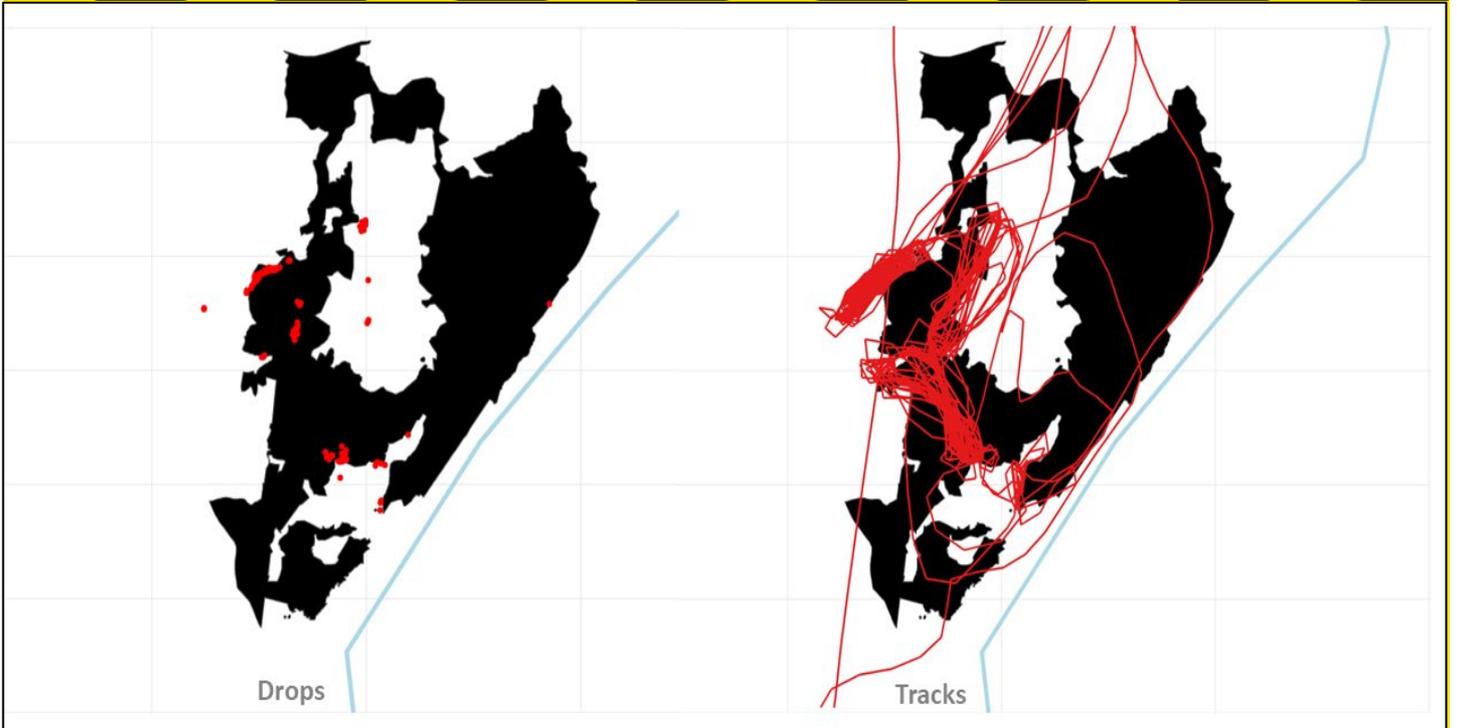




# INVESTIGATING THE SUITABILITY OF AVIATION TRACKING DATA FOR USE IN BUSHFIRE SUPPRESSION EFFECTIVENESS RESEARCH

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## EXECUTIVE SUMMARY

Aircraft are an important part of bushfire suppression and their use is increasing. They were used heavily during the 2019/20 “Black Summer” bushfire season in NSW and several inquiries have highlighted the need for research into their effectiveness.

Tracking equipment is becoming routinely deployed on aircraft and there is increasing availability of high-quality ancillary data such as aerial imagery and fire severity mapping. These allow detailed analyses of aircraft activities. However, the usefulness of the data needs to be evaluated, and the analysis needs to be informed by information about the tasking objectives of the aircraft and whether those objectives were met.

This project provides an initial investigation into the process of evaluating aerial suppression using these new data sources and interviews with personnel involved in the suppression activities.

Firebombing event data (drops/fills) from the 2019/2020 bushfire season in NSW from the National Aerial Firefighting Centre (NAFC)'s Arena database was provided by the NSW Rural Fire Service. This data included ~70000 aircraft suppression drop locations and times from aircraft that included helicopters (mainly large and medium helitaks), Single-Engine Air Tankers and Large Air Tankers. As an initial step, we examined the data for completeness, accuracy and errors, and described the data contents. This data was missing for most of the aircraft known to be dropping on the fires, especially the smaller ones. The type of drop (gel, water, retardant) was unknown in most cases, the quantity dropped was unknown in 45% of cases, and the location for the end of drops was often unreliable.

We then tested methods to identify drop objectives based on relationships between drops data and other spatial data including building locations and weather. Using a combination of automated pattern matching and manual checking, the data can be used to identify cases where the objective was initial attack, extinguishing spot fires, asset protection, pre-emptive laying of retardant lines and direct attack. There were a few cases where the success or failure of the objective could be assessed purely with the spatial data. We also explored two particular analytical methods for determining objectives. First, we compared the distribution of Forest Fire Danger Index (FFDI, fire weather) during a fire and for the drops within that fire. This identified several fires for which a large proportion of the drops were more likely to be during extreme fire weather even though extreme weather was rare in that fire. Second, we compared the distribution of distance to houses between all parts of the fire and the drops at that fire. Here we found many fires where the drops were clustered closer to houses than if the drops were (hypothetically) spread evenly across the fire ground. These analyses are preliminary but show great potential.

We conducted 10 interviews with personnel who worked as Air Attack Supervisors during the 2019/20 season. Interviewees were knowledgeable and experienced, and expressed the view that the aerial program could be improved with further knowledge sharing and training. They provided a lot of general information



about objectives, how they learned during the season, their views on limitations in aerial suppression, and their own capacity to document the process.

The interviews also highlighted several operational issues that warrant more investigation using a large number of aviation specialists and more specific questions. Chief among these are:

- To what extent does smoke and bad weather limit the capacity to deliver aerial suppression?
- The development of guidelines of the most appropriate tasks for each aircraft type (e.g., the LATs being used for strategic drops in locations away from smoke plumes). Can these be clarified to maximize the effectiveness of the aerial resources and if so, how could this be addressed?
- Do IMTs sometimes overestimate the capabilities of aerial suppression, especially during bad weather, and if so, how can this be addressed?

We conducted eight detailed case studies where there were interesting features in the drop data and insightful comments from the interviewees. These were particular days at a particular part of a fire. They included one example with multiple objectives playing out as one failed and the fire spread changed, several where property protection was the dominant objective (largely successful), one on spot fires, and two initial attacks, of which one succeeded and the other failed. The case studies demonstrate the power of the approach where spatial data and interview interpretation are combined.

The air drop data has the potential to enable deep analyses of aircraft use and effectiveness during real bushfire responses, especially when combined with other contextual information, such as objectives and environmental conditions. This will require more matching of the data to interviews to determine whether the drop data can be used in this way. We have started this process in this report, identifying clear clusters of activity related to weather and distance to houses, and cross-checking with interviews in the case study, and in some of these cases, the success could be judged. In order to realise the full potential of this approach, the completeness and accuracy of the drop data should be improved and interviews should become a routine part of the seasonal review process.



## END-USER STATEMENT

**Melissa O'Halloran**, *Predictive Services, NSW Rural Fire Service*

The extensive use of aircraft for aerial suppression in the 2019/2020 fire season provides an opportunity to start investigating how the data from aircraft tracking could be used in combination with other data to better understand aerial suppression effectiveness.

The research methodology used in this report highlights the extra value obtained from supplementing available aircraft data with the extensive personal experience of the people managing the use of aircraft during the fires. The results are superior to analysis using only tracking data as the range of suppression objectives are evident via the case studies.

As the aircraft tracking data continues to be more readily available and reliable we will be able to demonstrate the value that can be obtained from capturing aerial suppression objectives. This report shows a clear pathway for what is required to undertake suppression analysis and in future years we intend to overcome the data issues identified. This report is a start of what we hope will be an ongoing area of research. We are grateful to the Bushfire and Natural Hazards CRC for funding this research into the 2019/2020 fires in NSW.

## INTRODUCTION

Aircraft are an important component of bushfire suppression, they are also high profile and costly, comprising a large proportion of the overall bushfire risk management budget. Data provided by the NSW Rural Fire Service (RFS) to the 2020 Royal Commission into National Natural Disaster Arrangements shows that the average spend on aerial bushfire suppression in the years 2015-2018 was \$56m per year, and it has increased every year since then, with the 2019 spend being more than the previous four years combined (Figure 1 (NSW Rural Fire Service 2020)). The Australian and NSW fleets are getting larger, both in terms of the number of aircraft and their capacity, with the use of aircraft during the 2019/20 season estimated to have been around four times higher than recent seasons (ATSB 2020). In NSW, six large and very large airtankers were used to drop over 24 million litres of retardants and suppressants in 1708 missions during the 2019/20 season (Binskin et al. 2020).

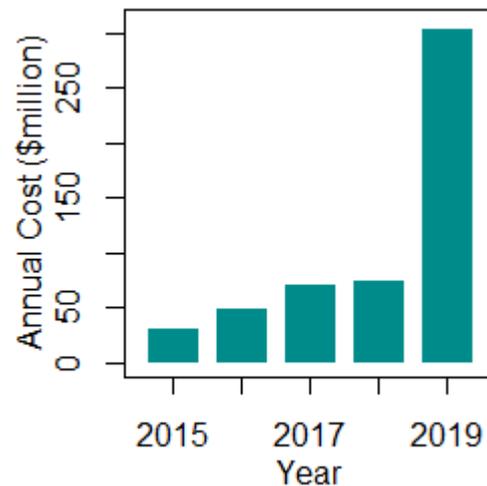


FIGURE 1: COST OF AERIAL SUPPRESSION BY THE NSW RURAL FIRE SERVICE (FROM EVIDENCE SUBMITTED TO THE 2020 ROYAL COMMISSION).

In an age of increasing accountability for actions and expenditure, bushfire preparedness and response is increasingly being evaluated through a risk prism by which the cost-effectiveness of different strategies can be gauged, which aids the process of designing optimum risk reduction strategies. For example, much progress has been made in measuring the effectiveness of prescribed burning (e.g. Price and Bradstock 2011, Pedroza et al. 2020), and in some cases, the costs and benefits of different treatment strategies (Penman et al. 2014).

None of the previous evaluations of aerial suppression have been able to consider the effectiveness of large numbers of drops made on bushfires. This is at least in part because aerial suppression is difficult to study for many reasons including the variety of tactics applied, the huge range of factors that can influence effectiveness (Plucinski 2019), lack of data access for research and operational reporting systems poorly suited to researching outcomes (Simpson et al 2019). Clark and Martell (2020) are the only other study to have used aircraft tracking data. They used the tracking data to model aircraft use during initial attack, but had to make assumptions about drop and fill events.

The limited research into aerial suppression has mostly been on initial attack, which is shown to be effective (Plucinski 2012, 2013, Plucinski et al. 2012), but there has been much less research investigating the effectiveness of aircraft on larger fires (Thompson et al. 2017). The most comprehensive study is the 'Aerial Firefighting Use and Effectiveness' (AFUE) project (USDA 2020) which is being conducted by the US Department of Agriculture Forest Service in response to concerns raised by the US Government Accountability Office on the lack of



information on the performance and effectiveness of firefighting aircraft. This large (~\$11 M US) study designed an evaluation framework of five objectives and seven outcomes, observed 27,000 drops over four fire seasons, each of which were assigned to an objective and an outcome. The study reported that 82% of drops were effective and that halting fire spread was the most common objective for larger aircraft but reducing fire intensity was the most common for the smaller aircraft (helicopters).

In recognition of the need to improve our understanding of suppression effectiveness and how to collect data to support that process, the NSW Bushfire Inquiry recommended the creation of a national bushfire database to store data on suppression, among many other types of data (Recommendation 3) (Owens and O’Kane 2020). Similarly, the 2020 Royal Commission into National Natural Disaster Arrangements (Binskin et al. 2020) recommended research and evaluation into aerial firefighting (Recommendation 8.2). The Department of the Prime Minister and Cabinet noted that they see this recommendation as being “pivotal to informing decisions on the future of aerial firefighting to deliver an operationally effective fleet that is scalable, adaptive and provides value for money” (Department of the Prime Minister and Cabinet 2020). Research into aerial suppression was also a recommendation of the 2004 COAG bushfire inquiry (Finding 8.7) (Ellis et al. 2004). The inquiry into the Victorian 2019-2020 fire season (Inspector-General for Emergency Management 2020) also made the observation (7.10) that a greater understanding of aerial suppression effectiveness would aid operational decision making.



## RESEARCH APPROACH

### RESEARCH OBJECTIVES

Given the importance of aerial suppression to the overall bushfire response, the longstanding lack of comprehensive research and the known difficulties in undertaking such research, this study is preliminary. The objectives are to evaluate the data that is currently available and determine if it can be reliably supplemented with intelligence from fire management personnel, to inform how future research into aerial firefighting could be conducted. In other words, we aim to evaluate how available data could be used to understand aerial firefighting actions, objectives and outcomes, supplement that data with interviews of people involved in air suppression at selected fires and design a protocol for data collection that could be used in the future for a more comprehensive evaluation of suppression effectiveness. The project is guided by the example of the AFUE project (USDA 2020).

More specifically, our research aims to meet the objectives outlined in the original research proposal, which described three main parts:

#### **Part 1 – investigate aerial asset data**

*Review aerial asset data and supplement with interview information. Interview incident management team members and State Air Desk for a case study fire to determine the objective of the aerial tasking. Include metadata describing confidence levels on the attribution of data.*

#### **Part 2 – correlation with spatial features**

*Using the improved data from part 1 determine if there are spatial features in the landscape that correlate to the type of aerial suppression activity. For example, can building envelope data or building density data be used to determine property protection tactics.*

#### **Part 3 – trial assessment of aerial suppression effectiveness**

*For a case study identify aerial suppression for a sample tactic (eg direct fire attack) and determine the effectiveness of the strategy taking into consideration of factors such as: Fire weather conditions at time of aerial suppression; Vegetation; Topography including slope and features such as cliffs; Time of day aerial suppression tactics deployed; Time of day the fire interacted with aerial suppression tactic; Fire weather conditions after fire interacted with aerial suppression; Effectiveness of complementary strategies (eg ground crews, use of disruptions)*

To address these three components, we 1) conducted a spatial data assessment and some example analyses of a statewide aircraft firebombing events (drop/fills) dataset and; 2) conducted interviews with aerial suppression personnel for several case study fires/days, and reported on aerial suppression objectives and outcomes based on these and available spatial data. Our report has the following main sections:

**Spatial data:** The project team was provided with spatially located aerial drop data for the entire 2019/2020 bushfire season for NSW. This section summarizes



the drop data, provides examples of classifying objectives based on drop (and other) data, and notes limitations of the data.

**Correlation with spatial features:** This section uses the firebombing event data (drops data) to conduct some example analyses across all drops for selected fires against building location data, forest fire danger index and gives an example of grouping drops based on time and date to identify potential large retardant lines. The limitations of these examples are also discussed.

**Interview data:** This section describes the method used to conduct semi-structured interviews with Air Attack Supervisors (AAS). These interviews were conducted to assess the viability of supplementing drops data with data from other sources to identify drop objectives for selected fires/days.

**Aerial suppression case studies:** Eight case studies are presented in this section to provide examples of aerial suppression use and impacts on some fires. The descriptions of the fire situation, response tactics, drop objectives and outcomes are based on the interviews and spatial data.

**Concluding discussion:** This section describes a process for evaluating aerial suppression data using learnings from the spatial data analysis and case studies, describes other themes that came up in the interviews that were not strictly within the set questions asked and provides research conclusions and recommendations.

## DEFINING AERIAL SUPPRESSION OBJECTIVES

Defining aerial suppression objectives is an important step for any research in the area. Firefighting aircraft are used for a variety of reasons and an evaluation of effectiveness must match suppression outcomes to the objective for any particular drop or task (Plucinski and Pastor 2013). For example, if the objective of a task was to protect properties, it is not valid to evaluate the task by determining whether it stopped fire spread, but rather on whether properties were saved. The AFUE study (USDA 2020) approached this problem by first defining five possible objectives, such as reducing fire intensity, slowing the spread or point (property) protection (see Table 1 for a description). Then they defined seven outcomes that can be matched to one or more of those objectives. These include having no interaction with the bushfire, having no observable effect and a range of increasing effectiveness including stopping the bushfire altogether (Table 2).



TABLE 1: AIR DROP OBJECTIVES DEFINED IN THE AFUE REPORT. THIS IS WHAT WAS INTENDED TO HAPPEN FROM A DROP(S).

Drop Objectives	Description
<b>Reduce fire intensity/flame length</b>	The intent of the drop(s) is to cool an area of fire activity. This may be needed so ground personnel can work closer to the fire activity (e.g., begin or continue to go direct). Examples include knocking down crown fire, torching, and preventing spotting, etc.
<b>Delay fire spread/retard growth</b>	The intent of the drop(s) is to delay the fire's rate of spread in the same location (head, heel, specific flank, spot, etc.) of the fire. Examples include buying time for ground resources to construct line or for evacuations.
<b>Point protection</b>	The intent of the drop(s) is to protect a value(s) at risk (VAR). These drops should be within the immediate area of the VAR or be executed primarily to reduce the probability of fire reaching the VAR or to reduce damage to the VAR.
<b>Line fire/halt advance</b>	The intent of the drop(s) is to construct an aerial line to halt fire spread. These drops are used to halt the spread of a section of the fire's edge before, during, or after ground engagement or without the aid of ground personnel.
<b>Extinguish fire/spot fire</b>	The intent of the drop(s) is to fully extinguish the entire portion of the fire or spot fires (generally a rare occasion, usually a small area, and likely a fine/flashy fuel).

TABLE 2: AFUE REPORT DROP OUTCOMES. THIS IS WHAT ACTUALLY HAPPENED AFTER A DROP(S).

Drop Outcomes	Description
<b>Unknown/no data</b>	The observer was unable to see the drop(s) outcome for a reason related to safety, access, smoke, fire behavior, etc. and could not acquire this information from any other source. Or, the observer knows the drop(s) interacted with the fire but does not know the outcome.
<b>No fire interaction (NFI)</b>	The drop(s) did not interact with wildfire or the drops were done to support ignition operations but did not interact with the main wildfire.
<b>Burned through, spotted over, outflanked, change in tactics/priorities, failed to contribute</b>	The drop(s) failed to contribute due to fire advancing past the drop(s) by burning across (through) the resource actions, by means of firebrand ignition, by burning around (outflanking) the end of the resource action, or the drops did not have a chance to contribute to broader task outcomes due to a change in tactics/priority.
<b>Reduced fire intensity</b>	The drop(s) successfully reduced fire intensity in the portion of the fire with which it interacted enough to contribute to successfully meeting planning area objectives without committing more resources.
<b>Protected point(s) successfully</b>	The drop(s) successfully prevented interaction or damage to the object of point protection
<b>Delayed fire spread</b>	Fire advanced past the drop(s), but the delay was enough to contribute to successfully meeting planning area objectives without committing more resources.
<b>Halted fire spread</b>	The drop(s) successfully stopped the portion of the fire it interacted with from advancing



## SPATIAL DATA

The RFS provided the project team with spatially located aerial drop data for the entire 2019/2020 bushfire season for NSW from the NAFC Arena database. This consists of the location and time of 70000 drops (and 35000 fills). We assembled a variety of other data to match the drops with, including fire progression (isochrones), building locations and hourly weather from the Bureau of Meteorology. We assessed the quality of the drops data and explored methods to analyse the drops data with reference to these other data.

