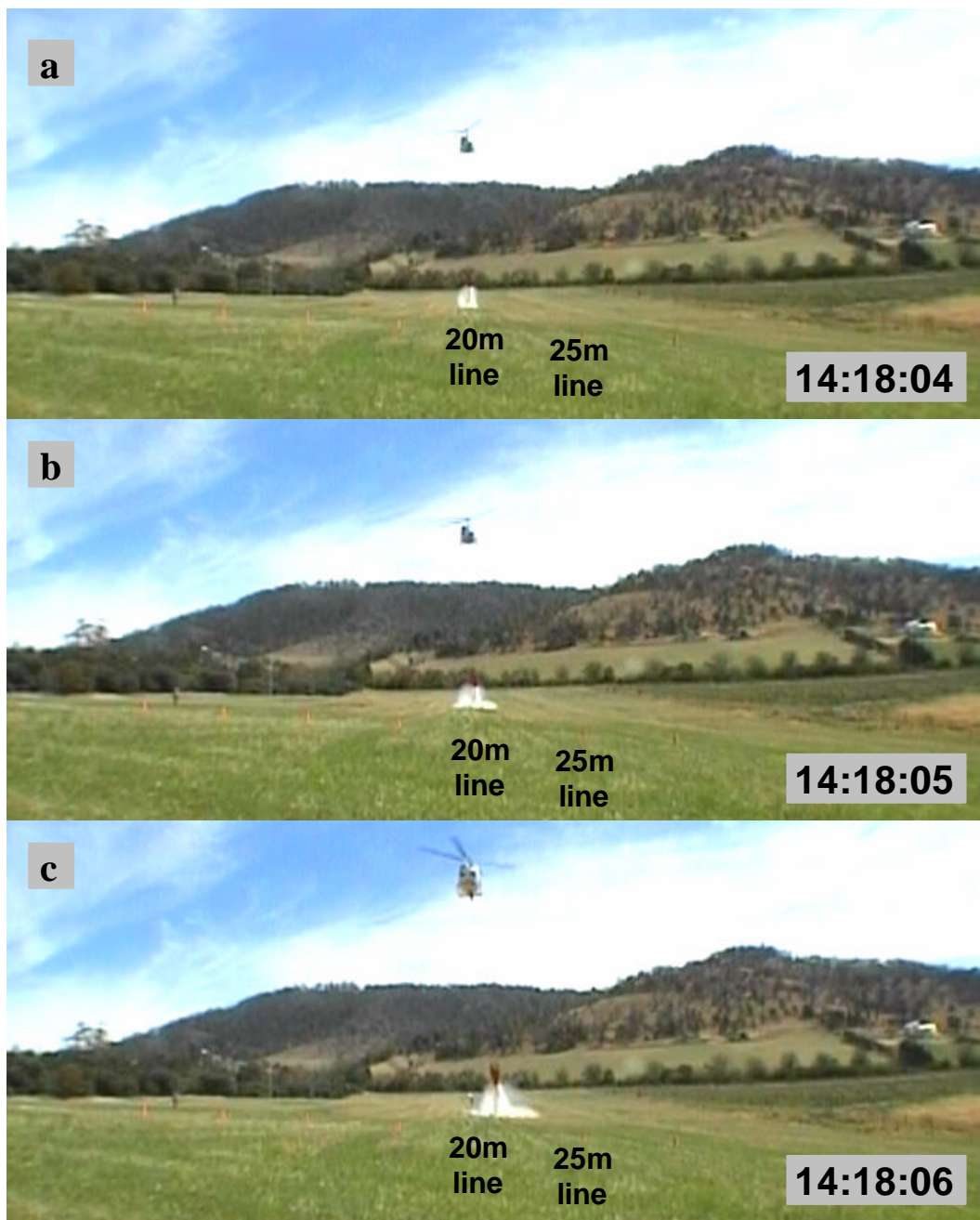


Figure A2-12: Images from drop 6