This section provides a summary of the aerial drops data and examples of how spatial data can be used to understand the objectives of different firebombing drops. The spatial data used in this section was provided by the RFS in a file named "DropsReport-22\_01\_2021\_21\_20.csv". The data is originally collected via equipment on-board firefighting aircraft. The equipment is required to meet the NAFC Standard OPS-014 Tracking, Event reporting & Messaging (NAFC 2018). All firefighting aircraft are required to have location tracking as a minimum, whereas only some aircraft (NAFC contracted aircraft) are required to have firebombing event logging (drops and fills etc.).

The file provided by RFS contains firebombing event logging data, i.e. fill and drop times and locations, for some firefighting aircraft used in NSW from July 2019 to March 2020 (Figure 2, Figure 3). This is referred to here as the "drops data" and is equivalent to the drop portion of "firebombing events data" (NAFC 2018). The data is extracted from a larger database that contains both firebombing event logging, other flight events (take-off/landing) and aircraft tracking (aircraft location coordinates and timestamps at regular intervals). In addition to the drops data, we use aircraft tracking data ("tracking data") for selected days at some fires for comparison to the drops data records. The tracking data overall has more aircraft recorded (all aircraft should have tracks recorded) and, although originally from the same data, some differences in aircraft may occur between the drops data and original dataset depending on the date the data was downloaded due to database changes, renaming of aircraft call signs or if aircraft are sold.

The drops data contains 34 fields (columns) that are a mixture of coordinate, timestamp and descriptive fields (see Appendix Table 7). In the context of using the drops data for spatial and temporal analysis of aerial suppression, the most relevant fields, and those focused on in this report, are "Aircraft" (a unique aircraft name/ID), the drop start and end coordinates fields, the drop start and end timestamp fields and "Event" (either "drop" or "fill"). Aircraft start and end altitudes and speeds may also be used for more detailed analyses of suppression tactics. Product types (e.g. water, gel, foam, retardant) and litres dropped (or filled) would be useful for analysis of, for example, the effectiveness of different product/amounts of products used on suppression success and for estimating drop objectives. However, these fields are mostly unpopulated; e.g. the "Product" field has "Unknown" listed for 80% of drop records and 52% of fill records (Figure 4). 62% of drop records and 9% of fill records have zero litres recorded (Figure 4). Litres drop in different locations is required as aircraft (mainly larger aircraft) may split their loads into more than one drop location. Certain aircraft may more reliably record data in these fields than others, which would



allow for aircraft-specific analysis. However, it is unclear from just the drops data which aircraft may be most reliable.

Other fields in the drops data (Appendix Table 7) that provide descriptive information are not used for analysis here. This includes general location fields (e.g. Incident Major Area, Staging Coordinates, and Incident Name) or ID fields (e.g. EFOR.No.). These fields can contain either many NA values or very general values, some of which may be more reliably derived from other fields, e.g. the fire name which the aircraft was attending can be derived from drop coordinates and fire history polygons.

As this report only focuses on NSW, we have only analysed drops and fills that occurred in NSW and ACT (Figure 2). In total there were 69513 drop and 35226 fill records in NSW from many different aircraft. Note that records of aircraft working over other states were also included in the data, although for an unknown reason only fills (i.e. no drops) were recorded in other states. The terminology used for different firebombing aircraft types used here is outlined in Table 3.

TABLE 3: AIRCRAFT TYPE TERMINOLOGY USED IN THIS REPORT

Terminology used	Description
<b>Helicopter</b> (incorporating both <i>Firebird</i> (light/ Type 3) and <i>helitak</i> (medium/ Type 2 and Heavy/ Type 1) categories)	<p><i>Firebird</i>: A variety of light rotary aircraft used in a variety of supervisory tasks and for bombing, usually with a bucket with capacities &lt;1133 litres. E.g. Bell 206, AS 350, EC130. There is drop data for only one of this aircraft type, although firebirds were widely used in firebombing roles in NSW in the 2019-2020 season. Call sign abbreviation FB###, where '###' indicates a unique number for each firebird aircraft.</p> <p><i>Helitak</i>: Mostly used for firebombing with buckets or belly-tanks. Also used for transporting remote area firefighting teams. Mostly used to directly suppress fires, but can also be used to deliver retardants. Call sign abbreviation HT###, where '###' indicates a unique number for each helitak aircraft.</p> <p>Medium (1134-2267 l) models include Bell 204/205/212/ 412, BK 117, EC145.</p> <p>Heavy (&gt; 2270 l) models include S-64 (aircrane), S-70A (Firehawk), S-61N, Bell 214B.</p>
<b>Single-Engine Air Tanker (SEAT)</b> (Synonymous with Type 4 fixed wing)	<p>Agricultural type fixed-wing aircraft with one engine used for bombing roles. Standard models (e.g. AT-802F, PZL M18T) must be reloaded at an airbase and can be used to deliver retardants or suppressants. Amphibious models (e.g. AT-802F Fireboss) can reload from suitable water bodies. Call sign abbreviation B###, where '###' indicates a unique number for firebombing fixed-wing each aircraft.</p>
<b>Large Air Tanker (LAT)</b> (Synonymous with Multi-Engine Air Tanker (MEAT), incorporating both Type 2 (LAT) and Type 1 (Very Large Air Tanker (VLAT)) Fixed-wing.)	<p>A large Multi-Engine Airtanker that operates with a lead plane to either deliver retardants or suppressants.</p> <p>Large (Type 2) models include AVRO RJ85, C130Q, Boeing 737.</p> <p>Very Large (Type 1) models include the DC-10.</p> <p>Call sign abbreviation B###, where '###' indicates a unique number for firebombing fixed-wing each aircraft (same as SEATS).</p>

## DROP LOCATIONS, TIMES AND AIRCRAFT

A substantial number of drops and fills are recorded. However, not all aircraft have firebombing event logging capability, thus there are missing aircraft from the drops data. NAFC contracted aircraft are required to have firebombing event logging (drop and fill etc.) whereas call-when-needed aircraft only require location tracking, but not event logging. Some aircraft may be missing due to equipment or logging error. In comparison to the aircraft dispatch report for the season, only 19 out of 42 bombers and 21 of 56 helitaks in the dispatch report are



captured in the drops data. Only 1 of 64 other aircraft callsign types (including 48 Firebirds, which can have firebombing or observation-only roles) listed in the dispatch report as having a firebombing role at some stage during the season is captured in the drops data. Figure 8 and Figure 9 show an example of how a large number of aircraft can be identified as missing from the drops data by using the aircraft tracking data (i.e. aircraft location only data). These figures also show the variety of fill locations used by different aircraft types. Ideally, all aircraft would have firebombing event logging capability to allow for robust statistical analysis during research around suppression. In addition, two Large Air Tankers (LATs) (B138 and B165) that were used extensively during the season are not captured in either the drops data or tracking data.

The drops data can be broadly split using the "Event" field into a drops dataset (69513 records) and fills dataset (35226 records), with the drops dataset being the focus of this report. Not all aircraft have recorded a similar number of drops to fills as could be expected. Some aircraft only have drops records (e.g. Bomber 352 and Helitak 227, Figure 5). Some aircraft, mostly recorded near either the Victoria or Queensland border, only recorded fills, possibly as the drops were in either Victoria or Queensland. However, some clear errors do exist. For example, Helitak 418 was working in the Blue Mountains and recorded only fills, both when the aircraft was over a dam or river and in the middle of a forest (i.e. presumably dropping). Helitak 212, 227 and 294 all had 9000 to 10000 drops each. However, it is unclear how many are actually drops on a fire. For example, Figure 6 shows both drops and fills recorded directly over the Shoalhaven River for Helitak 294 and drops only over the river for Helitak 227. This may result from a small amount of water being released during lift-off being recorded as a drop (doors open) or fills being incorrectly recorded as drops. The latter is likely the case for Helitak 227, which only recorded drops during the entire season but no fills (Figure 5).

The drops data provides start and end coordinates for both suppression aircraft drops and fills. A line can be drawn between drop start and end coordinates in a GIS, from which drop length and direction can be estimated (Figure 4). This indicates the line where aircraft was dropping water or retardant etc. It is only possible to assume and draw a straight line between the two coordinates, which prevents drops made on curved trajectories from being accurately mapped. It should be noted that the exact location of where the suppression product hit the ground is unknown, only where it was released (e.g. water may have drifted in wind between being released and hitting the ground). Start and end times are also recorded, which allows the total duration of a drop to be calculated (Figure 4). End coordinates or end times are missing for 8% of records in the drops data. The reason for this is unknown, but for this report we have assumed that in these cases end coordinates are equal to start coordinates.

All drops lines (total of 69513 lines) that intersect with NSW are shown in Figure 2. Some drop lines are too long to be legitimate records e.g. there were 44 bomber drops and 138 helicopter drops recorded as > 5 km in length (Figure 7, Figure 4). Most of these lines could be filtered out before conducting any spatial analysis simply removing all lines greater than a maximum distance for each aircraft type (i.e. setting a maximum possible drop distance for aircraft type). Drop altitude and speed fields may also assist in identifying illegitimate records. However, there



are likely to be some records remaining that have recording errors or show when delivery system doors have been left open long after the load has evacuated.

The issues above indicate that recording errors do occur that can potentially affect any subsequent analysis. While this can be dealt with somewhat via some assumptions and data filtering methods, it is unclear what the reasons for the errors are and whether they can all be removed. Also, these methods do not provide a solution for firebombing event recording in the future (i.e. equipment, recording errors not fixed). Site assessments and the use of high-resolution satellite and aerial imagery could also be used to determine how well firebombing event drop locations represent ground conditions and assess drop effects on the fire (e.g. Plucinski 2010, Plucinski and Pastor 2013), although for practical reasons could only be done for selected case studies. Ultimately, reducing errors during the recording of drops would be the best solution and worthy of a separate assessment.

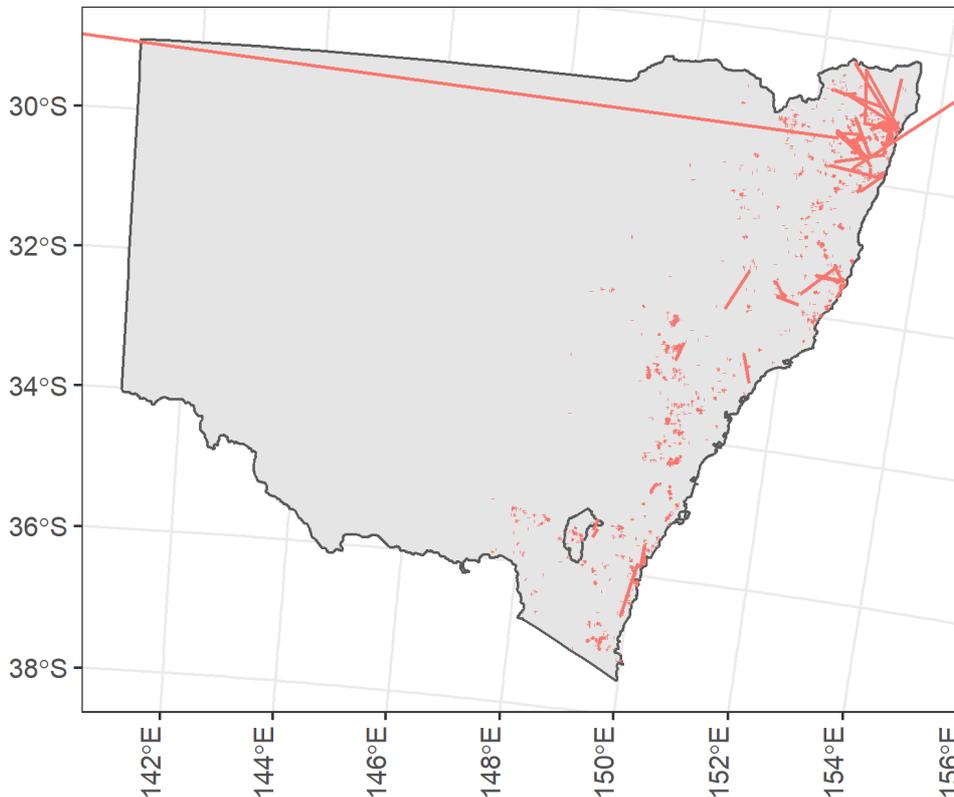


FIGURE 2: DROP LINES DRAWN FROM START AND END COORDINATES. ONLY LINES THAT INTERSECT NSW OR ACT SHOWN

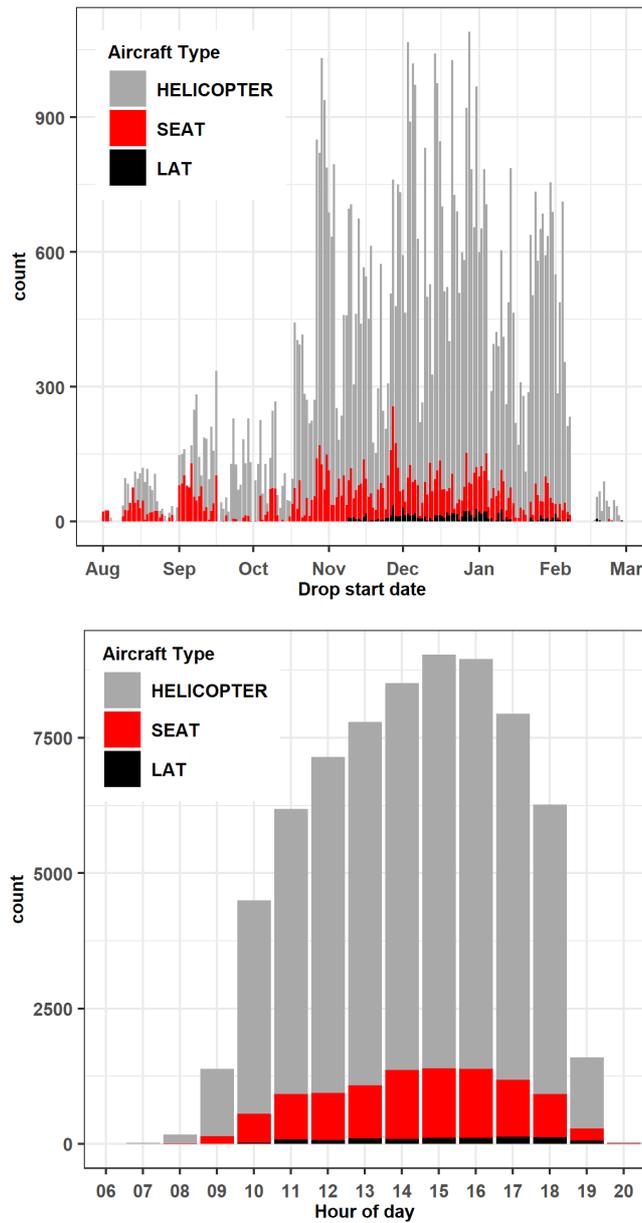


FIGURE 3: SUMMARY AIRCRAFT SUPPRESSION DROPS OVER 2019-2020 FIRE SEASON BY DATE (TOP) AND BY HOUR OF DAY (BOTTOM).

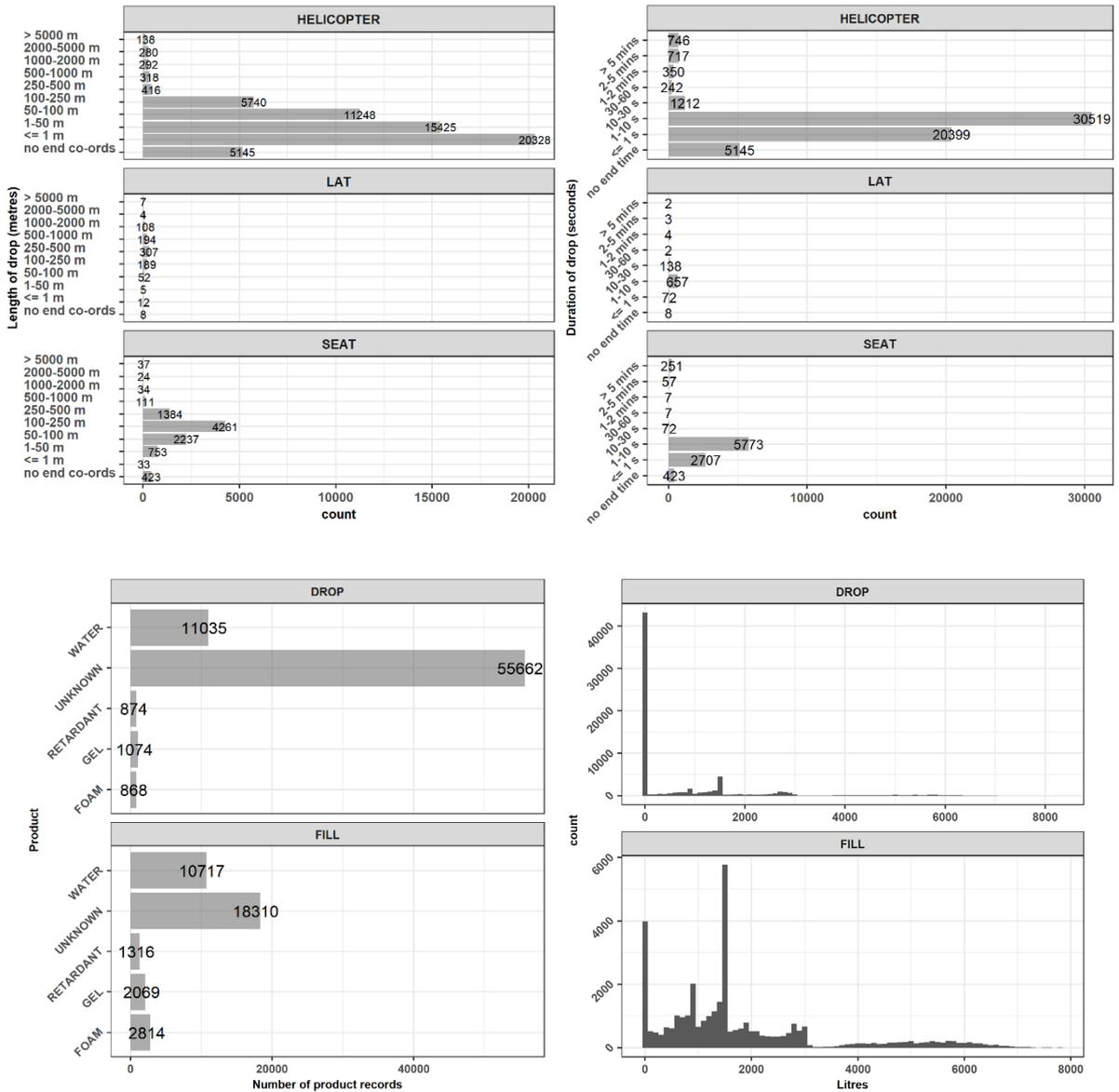


FIGURE 4: DROP DISTANCES (TOP LEFT) AND DURATIONS (TOP RIGHT) FOR AIRCRAFT TYPES DERIVED FROM DROP START AND END COORDINATES AND TIMES. PRODUCT RECORDED FOR DROPS AND FILLS (BOTTOM LEFT). HISTOGRAMS OF LITRES RECORDED FOR DROPS AND FILLS (BOTTOM RIGHT). NOTE SOME RECORDS HAD DROP START COORDINATES AND TIME BUT NO DROP END COORDINATES AND TIME.

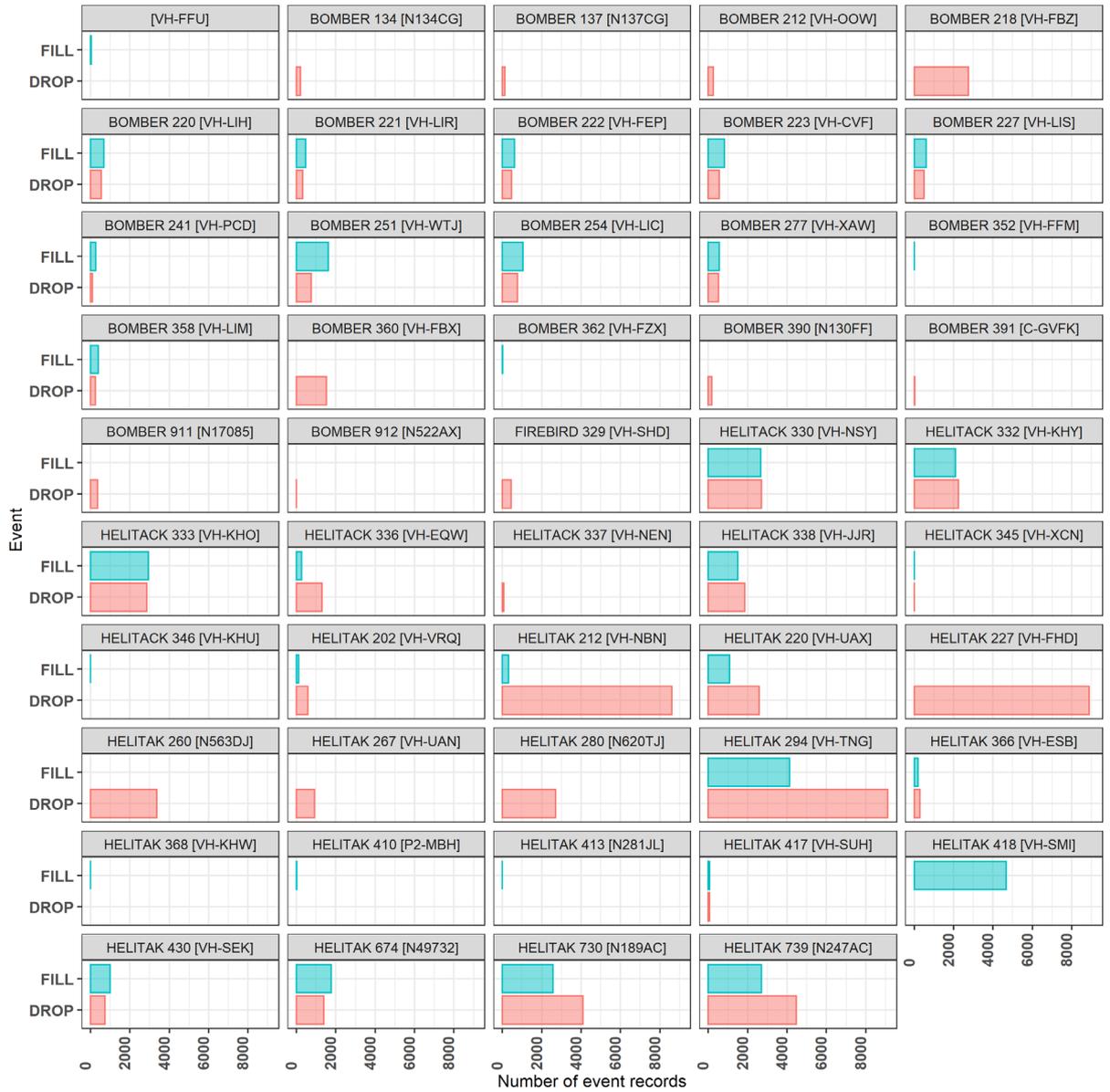


FIGURE 5: NUMBER OF FILLS AND DROPS FOR EACH AIRCRAFT (WITHIN NSW/ACT) IN DROPS DATA. NOTE THERE ARE NO RECORDS FOR SOME PROMINENT LARGE AIRCRAFT, INCLUDING BOMBERS 138 AND 165.

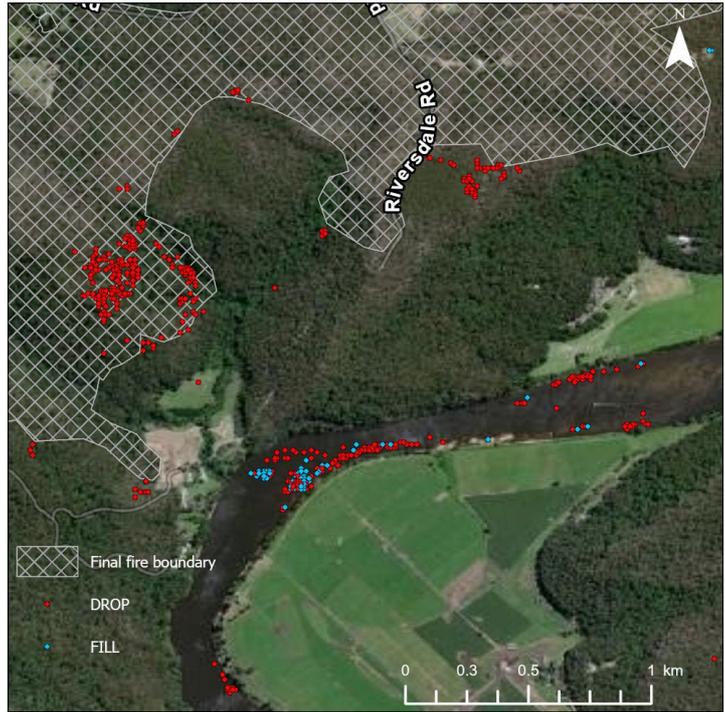


FIGURE 6: EXAMPLE OF AIRCRAFT “DROPS” RECORDS OVER A WATER SOURCE, SHOALHAVEN RIVER WEST OF NOWRA BETWEEN 7<sup>TH</sup> AND 28<sup>TH</sup> JANUARY 2020 FROM HELITAK 227 AND HELITAK 294. DROPS ARE RED POINTS (START OF DROP) AND FILLS ARE BLUE POINTS. THESE ERRORS MAY BE DUE TO AIRCRAFT DROPPING A SMALL AMOUNT OF WATER DURING LIFT OFF OR A LOGGING ERROR (RECORDING A FILL AS A DROP). SUCH RECORDS WOULD NEED TO BE EXCLUDED IN A SPATIAL ANALYSIS OF SUPPRESSION LOCATION OR EFFECTIVENESS.

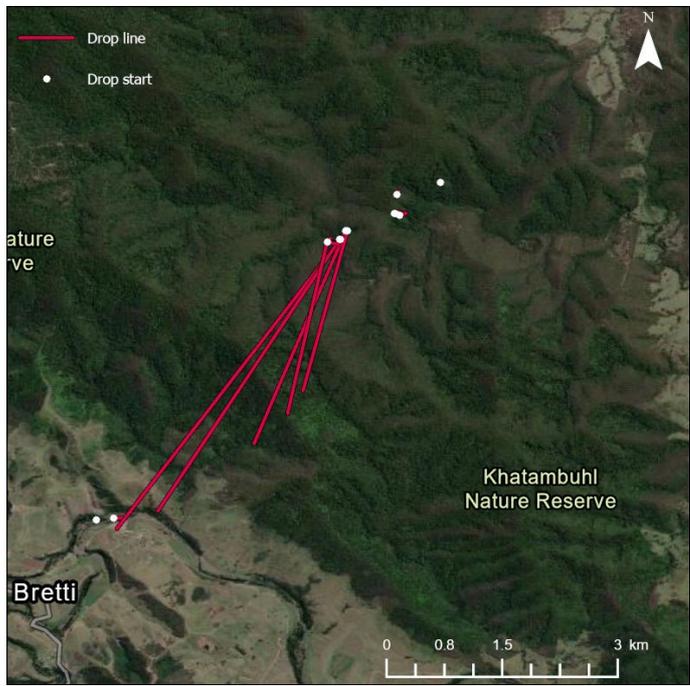


FIGURE 7: CLOSE UP EXAMPLE OF ERROR IN RECORDING OF DROPS COORDINATES. THIS CASE FROM HELITAK 220 ON 21/09/2019 HAS 5 LINES > 2 KM AND A LONGEST LINE OF ~4.5 KM BETWEEN DROP START AND END COORDINATES, MUCH LONGER THAN WOULD BE EXPECTED PARTICULARLY FOR A HELICOPTER. PROBLEMS LIKE THIS, POSSIBLY WITH CERTAIN AIRCRAFT, CAN BE EXPLORED USING DATA ON DROP LENGTH, DURATION AND LOCATION (E.G. APPENDIX FIGURE 30 AND FIGURE 31).

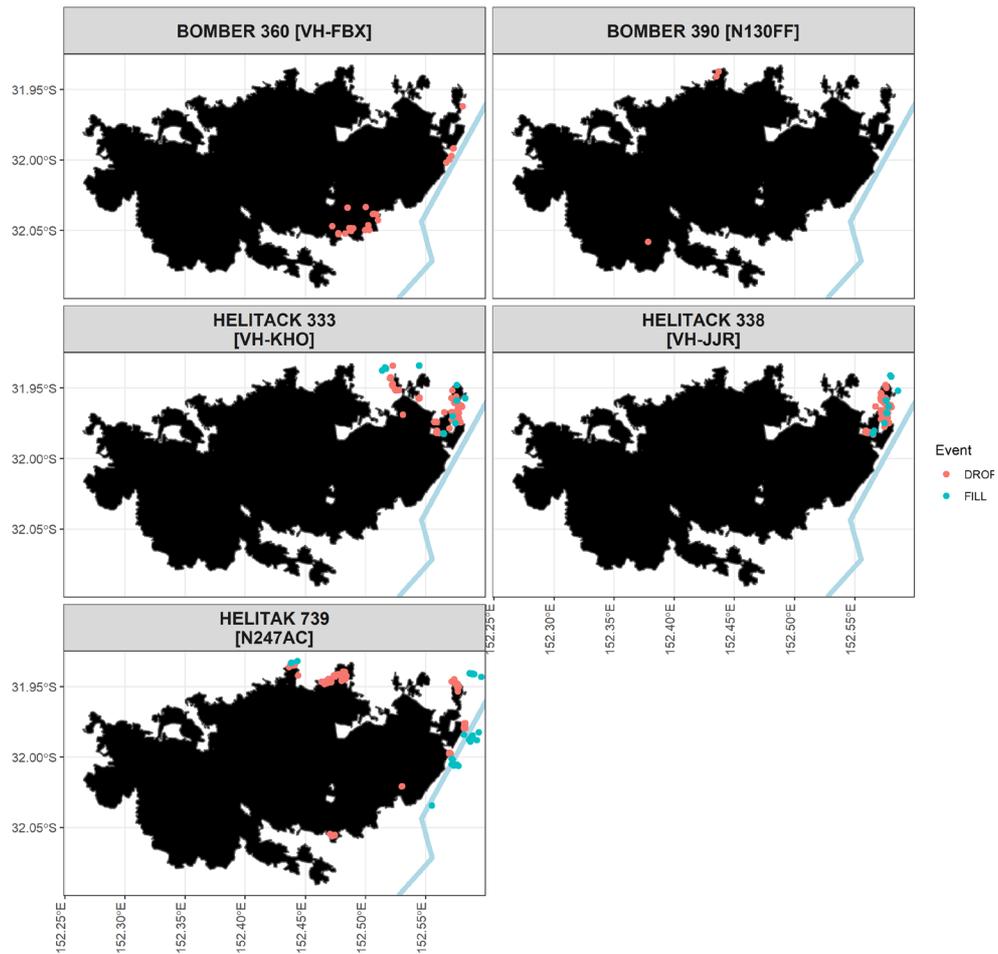


FIGURE 8: EXAMPLE OF DROP AND FILL LOCATIONS FROM DROP DATA FOR THE HILLVILLE FIRE ON 2019-11-09. IN COMPARISON WITH FIGURE 9, THIS EXAMPLE SHOWS THAT NOT ALL AIRCRAFT ARE CAPTURED IN BOTH DATASETS. TWO OF THE AIRCRAFT CAPTURED IN THE DROP DATA (HT739 AND BOMBER 390) ARE NOT IN THE TRACKING DATA (FIGURE 9).

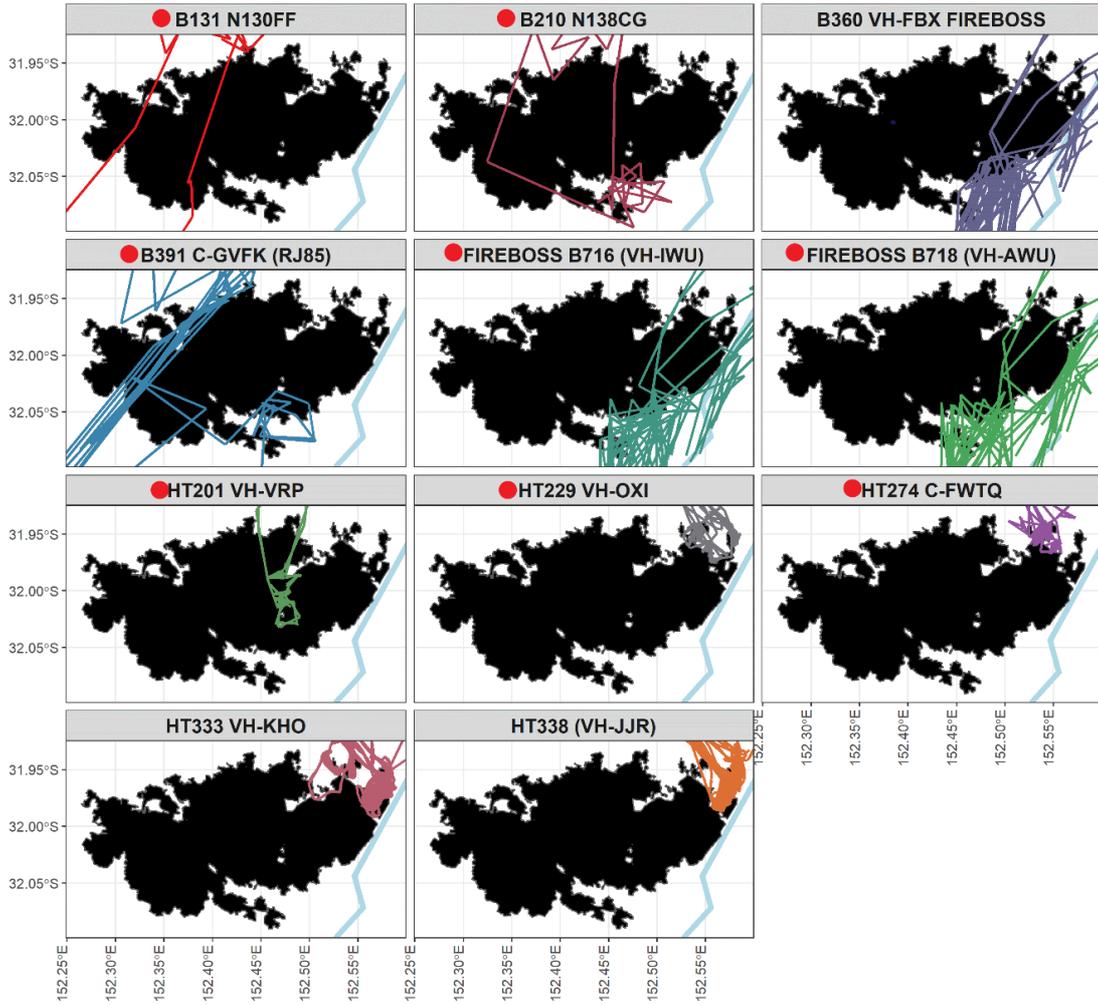


FIGURE 9: EXAMPLE OF AIRCRAFT LINES FROM TRACKING DATA FROM THE HILLVILLE FIRE ON 9/11/2019. IN COMPARISON WITH FIGURE 8, THIS EXAMPLE SHOWS THAT NOT ALL AIRCRAFT ARE CAPTURED IN BOTH DATASETS. ONLY 3 OF THE 9 AIRCRAFT RECORDED IN THE TRACKING DATA OVER THE FIRE (BOTTOM, HT333, HT338 AND BOMBER 360) ARE ALSO RECORDED IN THE DROP DATA (TOP). RED DOTS INDICATE AIRCRAFT THAT DO NOT HAVE DROP/EVENT DATA. NOTE FIREBIRDS, WHICH MAY HAVE A FIREBOMBING ROLE, NOT SHOWN.



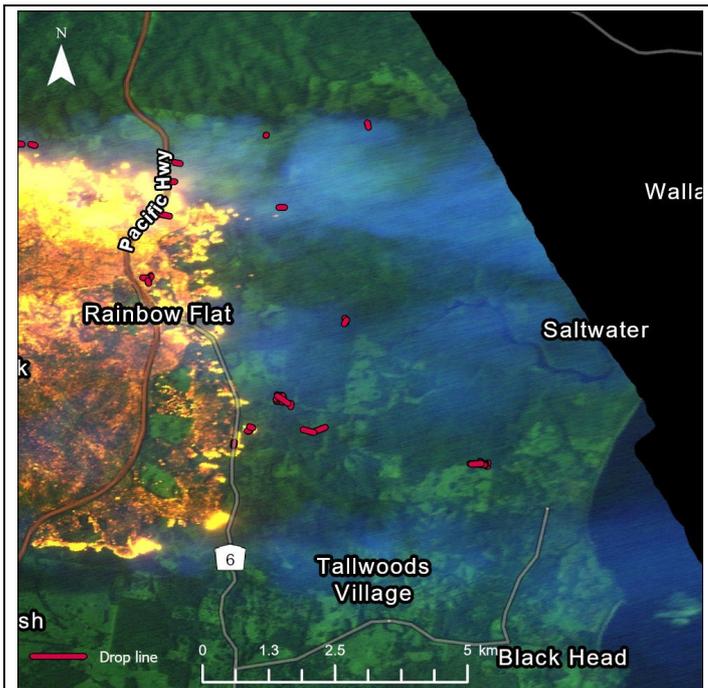
## CLASSIFICATION OF OBJECTIVES FROM SPATIAL DATA

The drops data provides the location and time of drops but does not provide information about the objectives of each drop. However, using certain assumptions, drops may be broadly classified into different drop-objective groups based on a subjective assessment of drop characteristics including the drop location and time, and reference to separate data such as fire progression polygons. While this can narrow the range of possible objectives, other information including interviewing aircrew or data on ground crew movements can be required to have high confidence, and a more detailed understanding, of the drop objectives. One advantage of classifying drops into different objectives based on just spatial data is that a large data sample can be created (i.e. only spatial data is required), whereas interviewing aircrew is much more time-consuming meaning there is a lower return for the effort required to collect it.

Table 4 below provides examples of classifying drop objectives based only on the spatial data available. Some of the classification steps can potentially be automated, while others require visual inspection. The classification examples below are subjective and rely on certain assumptions about the time and location of drops with reference to other data such as building locations, aerial imagery and fire progressions.

TABLE 4: EXAMPLES OF CLASSIFICATION OF OBJECTIVES BASED ON SPATIAL DATA AND THE ASSUMPTIONS NECESSARY. NOTE TABLE RUNS OVER MULTIPLE PAGES

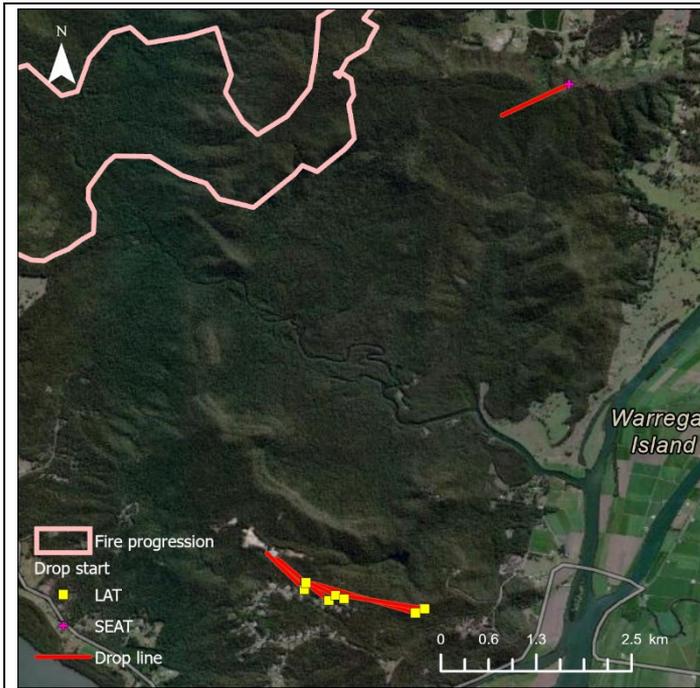
	<p><b>Asset protection:</b> A simple classification could assume that all drops close to houses or buildings (within a threshold distance) are aimed at asset protection. In this example, drops near Lewis St and along Forest Ln are directly adjacent to houses. Further information may assist in this classification, particularly around the timing of the drops: were they during the fire or after the fire passed (i.e. mopping up)?</p>
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**Asset protection or spot fire drops ahead of main fire:** By matching data describing drop location and time, with fire location and time, it is possible to determine if drops were outside the active fire area. In this example (Hillville 8/11/2019), the drops mainly occurred 1 to 2 hours before line scan time, meaning they were downwind of the main fire. This suggests that aircraft were dropping to extinguish spot fires or protect houses. Using a building location layer, the drops could be classed as either asset protection (close to building) or spot fire (not near a building) drops. Availability of regular line scans is required to conduct such a classification.

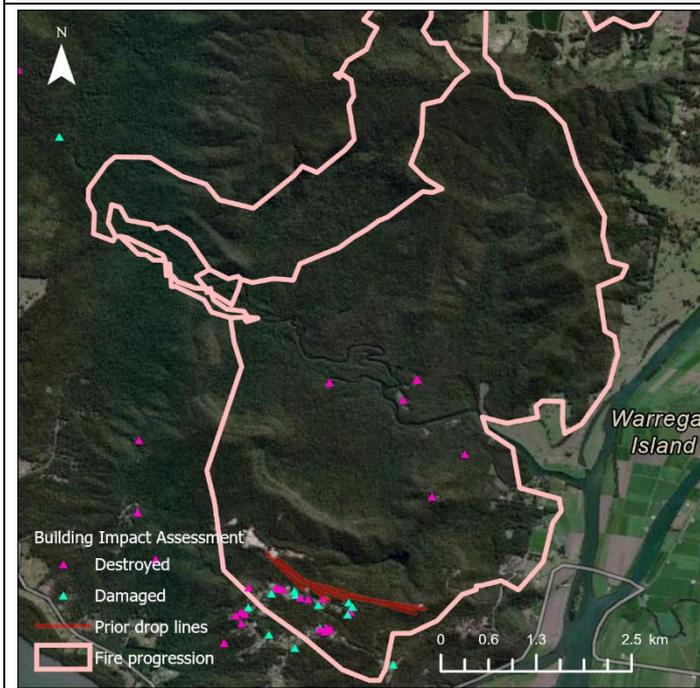


**Direct attack/drops on active part of fire:** As with the above example using drops data and progressions, in cases where time of drops and time of progression is similar, drops could be classed as direct attack on the active flank or head fire. In this case, the underlying line scan shows active fire at 12:12 pm and all drops are between 12 pm and 1 pm (2/11/2019).

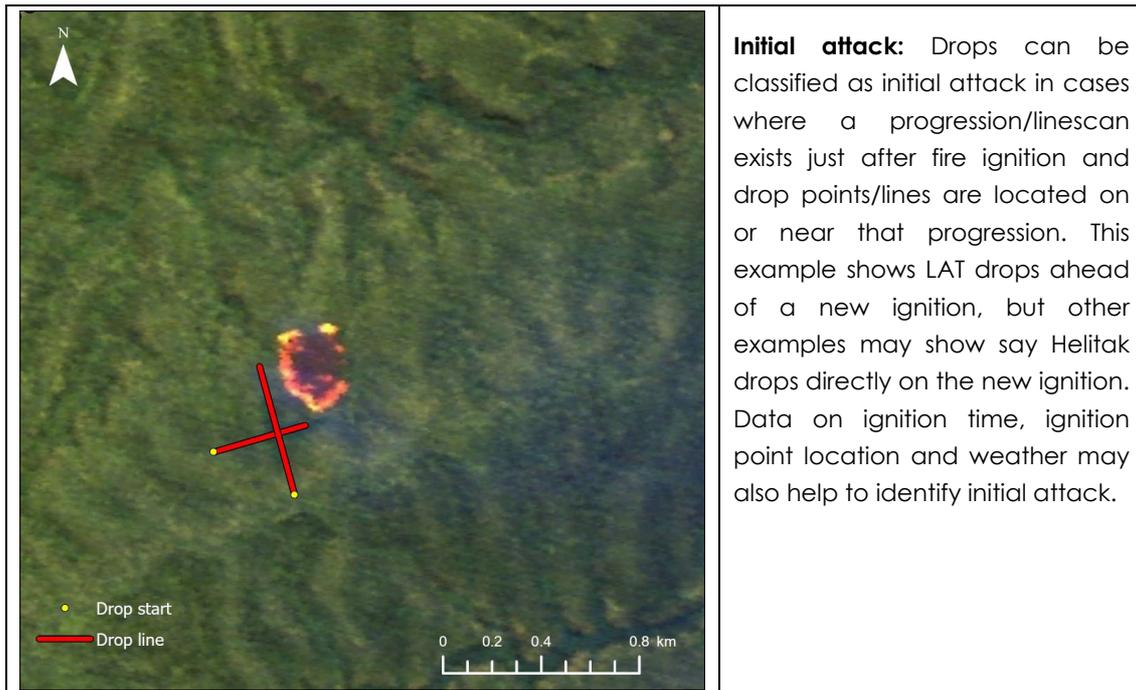


**Retardant line (pre-emptive):**

Using the lines that can be drawn from drop start and end coordinates, and the progression data, it is possible to identify a) a series of connecting lines from LATS and SEATS, in this example next to a group of houses, and b) that the series of lines were put in place well before the fire arrived (progression line (2:30 pm) is the same day as the 7 southern drops (3 pm to 5 pm)). It could be assumed in this case that the drops are aimed to create a barrier for later fire spread near the houses, or help widen control line for ground crews.



In addition to drop objectives, drop effectiveness may be explored. This example shows the same area as above, but two days after the retardant lines were put in place (note fire subsequently spread south). Building impact assessment (BIA) data can be used to identify if houses near the retardant line were impacted. Progression data can be used to determine if the fire passed the retardant line. In this case, the fire passed the line and destroyed houses. Statistical analysis would require many examples such as this.



## OTHER SPATIAL DATA

Other spatial data used for mapping and analysis included:

- **Building impact assessment** data (RFS), which identifies the location of destroyed, damaged and untouched buildings from inspections after fires during the 2019-2020 season, has been used for maps.
- **Building footprints** – a polygon layer produced by Microsoft based on automated analysis of satellite images to identify building footprints. <https://github.com/microsoft/AustraliaBuildingFootprints>
- **Weather observations** at Bureau of Meteorology weather stations across NSW. Hourly Forest Fire Danger Index was calculated from these observations and was accessed through a database held at the University of Wollongong.
- **Satellite imagery** was accessed through planet.com. This includes images from the Planetscope and Rapideye satellites, which have < 10 m resolution (Planetscope is ~ 3m) and are acquired every one to two days. Only screenshots of the images are used to demonstrate how they could be used. ArcGIS/Bing imagery basemaps have also been used for maps in the figures below.
- **Fire progressions** are polygons that have been drawn around fires in RFS linescan images. These polygons were originally drawn by RFS during fire response but were verified, updated and edited by the University of Wollongong for a separate project.



## CORRELATION WITH SPATIAL FEATURES

The drops data can be used to analyse drop patterns for a single fire or over an entire fire season. There are many types of analyses with varying degrees of precision and time required that can be used to characterise drops and their objectives. For example, a simple analysis could be conducted to calculate the density of drops by location (e.g. 1 km windows, by region) over the whole season or by date/hour. The drops data could also be used to answer questions about whether drops are more targeted near or far from different spatial features, e.g. buildings, ridges or roads, whether drops are more common under mild or more severe weather conditions or whether the density of drops affected fire severity or house loss (building impact assessment data). These analyses can be broken down by aircraft or aircraft type using the aircraft call sign field in the data.

The section below demonstrates some basic analyses that can be conducted using the drops data and other spatial data. Other more complex analyses are possible with the data but are not attempted here due to project time constraints. The analysis here was conducted in R using the 'sf' spatial data and analysis package. The two analyses below focus on drop distance to buildings and weather conditions.

### BUILDINGS/ASSET PROTECTION

The drop data can be combined with a building location layer to understand if asset protection was a likely objective of drops at a particular fire. The analysis here is coarse, as only one building layer is used, and does not use any other information on drop objectives. Rather the assumption is that the closer drops were to a building, the more important asset protection was as an objective.

The results of the analysis have been displayed to demonstrate different patterns that could be identified in the data. For an individual fire, the process was to:

- 1) Using R and the 'sf' package, select the fire history polygon, which defines the final fire perimeter.
- 2) Select all drops that either have a spatial intersection with the final fire perimeter or were within 1 km of the polygon edge.
- 3) Create a 250 metre resolution point grid over the entire fire history polygon.
- 4) Create an attribute for each grid point to identify the number of buildings within its 250m x 250 m area. We used the Microsoft Building Footprints data (<https://github.com/microsoft/AustraliaBuildingFootprints>) as our building layer. This is produced from an automated classification of building locations from satellite imagery. To help remove spurious buildings from this analysis (e.g. sometimes large rocks can be classified as buildings), a grid point was only identified as having a building if there were at least two records from the Microsoft Buildings layer within its 250 m by 250 m area.
- 5) Calculate the distribution to nearest building across the entire fire using the point grid: for each point, distance to nearest building was



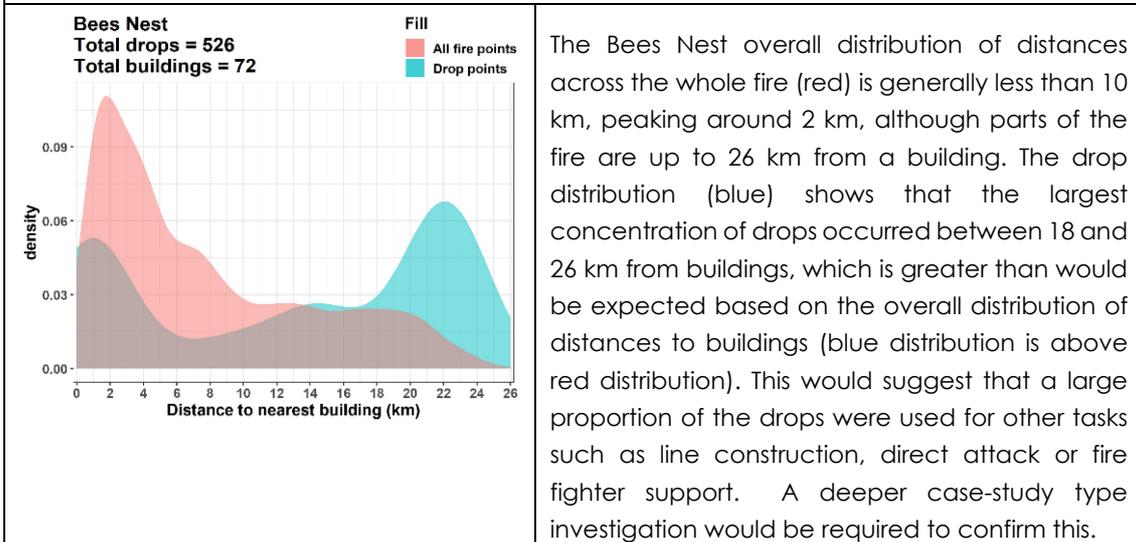
measured, and distances to all points were plotted as a single distribution (red distribution in the plots below, Table 5).

- 6) Calculate distribution of drops to nearest building: for each drop, calculate distance to nearest building, and plot all these distances as a single distribution (blue distributions in the plots below, Table 5).

The resulting plots presented in Table 5 can be interpreted as: if the total fire and drop distance to building distributions (i.e. red and blue) are the same, then drops were not occurring more often near buildings, i.e. drops would be evenly spread across the fire area. If the drop distance distribution (blue) is substantially skewed toward smaller distances, then drops were occurring more often near buildings and vice versa with greater distances.

The analysis could be improved by using a more precise building location layer (e.g. Geoscape data). For this analysis, we have also not attempted to identify the timing of drops. The analysis could be improved by removing drops that occurred after the main fire front had passed (e.g. removing drops that were for mopping up). The fires below were selected to demonstrate different patterns that can be identified in the plots.

TABLE 5: DISTRIBUTION OF DISTANCE TO BUILDINGS FOR ALL FIRE GRID CELLS (RED) VS DROP LOCATION POINTS (BLUE). TOP PLOTS SHOW ALL DROPS POOLED AND BOTTOM PLOTS SHOW DROPS SEPARATED BY AIRCRAFT TYPE. WHERE RED AND BLUE DISTRIBUTIONS ARE SIMILAR, THEN DROPS ARE EVENLY SPREAD ACROSS THE FIRE AREA. WHERE THE BLUE DISTRIBUTION IS ABOVE THE RED DISTRIBUTION, DROPS WERE MORE CLUMPED AT THAT DISTANCE FROM BUILDINGS THAN WOULD BE EXPECTED IF DROPS WERE EVENLY DISTRIBUTED ACROSS THE FIRE. NOTE TABLE RUNS OVER 2 PAGES





<p><b>Gospers Mountain</b> Total drops = 2071 Total buildings = 796</p>	<p>Overall distances to buildings across the fire were spread between 0 and 22 km, peaking around 0 to 2 km. However, the drop distribution (blue) is greater than the overall distribution between around 0 to 2 km, suggesting that drops were more concentrated near buildings than would be expected if drops were evenly distributed across the fire (red distribution).</p>
<p><b>Dunns Road</b> Total drops = 1061 Total buildings = 561</p>	<p>The Dunns Road fire distributions have been separated by aircraft type. Drops from SEATs had two peaks in density within 8 km from buildings, whereas helicopters were used further from buildings, peaking at around 13 km and 20 km, despite only a small fraction of the fire being situated that far from buildings (red distribution is mostly &lt; 12 km). LAT drops were distributed slightly closer to buildings than SEATs, with LAT drops peaking at &lt; 1 km.</p>
<p><b>Myall Creek Road</b> Total drops = 3064 Total buildings = 263</p>	<p>The Myall Creek Road distributions have been separated by aircraft type. Helicopters and LATs were similar, with peaks in drop density close to buildings (0 to 1 km) and 4 or 5 km from buildings. Drops from SEATs differed, as these were heavily clumped close to buildings (&lt; 2km), much more than would be expected if drops were evenly distributed across the fire area (red distribution).</p>

## FOREST FIRE DANGER INDEX

The drop data can be combined with Bureau of Meteorology (BOM) hourly weather observations to provide some understanding of the weather conditions under which drops occurred, e.g. if drops occurred under milder or more severe weather at a particular fire. This can help to understand the most common weather conditions under which different aircraft types were used at a fire. This information may be used to help understand drop objectives in some cases, e.g. asset protection may have been occurring under extreme FFDI but the building of retardant lines under mild FFDI. The process for this analysis was to:

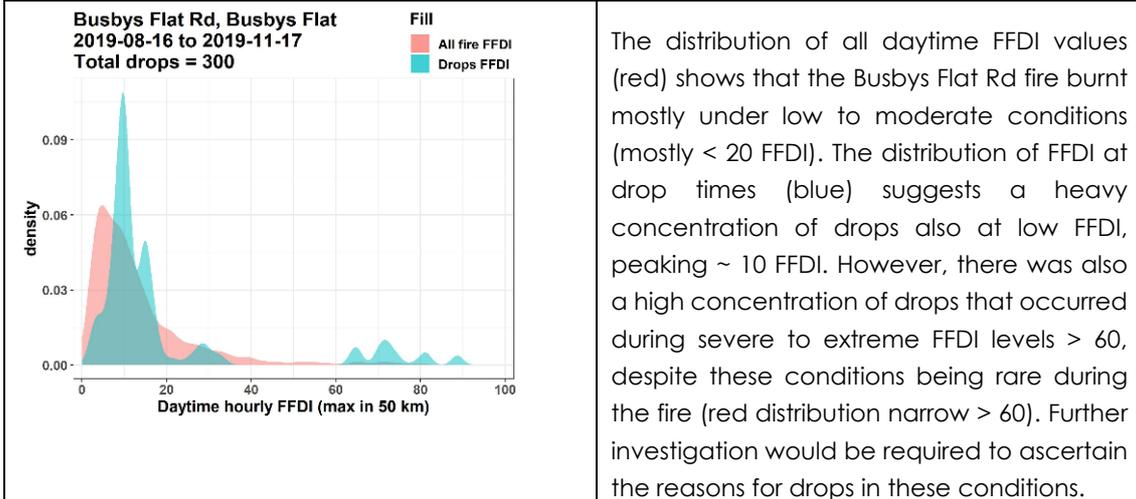
1. Using R and the 'sf' package, select the fire history polygon, which defines the final fire perimeter.
2. Select all drops that either have a spatial intersection with the final fire perimeter or were within 1 km of the polygon edge.



3. Extract all BOM weather observations for daytime hours (we used 0900 to 2000 as aircraft don't fly at night) within 50 km of the centroid of the final fire polygon. We only extracted hourly values that were between the first timestamp and last timestamp of any drops from the drop data. This was to ensure only weather while suppression was occurring was sampled.
4. Calculate the Forest Fire Danger Index (FFDI) for each hour from the weather observations (note this was available pre-calculated through a database held at University of Wollongong/Centre for Environmental Risk Management of Bushfires).
5. Plot distribution of all the daytime hourly FFDI values (red in plots below, Table 6), to represent the distribution of FFDI values across the fire (when aerial suppression was occurring).
6. Match each drop with the FFDI of the hour closest to the drop timestamp
7. Plot distribution of all drop FFDI values (blue in plots below, Table 6), to represent weather under which drops occurred.

The analysis uses a maximum FFDI value within 50 km of the fire centroid, but alternatives could be to use the nearest weather station, mean FFDI within 50 km or select a most representative station (e.g. station on the coast for coastal fire) etc. The fires below were selected to demonstrate different patterns in firebombing under different weather conditions that it is possible to identify using the drops data.

TABLE 6: DISTRIBUTION OF FFDI FOR ALL FIRE DAYTIME HOURS BETWEEN THE FIRST DROP AND LAST DROP AT THE FIRE (RED) VS FFDI AT DROP TIMES (BLUE). TOP PLOTS SHOWS ALL DROPS POOLED AND BOTTOM PLOTS SHOW DROPS SEPARATED BY AIRCRAFT TYPE. THESE PLOTS CAN BE USED TO UNDERSTAND THE WEATHER CONDITIONS THAT OCCURRED AT A PARTICULAR FIRE, AND WHEN DROPS OCCURRED. DROPS OCCURRED EVENLY ACROSS ALL CONDITIONS EXPERIENCED AT A FIRE WHEN THE BLUE AND RED DISTRIBUTIONS ARE SIMILAR. WHEN AIRCRAFT WERE USED IN MORE EXTREME WEATHER CONDITIONS THE BLUE DISTRIBUTION IS TO THE RIGHT OF THE RED. NOTE TABLE RUNS OVER 2 PAGES





<p><b>Kerry Ridge</b> 2019-11-25 to 2020-01-21 Total drops = 1724</p>	<p>This example from the Kerry Ridge fire suggests that daytime FFDI values were most common at ~10 FFDI (red), although a substantial portion of the fire also burnt under more moderate to severe conditions. However, the drop distribution (blue) suggests that drops were concentrated mostly under the very high to severe FFDI, peaking at ~ 40 FFDI.</p>
<p><b>Warm Crossing</b> 2019-12-03 to 2019-12-21 Total drops = 148</p>	<p>This example from the Warm Crossing fire suggests that SEAT and helicopters were used under different conditions at the fire. SEATs were mostly used when FFDI was below 20, whereas helicopters were mostly used when FFDI was above 20, and up to FFDI ~ 70. However, there was some crossover, with SEAT drops also occurring above FFDI 20, but much less so than helicopters. No LAT drops were recorded at this fire. Further investigation of this incident would be required to ascertain the reasons for the drops made in these extreme conditions.</p>
<p><b>Carrae East</b> 2019-08-16 to 2019-12-28 Total drops = 779</p>	<p>This example of drops at Carrae East fire suggests that SEATs and helicopters were used under similar weather conditions, most commonly when FFDI was around 10. However, LAT drops occurred under different conditions, mainly with FFDI &gt; 18 despite these FFDI conditions not occurring often at the fire (red distribution narrow &gt; 18)</p>

## CLUSTERING OF DROPS BY DATE AND AIRCRAFT

Automating the spatial analysis of the drops data would allow data from many or all fires to be analysed much more quickly than if methods requiring manual identification and visual inspection of the data are required. Automated analysis may not produce perfect results, but may allow broad trends to be identified in the data without requiring time-consuming manual classification and visual inspection. Higher quality data is harder to collect (e.g. interviews) so assumptions need to be made for automated analysis with all the data.

This section demonstrates an automated spatial analysis method applied to the drops data. The method attempts to group drops based on time and location,



with the idea that such a process may be useful in identifying firebombing strategies. Specifically, below we show a simple spatial method that may be useful in identifying large multi-drop retardant lines from LATs. Other aircraft, especially SEATs, can be involved in retardant line construction, but we limited the analysis to LATs to test the method. To identify groups of LAT drops that may be multi-drop retardant lines, GIS methods were implemented using an R script and the “sf” package, making it easily repeatable. The process was:

- Create drop lines from drop start and end coordinates.
- Split data by individual LATs and by drop date.
- For each LAT on a selected date, identify groups of drops. All drops in a group were within 250 m of at least one other drop in that group.
- Repeat grouping step above for all LATs and all dates.
- Count the number of drops in each group.

The results suggest that LATs were mostly used in single isolated drops, or small groups of 2 or 3, over the 2019-2020 season (Figure 10). The results also show that on some occasions LATs were used for many drops in the same area, with a maximum of 16 drops from Bomber 390 (Figure 10). Visual inspection of drop maps shows that the method used can identify groups of drops, but not their configuration. Two of the top three groups (there were three groups with over 10 drops) appear to be large retardant lines, based on a simple visual inspection of the map data (Figure 11). However, the other appears to be more aimed at asset protection as the drop lines are scattered amongst houses (Figure 11). This shows that to identify multi-drop retardant lines, visual inspection is required given the spatial analysis method we used. However, the exact method used could be refined to produce better results e.g. the distance between drops in one group could be reduced from the 250 m we used.

The results here demonstrate that automating the spatial analysis of the data can help to identify multi-drop retardant lines, although some visual inspection may be required. Similar methods may be applied to identify other tactics e.g. dense groups of helitak drops, or SEAT drop lines. Acquiring drop data from all aircraft assigned to fires would allow for more accurate results to be produced from such methods and the examples presented here only demonstrate the methodology because there is a significant proportion of LAT drop data missing from the 2019/20 season.

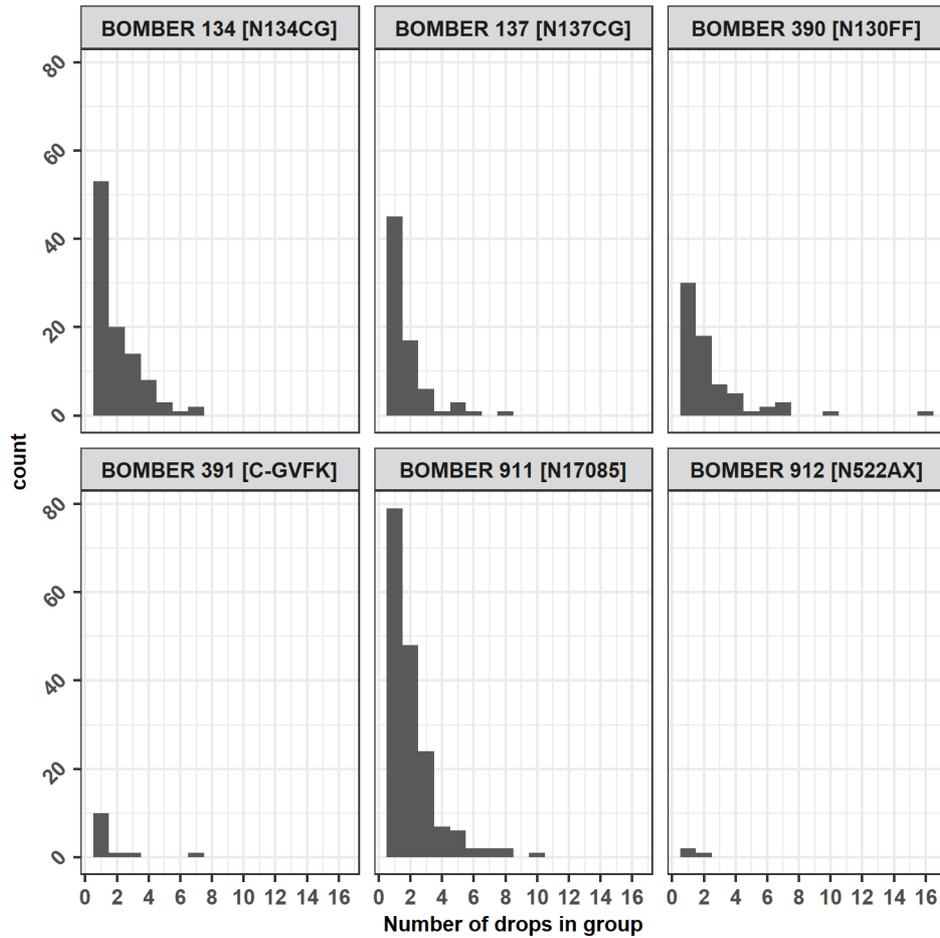


FIGURE 10: HISTOGRAM SHOWING NUMBER OF DROPS IN EACH DROP GROUP FROM EACH LAT BOMBER IN THE DROPS DATA FOR THE ENTIRE SEASON. DROPS FORM A GROUP WHEN THEY ARE FROM THE SAME AIRCRAFT ON THE SAME DAY AND ARE WITHIN 250 M OF EACH OTHER. THE LATS APPEAR TO BE MOST COMMONLY USED IN SINGLE ISOLATED DROPS, OR A SMALL GROUP OF 2 OR 3. HOWEVER, SOME LARGER GROUPS EXIST (MAX 16). THE PROCESS DIDN'T CONSIDER SEATS OR HELITAKS, SO DROPS MIGHT NOT BE ISOLATED. SEATS AND HELITAKS COULD BE ANALYSED IN A SIMILAR WAY, OR ADDED.

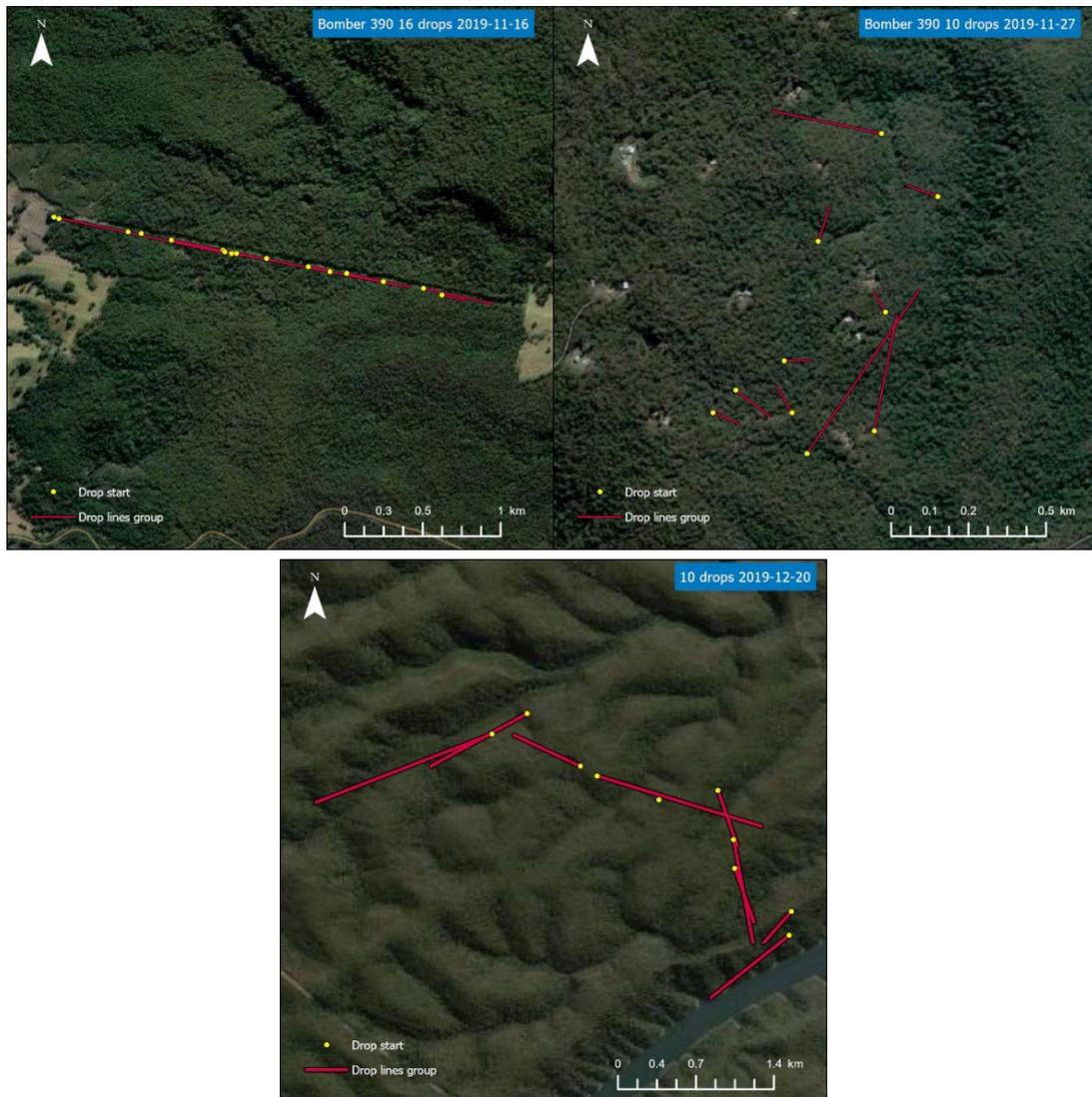


FIGURE 11: THERE WERE THREE DROP GROUPS (DROPS ONE SAME DATE WITHIN 250M OF EACH OTHER) FROM LAT BOMBERS THAT HAD 10 OR MORE DROPS: TWO FROM BOMBER 390 (16 AND 10 DROPS) AND ONE FROM BOMBER 911 (10 DROPS). THE DROPS FROM THE LATS CAN BE GROUPED USING THE AUTOMATED PROCESS BASED ON DISTANCE AND TIME, HOWEVER, FURTHER INSPECTION IS REQUIRED TO HELP IDENTIFY OBJECTIVES. FOR EXAMPLE, TOP LEFT IMAGE SHOWS A PROBABLE RETARDANT LINE IN A LONG NARROW SERIES OVER THE TOP OF A CLEARING IN FOREST. THE TOP RIGHT IMAGE SHOWS SPREAD OUT DROPS AMONGST ISOLATED HOUSES – PROBABLE ASSET PROTECTION. THE BOTTOM IMAGE SHOWS A SERIES OF CONNECTED DROPS IN AN ARC. INFORMATION FROM FIRE PROGRESSION WOULD HELP IDENTIFY PRECISE OBJECTIVES.



## INTERVIEW DATA

### DATA COLLECTION PROCESS

We conducted semi-structured interviews with AAS to assess the viability of supplementing spatial data (drops data) with data from other sources. The AAS oversees the aerial resources on the fire ground and their primary responsibility is to provide safe oversight to all aircraft attending an incident. They manage the tasking aircraft, provide intelligence to the Incident Management Team (IMT) and State Air Desk, and in conjunction with the IMT, develop and implement aerial suppression strategies. When aircraft were managed by a local IMT, their reporting relationship would be through the Air Operations Branch (if established) of the Operations Section.

The primary focus of interviews was to review the objectives and outcomes of individual fire events. Information was sought about the objectives of the aerial suppression actions, how the day or event evolved, what aircraft were present and how they were used, the outcomes, challenges, how decisions were made and documented, and suggestions for improvements. Ethics clearance was granted by the University of Wollongong Human Ethics Committee beforehand. Candidate interviewees were sourced by asking the RFS's Aviation Supervisor to identify people who were rostered as AAS during the fires and by the suggestion of other AAS who were interviewed.

Interviewees were emailed an invitation to participate. Before the interview, respondents were provided with a list of potential case study dates/fires, simple maps (linescan progression and drop event data) and example questions. This list contained examples of days where there were higher quantities of drops and fire spread data. Interviews were conducted remotely using video meetings (Zoom) that were recorded and the audio was transcribed. The list of example questions was used to guide a conversation between the interviewee and two of the authors (Matt Plucinski and Heather Simpson). Not all the interviewees attended the fires on the potential case study list. In such cases, interviewees were asked to discuss fires/days of their choosing, though there was some guidance for them to select case studies that had more supporting data or that had differences (e.g. fuel type, fire stage, weather conditions, location etc.) to other case studies previously selected.

### INTERVIEWEES AS A DATA SOURCE

We conducted 10 interviews. Interviewees were an invaluable data source. It was clear that they are highly skilled and highly experienced experts in their field who apply their knowledge when making tactical decisions. Interviewees came from three different agencies, the NSW National Parks and Wildlife Service, the RFS, and the British Columbia Wildfire Service. On average, they had 13 years of experience in air attack, and 28 years of experience firefighting. Their knowledge and recall were well above expectation, especially given the time that had elapsed between the events and interviews (~18 months). The interviewees provided rich contextual information, including videos, photographs, and maps, which aided their recall of the case study incidents and allowed them to



describe drop objectives and conditions. They were enthusiastic about sharing and participating; several interviewees expressed their desire to be engaged in further research that could improve future outcomes.

## INTERVIEW FORMAT

Interviews ranged from one to two hours in duration. The majority of each interview was spent discussing one or two case study fire(s) days (location, objectives, aircraft, context, etc.) in depth. The video meetings enabled the sharing of photos, videos, and location information. The interviews unfolded as a guided conversation. A short list of questions (listed below) was used to guide the conversation through several areas. Most of the interview time was spent on the first question.

1. On a specified day, what was the objective of the air campaign? Give as much detail as possible, for example, expanding on how the objectives evolved during the day or in different parts of the fire.
2. What suppressants were used in which aircraft or in which parts of the fire?
3. What challenges did you encounter with achieving the original objective?
4. What outcome did you observe as a result of the campaign?
5. How did you document the decisions that were made (e.g. target locations, objectives, suppressant types)?
6. What improvements could be made to data gathering or the reporting systems to improve our ability to learn?



## AERIAL SUPPRESSION CASE STUDIES

In this section, we present eight case studies to provide examples of aerial suppression use and impacts on some fires (or part of a fire). The case studies were compiled from the different sources of data presented in the Spatial Data section but were primarily led by interviews, where important background information on the environmental conditions, objectives, rationale behind tactics and suppression outcomes were provided. Other data sources, including drop data, other spatial data, incident records and imagery have been used to support the interview information. Not all of the case study events discussed in the interviews are presented here because the objectives for some events were similar or the supporting data was limited. These case studies provide high-level overviews of the sorts of information that can be obtained from the available data. More comprehensive case studies covering other important characteristics such as weather, fuels, fire behaviour and ground suppression tactics could be undertaken but would require significantly more time and were outside of the scope of this project.

### MULTIPLE OBJECTIVES (SHARK CREEK 2 FIRE) 9-10/9/2019

This case study is focused on a large rapidly spreading fire that mostly burnt through coastal heathland fuels in northeast NSW on two windy days. The fire had been burning for many days in a swampy area and had proved difficult to keep contained because combustion in dried peat fuels kept allowing it to rekindle. An escape on the 9th of October led to a major easterly run towards the coast prior to a southerly wind change. This caused it to burn towards small coastal villages and a larger town (Yamba).

An interview with one of the AAS revealed three different objectives for aerial suppression that occurred on the afternoon of the 9th of October and the following day in the north eastern extremity of this fire.

The first objective was asset protection. On 09/09/2019 a line of retardant was laid to the south-west of the town of Angourie using LATs and SEATS (Figure 12). The aim of the retardant line was to increase the asset protection zone to protect houses that were expected to be in the path of the fire following the forecast southerly wind change. The interviewee reported that the fire stopped at a gravel road ahead of the retardant line, so did not directly interact with it. However, later aerial imagery (Figure 13, 12/9/2019) indicated that some areas on both sides of the drop had burned, although there is no information on the timing of this. Two different LATs (B138 and B165) laid the majority of this retardant line and were shown in a range of media videos. However, there is no drop data from these aircraft in the entire drops dataset. The only drops data available for this case study is from some SEATs that were used to strengthen any gaps between these drops.

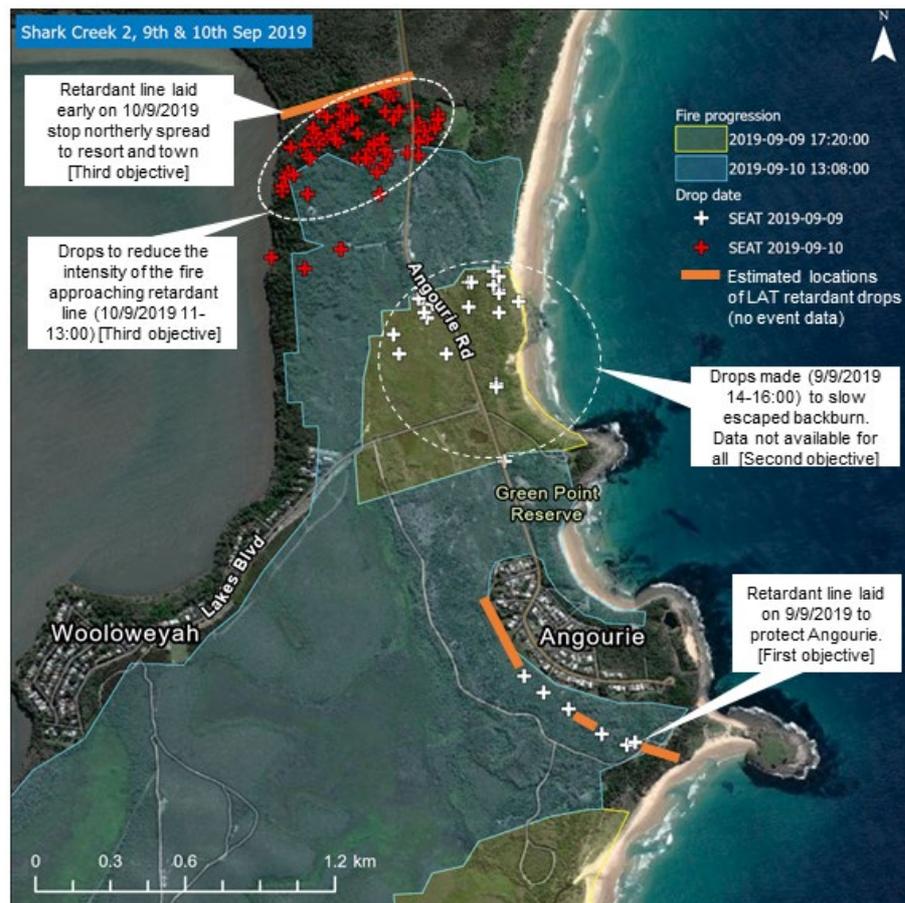


FIGURE 12: OVERVIEW MAP OF THE SHARK CREEK 2 FIRE BURNING AROUND ANGOURIE ON 9 AND 10 SEPTEMBER 2019 SHOWING THE MAIN FOCUS OF AERIAL SUPPRESSION. THE CROSSES INDICATE ALL AVAILABLE DROP DATA RECORDS FROM THE TWO DAYS. THE ORANGE LINES ARE MANUALLY DRAWN ESTIMATES OF RETARDANT LINE LOCATIONS, AS THESE DROPS ARE NOT CAPTURED IN THE DROPS DATA.

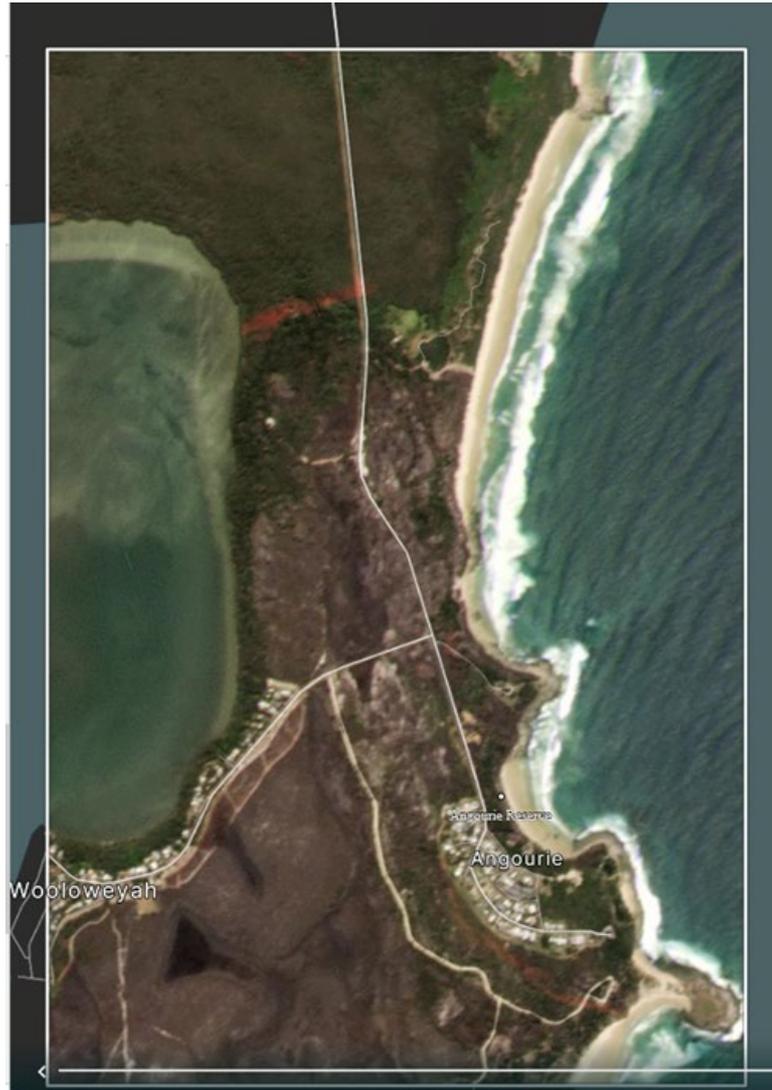


FIGURE 13: POST FIRE AERIAL IMAGERY SHOWING THE LOCATIONS OF RETARDANT LINES THAT WERE NOT RECORDED IN THE DROPS DATA. SOURCE: PLANET.COM

The second objective was to halt fire spread where a containment line had been breached. At 14:00 on 09/09/2019, a backburn was lit as a containment effort north of the town of Angourie (Figure 12). The backburn escaped the intended burn area and ground crews and aerial suppression were used to reduce the fire spread. At the time, the fire was spreading toward the ocean and there were people (public) sheltering at the beach nearby who were isolated because the access road was cut off. Some drops reduced the intensity of the fire along the access road but the fire continued to progress northwards in the thick coastal heath vegetation. Many of the drops, including from helicopters, used on this breakout are not recorded in the drops data, including those along the beach access road.

The third and final objective was to stop the fire between Angourie Road and Wooloweyah Lagoon to the north of Angourie (Figure 12) to prevent it from spreading to a nearby resort and town (Yamba). A retardant line was laid between the two features and anchored well at each end. The line was made during the early morning when there was little wind or smoke, using the RFS-737



LAT (B138) for which there is no drop data. In addition to the retardant, a posi-track mulcher was used on the ground to clear ground fuels in the thick coastal scrub. The fire was pushed towards the line by a strong southerly wind. Further aerial suppression was used south of this line to decrease the fire intensity as it approached the line and the fire was successfully contained by the retardant/posi-track line (Figure 14). A combination of aircraft and ground crews were able to stop the fire to the east of Angourie road where they could work from a beach access road.

The fire did not spread any further beyond the drop and beach road. As such, this tactic, using the combination of different suppression resource types, had a successful outcome in halting the fires spread (Table 2).



FIGURE 14: PHOTO TAKEN AT 12:25 10/9/2019 FACING NORTH, SHOWING THE RETARDANT LINE BETWEEN ANGOURIE ROAD AND WOLOWEYAH LAGOON THAT HELD THE NORTHERLY SPREAD OF THE FIRE WITH A BOMBER BEING USED TO REDUCE THE INTENSITY OF THE APPROACHING FIRE (THIRD OBJECTIVE). SOURCE: ICON

### **ASSET PROTECTION (MYALL CREEK ROAD FIRE) 25-26/11/19**

The primary objective of the aerial suppression on the eastern part of the Myall Creek fire on 25/11/2019 was asset protection. It was a large, uncontained fire and fire behaviour analysts had predicted that the fire would make a substantial run on 26/11/2019. It was anticipated that the fire would impact several isolated properties and the town of Woombah. The significant use of SEATs and LATs around properties on this fire is evident in the plots for this fire in Table 5 (see plot labelled "Myall Creek Road").

Retardant drops were made in the forest around the isolated properties to bolster the asset protection zone (Figure 15). Drops were made in V-shape (chevron pattern) facing towards the anticipated fire spread. It was thought that these



drops would lower the intensity of the fire behaviour as it approached the properties. Most of these drops were made using aircraft that are missing from the drops data. These drops may have helped to prevent damage to the houses, however, the outcome for the houses, nature of the fire impact and role of house condition, ground suppression, resident actions are unknown.



FIGURE 15: RETARDANT DROPS AROUND ISOLATED PROPERTIES. THE RETARDANT DROPS WERE PLACED IN THE TIMBERED AREA TO MAXIMIZE THE ASSET PROTECTION ZONE AROUND THE STRUCTURES. THE OBJECTIVE WAS FOR THE RETARDANT TO REDUCE THE FIRE INTENSITY AS IT APPROACHED THE PROPERTIES. SOURCE: INTERVIEWEE.

The most significant use of aircraft for house protection on this fire was the preparation of a long retardant barrier (~ 4 km long) to the north of the town of Woombah (Figure 16). The objective of this retardant line was to protect houses in Woombah. The majority of this retardant line was laid on 25/11/2019, the day before fire impact, in order to take advantage of clear air (no smoke) and calmer conditions. Water bombing aircraft were used to re-wet some of the retardant drops on 26/11/2019 to increase the effectiveness. Building impact assessment data in the Woombah area only shows one damaged house. There would likely have been significantly more damage to properties without the aerial suppression, however, the effect of the retardant line cannot be assessed directly as the effects of other important factors, such as ground suppression, fire behaviour and the conditions of houses and availability of defensible space are not known. Further work would be needed to gather this information, though it may now be too long after the event to obtain the information in adequate detail for a comprehensive analysis.

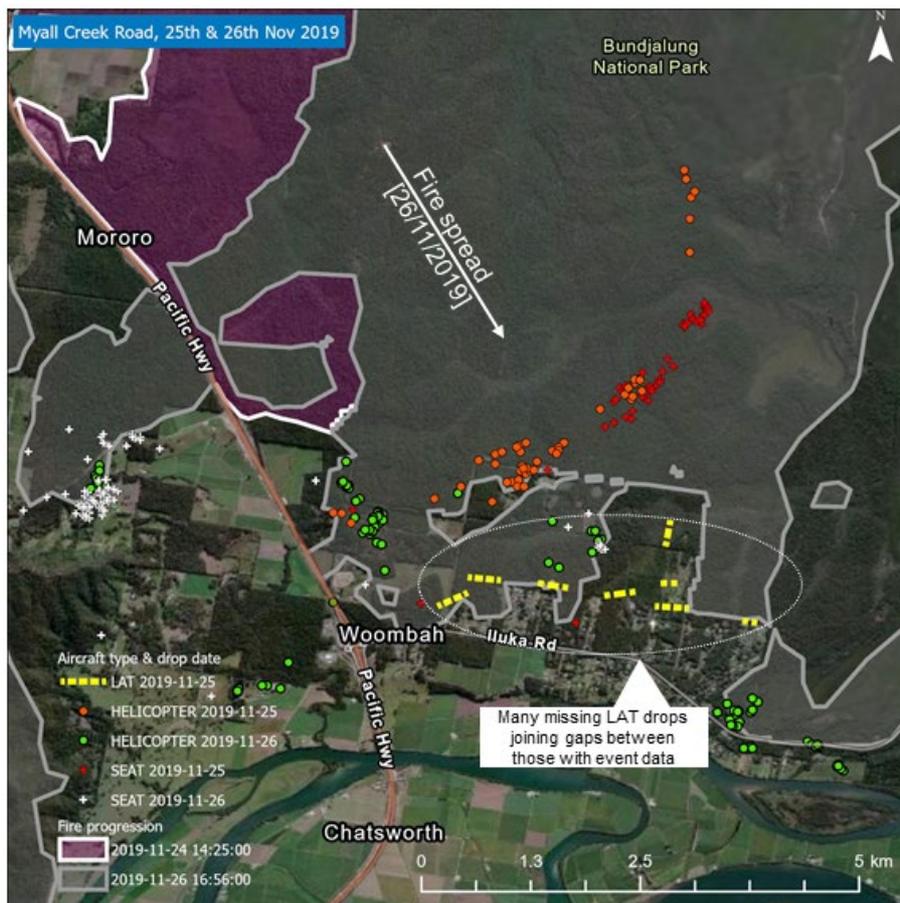


FIGURE 16: OVERVIEW MAP OF THE MYALL CREEK FIRE BURNING AROUND WOOMBAH AND AIRCRAFT TACTICS ON 25 AND 26 NOVEMBER 2019. YELLOW DOTTED LINES, POINTS AND CROSSES ARE FROM THE DROPS DATA. SIGNIFICANT PORTIONS OF THE RETARDANT LINE PREPARED BY LATS (YELLOW) WERE NOT CAPTURED IN THE DROPS DATA. POST-FIRE SATELLITE IMAGERY SHOWS A CONTINUOUS LINE OF RETARDANT FROM THE WESTERN TO EASTERN ENDS OF THE ELLIPSE.

### SPOT FIRES (HILLVILLE FIRE) 8-9/11/19

The objective of the aerial suppression on the Hillville fire on 08/11/2019 was to support the suppression of spot fires that were threatening or impacting assets and to wet down assets that were about to be impacted. The fire was burning aggressively with a wide fire front and many spot fires were igniting ahead of the fire (second row of Table 4). Aerial resources were working closely with ground resources to extinguish spot fires that were threatening properties. Several fires were burning in the area and the asset protection was largely reactionary and subject to the flying conditions (smoke and turbulence). Initially, the aerial suppression was concentrated in the Rainbow Flat area (Figure 17). However, the smoke and turbulence became too much and the aircraft had to leave the area. The aircraft moved towards the coast and continued to work on spot fires in the Diamond Beach area. Asset protection continued the following day when the fire spread northwards around the Old Bar area (first row of Table 4).

Important drops from the aircraft used on this fire were missing (not recorded) from the drops data (Figure 8 and Figure 9). The outcomes from the use of aircraft



on this fire cannot be readily determined owing to the missing drop data and infrequent fire progression data.



FIGURE 17: SPOT FIRES IGNITED AHEAD OF THE MAIN FIRE FRONT (HILLVILLE FIRE), THREATENING ASSETS IN THE RAINBOW FLAT AREA. THE MAIN FIRE FRONT GENERATED SUBSTANTIAL SMOKE AND TURBULENCE AND THE AERIAL RESOURCES HAD TO LEAVE THE AREA SHORTLY AFTER THIS PHOTO WAS TAKEN. SOURCE: INTERVIEWEE

### INITIAL ATTACK (GREEN WATTLE CREEK FIRE) 27-28/11/19

The objective of the aerial suppression on the Green Wattle Creek fire on the day of detection (27/11/2019) and the following day was containment. The objective set by the IMT was to use Bomber 911 (LAT/DC-10) to box the fire in with retardant (Figure 18). Aircraft were also tasked to work on another nearby ignition (Butchers Creek). This initial containment objective failed and the fires merged the following afternoon. During the interviews, we identified several contributing factors that negatively impacted the suppression effectiveness. Firstly, there was a delay of nearly 3 hours between detection and the first suppression (DC-10 drops at 10:50). During this time, the fire behaviour escalated, with the wind pushing the fire upslope. When the aerial resources arrived overhead the fire had expanded to more than 10 ha and the retardant containment objective was no longer achievable.

The objective shifted to halting the uphill spread of the fire onto a large plateau to the southeast (Lacy's Tableland). The fire burned through the retardant on the hillside below the cliff line, resulting in another shift in objective.

The final objective of the aerial suppression during this period was to maximize the effectiveness of the retardant by using the natural features, the cliff line, and hold the fire below (Figure 19). The steep terrain provided a break in the fuel and



the retardant was dropped along the cliff top to prevent spread to the top. The interviewee indicated that this was a common tactic for fires in this landscape. This objective, laying retardant along the cliff line, was continued the following day. This retardant line was successful in holding the fire below the cliff. One of the interviewees noted that the area along the cliff top was still unburnt while flying over the area weeks after the retardant drops were made, though the fire had spread around the drops burning most of the area within a few days of the drops being made.

Resourcing was identified as another factor that negatively impacted suppression effectiveness. There were no ground resources or additional aerial resources tasked to the Green Wattle Creek fire on the morning of 27/11/2019. Interviewees indicated that this was reflective of a shortage of resources, due to the existing high fire load across NSW. Had the fire occurred earlier in the season or on a different year, there would have been additional aerial resources, particularly large and medium helicopters available, which may have been able to respond to the fire earlier and have more success in holding it. One interviewee noted that normally Aircranes (heavy helicopter) would be available for work within this region (Sydney basin) but they were deployed to other fires within the state.

Initially, there was a greater success with the Butchers Creek ignition, which was smaller and had more favourable terrain. Bomber 911 (LAT/DC-10) had been used to make a wedge of retardant on the Butchers Creek fire, with the aim of stopping the fire from moving upslope. A medium bucketing helicopter had been engaged in water bombing (there is no drop data for this aircraft) but had to leave the fireground because of a mechanical issue. A RAFT crew was working from the rear of the fire and initially they were having some success, but the initial attack ultimately failed. Inadequate bucketing support was identified as an issue by the AAS.



FIGURE 18: EXAMPLE OF TASKING PROVIDED TO THE LAT AAS ON 27/11/2019 AROUND THE TIME OF THE FIRST DROPS AT THE GREEN WATTLE CREEK FIRE. RED DOTTED LINE REPRESENTS FIRE AREA, BLUE DASHED LINES ARE PROPOSED RETARDANT LINE LOCATIONS (SOURCE: ICON)

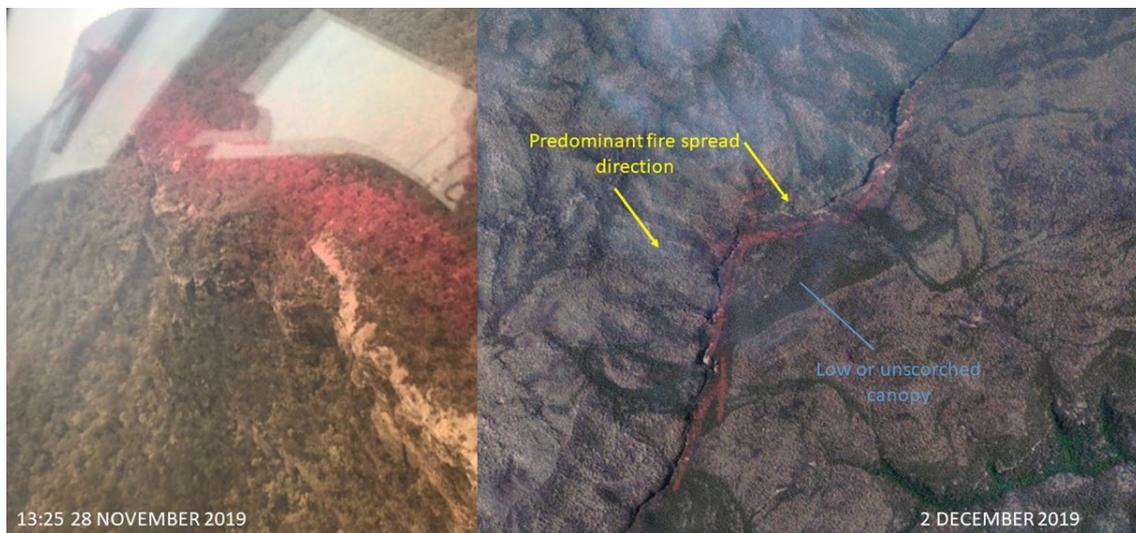


FIGURE 19: RETARDANT LINE PLACED ON TOP OF THE CLIFF LINE AHEAD OF THE GREEN WATTLE CREEK FIRE. LEFT: AS VIEWED FROM THE AAS ON 28 NOVEMBER (SOURCE: INTERVIEWEE), RIGHT: FROM SATELLITE IMAGERY 2 DECEMBER 2019 (SOURCE: PLANET.COM)

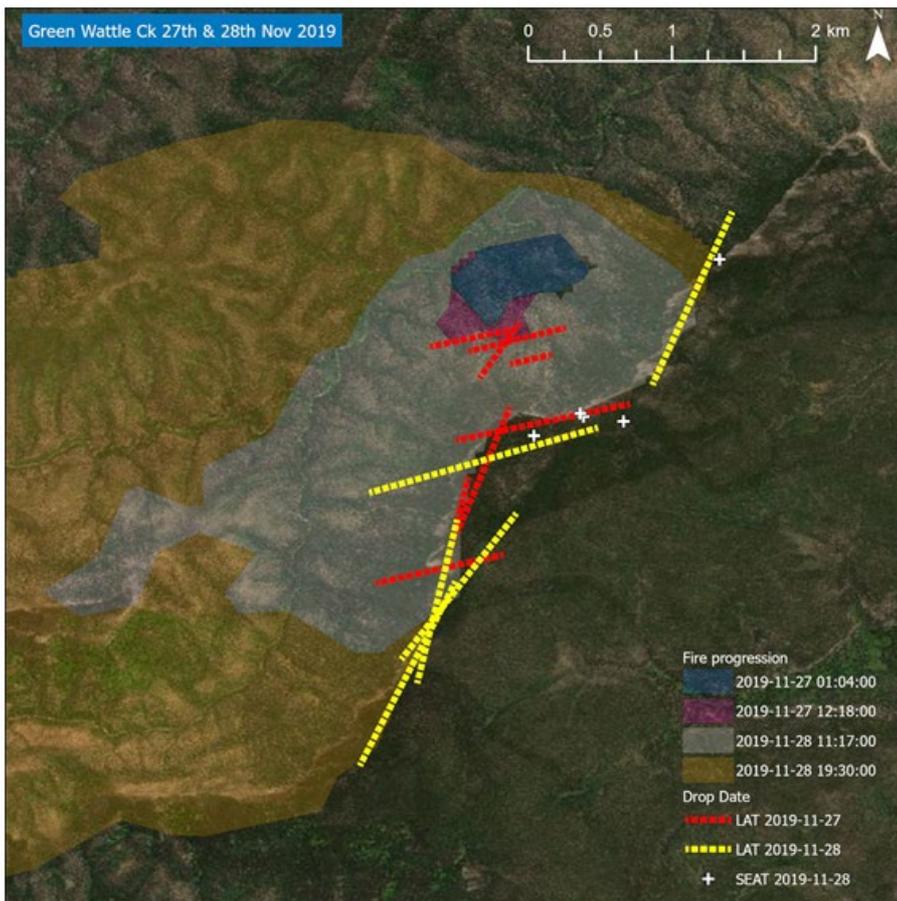


FIGURE 20: OVERVIEW MAP OF THE INITIAL ATTEMPTS TO HALT THE SPREAD OF THE GREEN WATTLE CREEK FIRE ON 27 AND 28 NOVEMBER 2019. THE LAT DROPS SHOWN ARE THOSE FOR BOMBER 911 (DC-10), HOWEVER, THERE WERE OTHER DROPS MADE BY A 737 LAT IN THE AREA ON 28 NOVEMBER THAT ARE NOT AVAILABLE IN THE DATA.

### ASSET PROTECTION (BUSBYS FLAT RD FIRE) 8/10/2019

The main objective of the aerial suppression on the Busbys Flat Rd fire was to protect life and property. The fire took a significant run on 8/10/2019 pushed by extreme westerly winds (Figure 21). The original objective from the IMT and the State Air Desk was for a LAT to deliver a retardant line to cut off the head of the fire. The dispatch instructions to the AAS included a line scan image (Figure 22) of the active fire run. This objective was not achievable because the large aircraft could not approach the fire as there was too much turbulence and smoke (Figure 23). A fallback objective for the LAT was a retardant line ahead of the town of Rappville, which was only partially achievable. The flight conditions triggered shear warnings in the LAT and ultimately it had to leave the fireground. There was more success getting the smaller aircraft (SEATs and helicopters) under the smoke plume to provide asset protection. A straight line of retardant was constructed upwind of the town of Rappville, mostly using SEATs, to aid the ground crews. With the smoke, turbulence and rapid fire spread, the asset protection was largely reactionary. In addition to the line at Rappville, the aircraft worked to protect isolated properties by laying retardant in V-shaped formations with the hope of splitting the fire as it approached properties. There is no



information about the actions of ground crews and aircraft drop data is incomplete, so we cannot determine whether the objective was met.

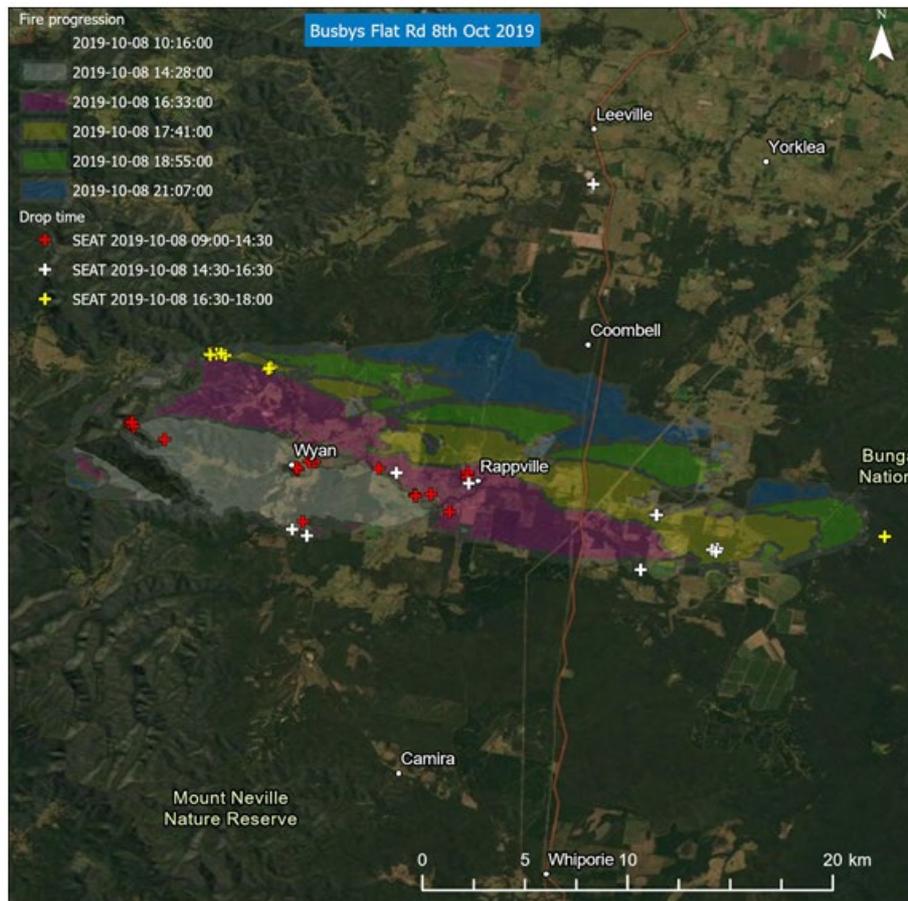


FIGURE 21: OVERVIEW MAP OF FIRE SPREAD AND AIRCRAFT DROPS AROUND RAPPVILLE ON 8 OCTOBER 2019 (BUSBYS FLAT RD FIRE). DROP DATA IS INCOMPLETE E.G. ALL HELICOPTERS AT THE FIRE ARE MISSING

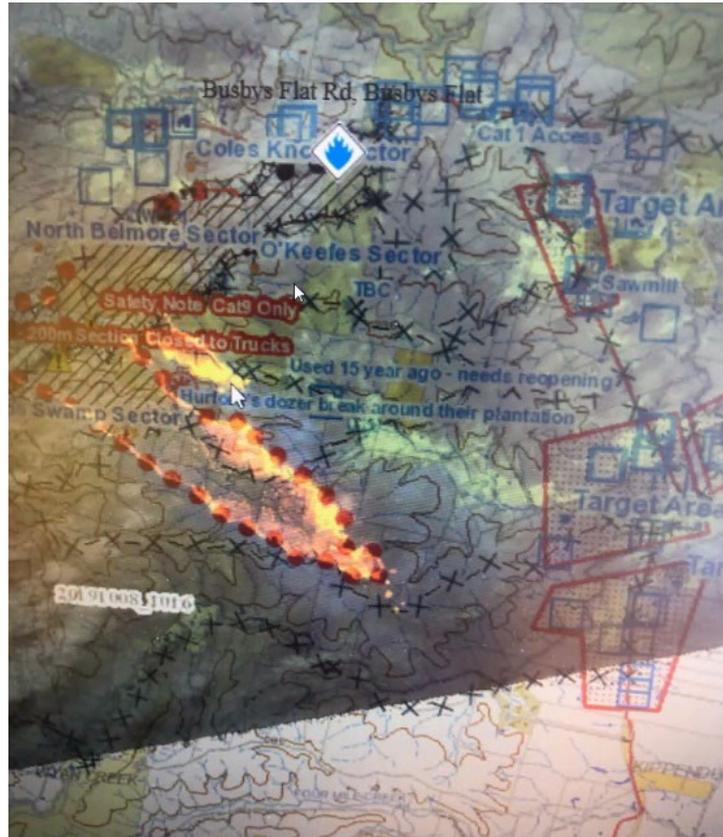


FIGURE 22: A PHOTO OF THE LINE SCAN IMAGE FOR THE BUSBYS FLAT RD FIRE PROVIDED TO THE AAS. THE DISPATCH CAME WITH THE INSTRUCTION TO USE THE LAT TO STOP THE HEAD OF THE FIRE BUT THIS WAS DEEMED UNACHIEVABLE BECAUSE OF SMOKE AND TURBULENCE. (SOURCE: INTERVIEWEE)



FIGURE 23: THE SMOKE COLUMN AT THE BUSBY FLAT RD FIRE (08/10/2019). THE WHITE CURSOR AT THE BOTTOM CENTRE OF THE IMAGE POINTS TO THE TOWN OF RAPPVILLE. THERE WAS TOO MUCH SMOKE AND TURBULENCE TO ACHIEVE THE ORIGINAL OBJECTIVE TO STOP THE HEAD OF THE FIRE WITH THE LAT. (SOURCE INTERVIEWEE.)

### **ASSET PROTECTION (CRESTWOOD DRIVE FIRE) 29-30/10/19**

The main objective of the aerial suppression on the Crestwood Drive fire was asset protection. The interview revealed that Bomber 138 and 165 (LATs) were at the fire on the 28-30th for a total of 11 loads of retardant. These LAT drops were not recorded in the drops data. The drops were made to protect properties near the Port Macquarie Golf Club and Lake Cathie. The drops along the northern edge of the Lake Cathie urban area (Figure 24) were particularly significant in that they were impacted by the edge of the head fire in heavy fuels. Examples of maps used by the AAS to communicate drop locations to the IMT and State Air Desk are shown in Figure 25.

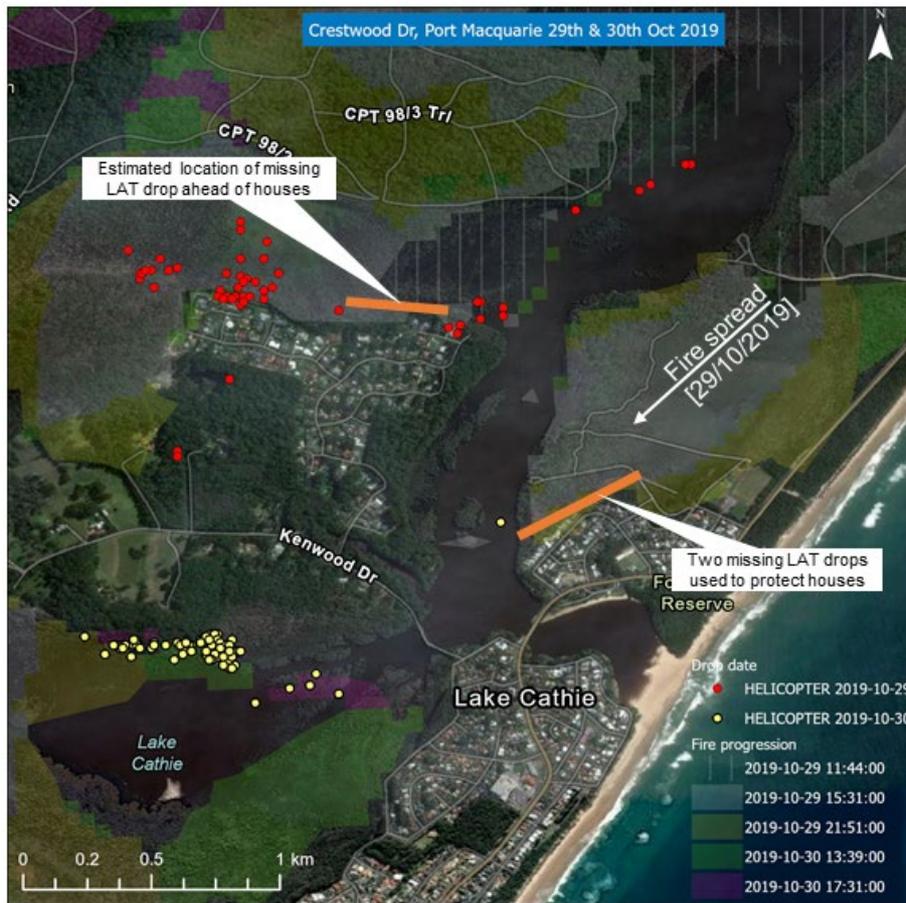


FIGURE 24: OVERVIEW MAP OF THE LAKE CATHIE AREA IMPACTED BY THE CRESTWOOD FIRE ON 29 AND 30 OCTOBER 2019. POINTS ARE ALL AIRCRAFT RECORDS IN THE DROPS DATA. THE LOCATIONS OF THE LAT DROPS (ORANGE) ARE ESTIMATED FROM SATELLITE IMAGERY AND AERIAL PHOTOGRAPHY AS THEY WERE NOT RECORDED IN THE DROPS DATA.

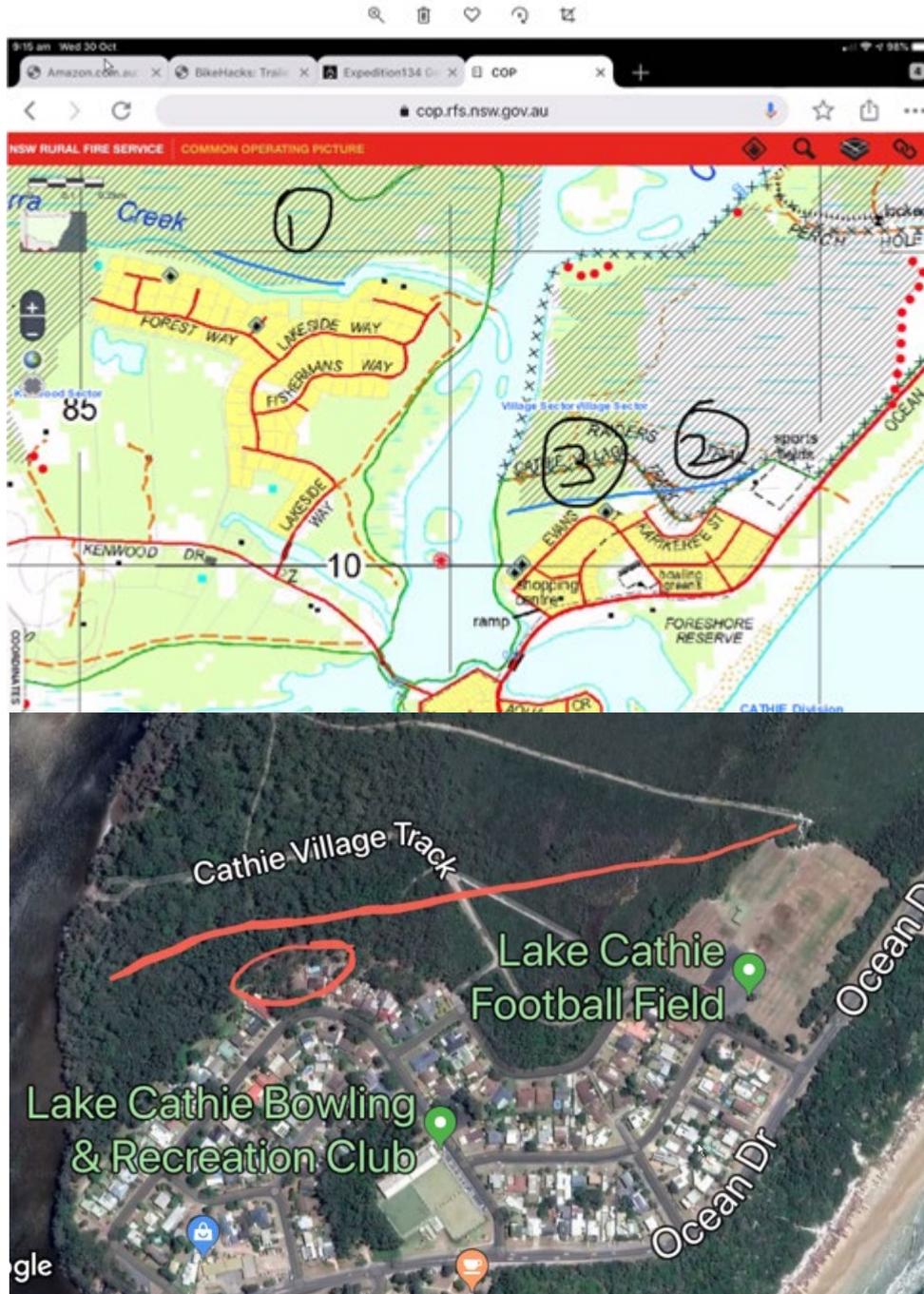


FIGURE 25: EXAMPLES OF ANNOTATED MAPS PREPARED BY THE AAS TO COMMUNICATE THE LOCATIONS OF DROPS TO THE IMT AND STATE AIRDESK AFTER PLACEMENT (TOP) AND THE LOCATION OF RETARDANT IMPACTED RESIDENCES AFTER PLACEMENT (BOTTOM).

On the 30<sup>th</sup>, Bomber 138 was used to make gel drops on the southern part of the fire. There were ground crews in the area protecting assets and the aim was to reduce the fire intensity as it approached the crews and assets. The interview provided clear evidence a substantial amount of firebombing drops (the LAT drops) were not recorded in the drops data for this fire.

## ISOLATED HOUSE IN GRASSLAND (CLEAR RANGE FIRE) 1/2/20

A single isolated property provides a clear objective for aerial suppression: to save the structures. In this case, the result was a clear success as structures were intact after the fire passed. This property was exposed to wind-driven head-fire resulting from an upwind spot ignition that burned through grassy paddocks containing sections of ungrazed African lovegrass. The photos below (Figure 26, Figure 27, Figure 28) provide a visual reference of the fire behaviour. This example illustrates several complexities when examining aerial suppression effectiveness. We were informed during an interview that two bucketing helicopters attending, but there is no drop data. With incomplete data, we cannot determine the extent of the aerial suppression that occurred at this property, only that it did occur. The interviewee provided a short video clip (15 seconds) and photographs that provide evidence of the bucketing, fuels and fire behaviour conditions. In this case, aerial suppression must be recognised as one of several contributing success factors. There is a clear asset protection zone around the structures, as well as roads to act as mineral earth fuel breaks. It was unclear during the interview if there were people (property owners) in attendance, but there were some ground crews that attended later on (Figure 28).



FIGURE 26: STILL IMAGE CAPTURED FROM A SHORT VIDEO CLIP (1 FEBRUARY 2020 17:25) PROVIDES EVIDENCE OF THE FUEL AND FIRE BEHAVIOUR AS THE CLEAR RANGE FIRE APPROACHED THE PROPERTY. THERE ARE TWO TANKS CIRCLED IN BLACK AT THE BOTTOM RIGHT OF THE IMAGE THAT ACT AS A VISUAL REFERENCE FOR THIS AND THE FOLLOWING TWO IMAGES.



FIGURE 27: FIRE APPROACHING THE PROPERTY, CAPTURED MOMENTS AFTER THE PREVIOUS IMAGE (17:25). A BUCKET DROP IS INDICATED BY THE GREEN ARROW. THE TANKS ARE AGAIN ENCIRCLED WITH BLACK AND AN RFS TANKER DRIVING INTO THE PROPERTY IS INDICATED BY THE GREEN CIRCLE.



FIGURE 28: AFTER THE FIRE FRONT HAS PASSED, THE SUCCESSFUL ASSET PROTECTION IS APPARENT AS THE STRUCTURES REMAIN INTACT. THE VISUAL ORIENTATION OF THE PROPERTY HAS CHANGED BY 90 DEGREES. THE BUCKET DROP WOULD HAVE FALLEN TO THE RIGHT OF THE TWO TANKS. NUMEROUS TANKERS ARE VISIBLE AT THE BOTTOM OF THE IMAGE.

**INITIAL ATTACK (SANDY CREEK, WOLLOMOMBI FIRE) 27/9/19**

The objective of the aerial suppression on the Sandy Creek fire was initial attack containment. There were other large fires in the area, and the fire was spotted by an AAS travelling from one of them. The AAS immediately called for a rapid



response because of the dry and windy conditions. There was a combination of aircraft working at the fire, which had responded from the nearby fires. The smoke column was used to divide the fire in two to maintain a safe separation of aircraft. The helicopters and the smaller fixed-wing aircraft were tasked to work with ground crews (local RFS and Forestry tankers) on the northern flank (Figure 29). The objective of this tactic was to contain the northern flank around the edge of the forest. This was achieved on the first afternoon (27/09/2019) and demonstrates the benefits of aerial and ground resources working together and the increased suppression ease in more open vegetation. Unfortunately, there is no available drops data for the aircraft used on this flank.

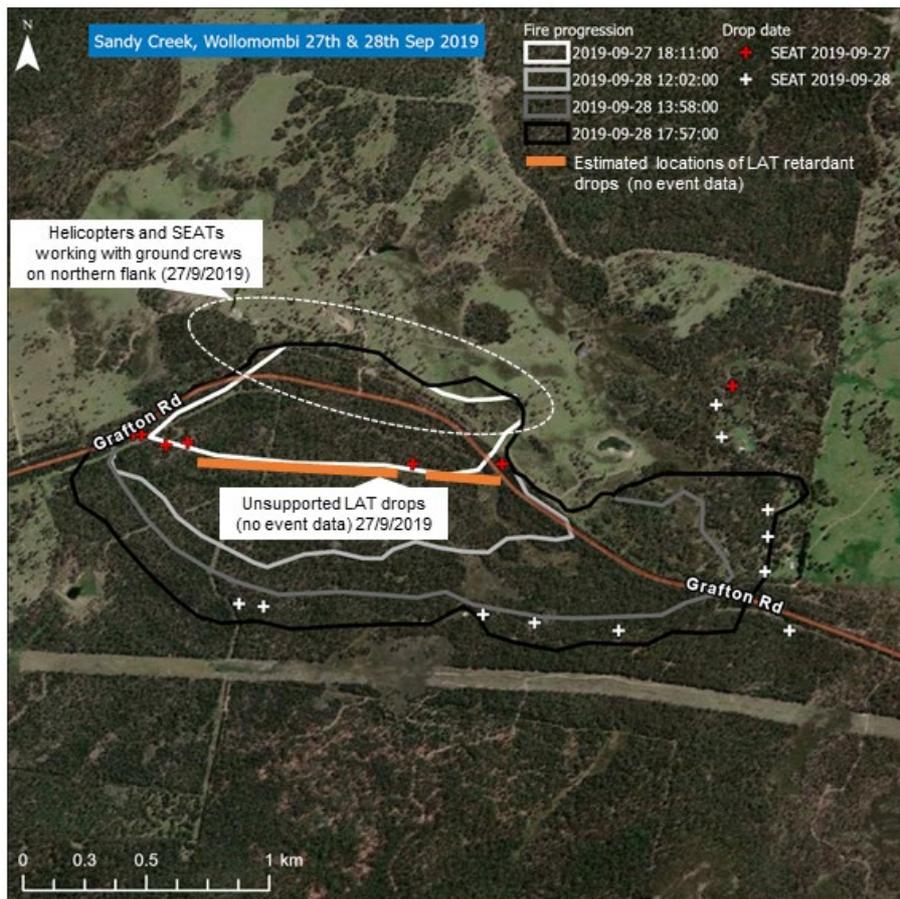


FIGURE 29: OVERVIEW MAP OF THE SANDY CREEK FIRE SHOWING THE MAIN AERIAL SUPPRESSION TACTICS USED TO CONTAIN IT. CROSSES ARE ALL DROPS RECORDED IN THE DROPS DATA FOR THE TWO DAYS. ORANGE LINE IS A MANUALLY DRAWN ESTIMATE, AS DROPS DATA WAS NOT RECORDED FOR THIS LAT.

The objective for the LATs (Bombers 138 and 165) was to lay a retardant as a containment line. There is public video footage of LAT drops laying this retardant line captured from Firebird 200 (RFS intelligence helicopter) (<https://www.facebook.com/watch/?v=786109291822827>) and from the lead plane for the Bomber 138 (<https://www.youtube.com/watch?v=MLu8mpJrAY4>). The tactical objective for the retardant line was to provide a sufficient delay in fire spread for a dozer to follow up and complete the containment line. The retardant held through the night, but the dozer never arrived, and the fire ultimately burned



through the retardant the next morning. This retardant line had the desired outcome of delaying fire spread (Table 2), however, the absence of ground support prevented the overall containment objective of halting the fire spread from being achieved.

Aerial suppression was used the following day to retard fire behaviour and the fire was contained along a powerline easement. Even though this fire burned to an area of 315 ha, it is still considered to be a good save as it had the potential to grow much larger owing to the extreme dryness, strong winds and scarcity of ground resources because of the high fire load in the area. Unfortunately, there is only drops data for the SEATs (Bombers 220, 254), but not the LAT or helicopters. The location of the retardant line (Figure 29) has been estimated from aerial and satellite imagery.

## CONCLUDING DISCUSSION

### A PROCESS FOR EVALUATING AERIAL SUPPRESSION

Considerable advancements have been made in aircraft tracking and ancillary data that will enable substantial progress in aerial suppression research. The availability of tracking and events data provides the ability to understand how aircraft are used during real firefighting operations. When used in combination with other data providing information on objectives, fire behaviour, environmental conditions and ground suppression, this data has the potential to facilitate comprehensive analyses of aerial firefighting effectiveness that were not previously possible. This work explored methods and case studies that could be expanded into comprehensive evaluation. A comprehensive evaluation of aerial suppression must consider a number of steps:

1. The firebombing drops data has a range of omissions that hamper learning and needs to be improved before thorough evaluation can take place. The problems include:
  - Many aircraft are missing from the data. Dispatch data listing all of the aircraft sent to each fire indicate that about 60% of specialized bombing aircraft used (i.e. Helitaks, SEATs and at least two LATs) had no drop data at all. Also, 63 of 64 smaller aircraft (including 48 firebirds) listed as having a firebombing role at some point during the season were not captured in the drops data.
  - Fill and Drop attributes were often entered incorrectly (fill in an obvious drop location and vice-versa).
  - The product dropped (gel, foam, retardant, water) was missing in 70% of cases.
  - Drop volume (litres) was missing in 44% of cases.
  - There is no information on the coverage level settings applied (delivery flow rate setting to regulate the depth of product delivered). This is something that should come from aircrews, as it reflects drop objectives.
  - The lengths of LAT and SEAT drops cannot be readily assumed from the data because the end points for drops are recorded when the drop doors close, not when the drop actually finishes.
2. The objectives of the drops or broader tasks should be documented by the personnel since this cannot be done with certainty from drop data. It would



be possible to do this in real-time when aircraft are tasked, but we recognise that this may be impractical in the near future. Alternatively, there should be a routine interview or survey process for AAS after the bushfires. This should be short, timely (not long after the fire) and aimed at identifying objectives and outcomes. It would also be an opportunity to reflect on issues of safety and improving communication. All of the interviewees were supportive of this initiative.

3. Some ground truthing is required to verify that inferences made about air drops such as location and dimensions and to quantify environmental conditions and determine reasons for drops being breached when they are overcome.
4. Ancillary data that helps to understand the drops or fire behaviour such as linescans, fire progression polygons, severity maps and high-resolution satellite imagery should be used for verification of drop locations and outcomes. For example, retardant drops can be clearly identified from high resolution (3 to 4 m) satellite images (e.g. Figure 13).
5. Fire management agencies should create an evaluation database that summarises objectives, outcomes, the number and type of aircraft, drops, type and litres, and ancillary observations such as weather, resources available etc. The database would extract objectives and outcomes from a combination of the drop data and the interviews, and that will require a process to be developed. Measuring outcomes is the most challenging part of this.
6. The most straightforward analysis of effectiveness is the proportion of objectives that were met. The next step would be to investigate the conditions associated with success or failure, including weather, size and behaviour of the fire, scale of the objective, amount of resources available, drop quantity and type etc. Ultimately, there should be research that examines the full context of aerial suppression, which includes how effective it is when combined with other types and amounts of suppression, but since this information is difficult to piece together, conclusions from that research are some years away.

## CONCLUSIONS & RECOMMENDATIONS

This project is an initial investigation into the process of evaluating aerial suppression and utilises data sources such as firebombing event data that were not available in previous studies. It has provided a wealth of information about objectives, outcomes, challenges, successes and failures, and points the way toward a thorough evaluation of aerial suppression. The most significant findings are listed below.

1. The drop data has a great potential for analysis of aerial suppression tactics, objectives and outcomes that have not been available previously. Large scale trends may be analysed with the drop data and the data is powerful when combined with other spatial data (progressions etc., buildings) and aircraft crew accounts. Important insights can be gained that will inform future resourcing, costs and tactics.



2. However, to allow for more comprehensive aerial suppression analyses, there is a need to improve the recording of firebombing event data (drop data), in terms of completeness (aircraft included), data fields covered (e.g. product type, drop volume) and the correct assignment of events (e.g. drop/ fill).
3. There is also a need for information on the presence and actions undertaken by ground suppression resources, as their support is often essential for aerial suppression objectives to be met.
4. In our case studies, property protection was the dominant objective. However, all of the objectives defined in the AFUE report (Table 1) were found in these case studies. More research would be required to provide a representative sample of drops for a comprehensive overview of the dominant objectives in different conditions and with different aircraft types.
5. Post-fire observation by the AAS or other persons involved is invaluable. These observations help with the determination of drop outcomes (Table 2) though it is unlikely that they are always conclusive as they often have to move on to other tasks.
6. There is much potential to research how to use the air drop data to define objectives and outcomes. This will involve more matching of the data to interviews to determine whether the drop data can be used in this way. We have started this process in this report, identifying clear clusters of activity related to weather and distance to houses, and cross-checking with interviews in the case study. Much more is needed.



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## APPENDIX

TABLE 7: DROP DATA FIELD NAMES, DESCRIPTION OF FIELD VALUES, EXAMPLE FIELD VALUES AND PERCENT OF EACH FIELD THAT IS POPULATED (I.E. VALUES NOT MISSING, NA OR "UNKNOWN") SEPARATELY FOR DROPS AND FILLS. NOTE THE DESCRIPTION ARE BASED ON THE AUTHORS' ASSESSMENT OF DATA AND HAS NOT BEEN CONFIRMED.

Field Name	Description	Example value/s	% of field populated (drops)	% of field populated (fills)
Operator	Name of aircraft company		100	100
Aircraft	Aircraft name	HELITAK 227 [VH-FHD]	100	100
EFOR No		FR-190801-00093	100	100
Paper FOR No	Unknown. Nothing recorded in field	NA	0	0
Dispatch	Aircraft dispatch number	RFS-011-426	99.4	66.2
Incident Name	A name for the incident to which aircraft has been deployed.	NSW - RFS - NSW ALPINE RESORTS	99.4	66.2
Incident Number	Incident number for which aircraft has been deployed	NA	0	0
Responsible Agency	Responsible agency for fire	RFS, NPWS.	98.1	66.1
Staging	Aircraft staging area location	KEMPSEY AIRPORT	24.7	27.7
Staging Latitude	Aircraft staging area coordinates		12.5	13.4
Staging Longitude	Aircraft staging area coordinates		12.5	13.4
Incident Locality	General description fire location	Lithgow, Bega Valley	73	37.9
Incident Latitude	Fire location coordinates		85.9	51.3
Incident Longitude	Fire location coordinates		85.9	51.3
Incident Major Area	RFS region	East	86.8	63.3
Incident Minor Area	RFS district of fire	Blue Mountains	78.1	58.1
Event	Drop or fill	Drop, fill	100	100
Product	Product carried by aircraft for drop	Foam, Gel, Retardant, Water or Unknown	19.9	48
Litres	Litres of product dropped or filled	from 3077 to 8267	38.1 (remainder are 0L)	91.5 (remainder are 0L)
Timezone	Timezone for drop or fill timestamp	Australia/Sydney	100	100
Start Date		2019-08-01, 2020-02-28	100	100
Start Time			100	100
Start Locality			100	100
Start Latitude	Time, location (coordinates), altitude and speed of aircraft at start of drop (e.g. doors open) or fill		100	100
Start Longitude			100	100
Start Altitude		from -4 to 3830	100	0
Start Speed		from 0 to 615	100	0
End Date		2019-08-01, 2020-02-28	92	0
End Time			92	0
End Locality			92	0
End Latitude	Time, location (coordinates), altitude and speed of aircraft at end of drop (doors closed) or fill		100	100
End Longitude			100	100
End Altitude		from -351 to 3790	100	0
End Speed		from 0 to 568	100	0

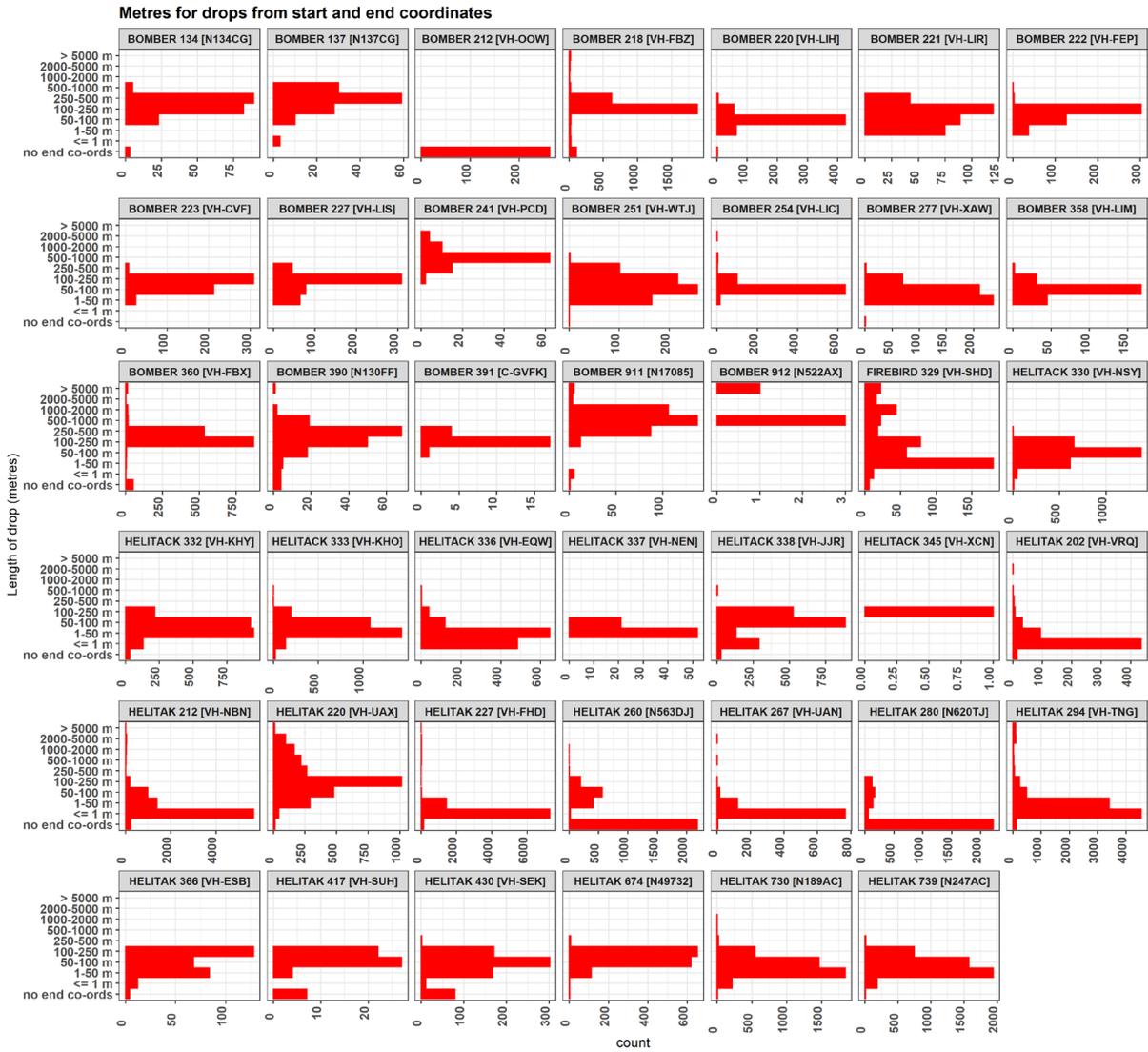


FIGURE 30: DROP DISTANCES DERIVED FROM DROP START AND END COORDINATES FOR EACH AIRCRAFT IN THE DROPS DATA

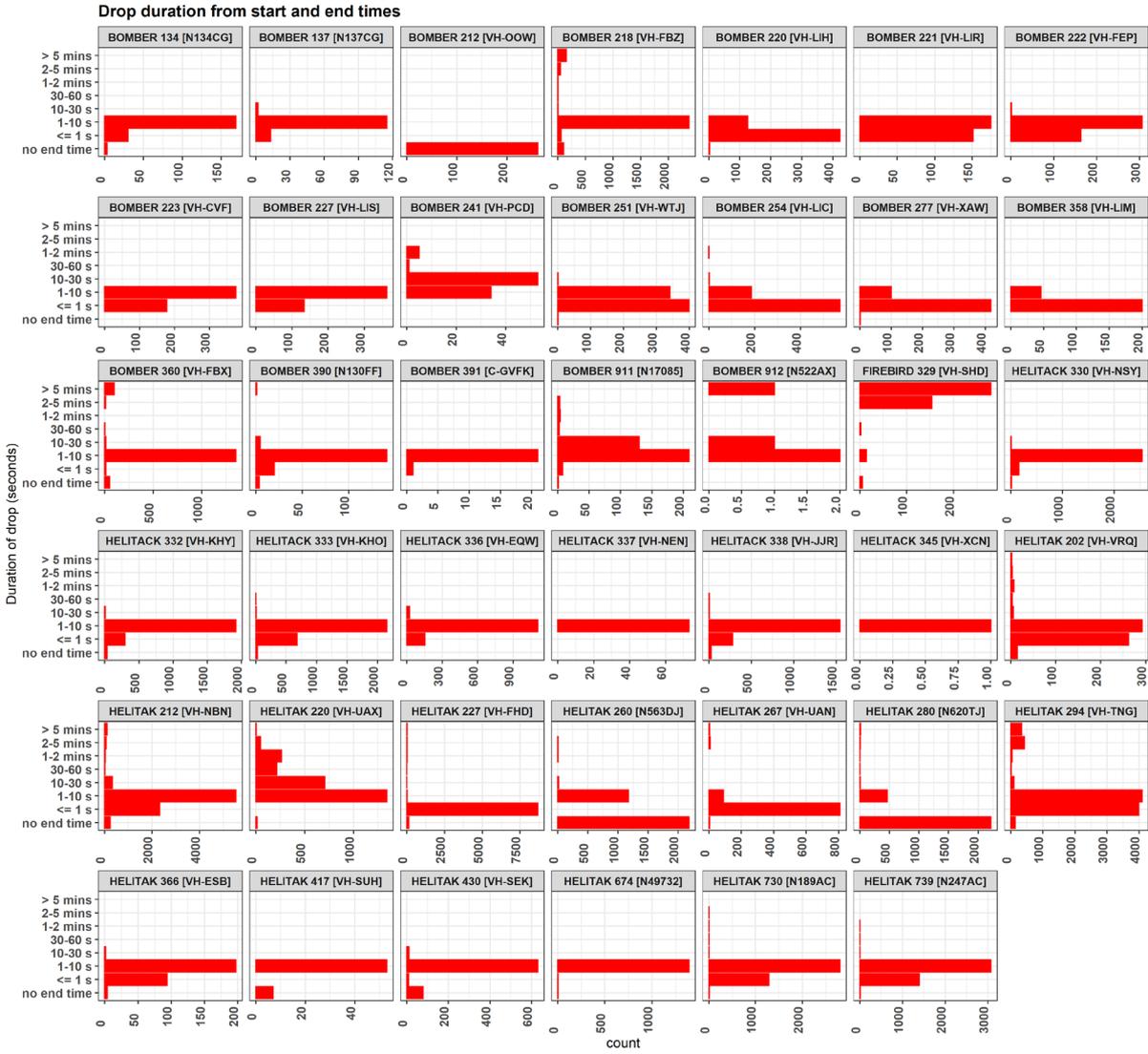


FIGURE 31: DROP DURATIONS DERIVED FROM DROP START AND END TIMES FOR EACH AIRCRAFT IN THE DROPS DATA.