FOREST AND RURAL FIRE RESEARCH

Fire Technology Transfer Note

Number - 15 January 1998

Comparison of the cost-effectiveness of some aircraft used for fire suppression - Part 2.

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Introduction

This *Fire Technology Transfer Note* (FTTN) extends the information presented in FTTN 8, which compared the cost-effectiveness of some commonly available rotary-blade and fixed-wing aircraft by estimating:

- the cost of delivering each litre of water to the fire; and
- the volume of water delivered to the fire;

when filling was carried out using different methods (dip filling, and filling with high and low volume pumps) at a range of distances from the fire.

The comparison in FTTN 8 involved estimating factors such as flying speed, drop capacity, refilling time and operating costs, which were obtained from the owners of the aircraft tested. Because the original cost-effectiveness analysis considered only eight different models of aircraft, and the performance data came from individual owners or operators, only general conclusions were drawn in FTTN 8. These were:

- Fixed-wing aircraft can deliver large volumes of water to a fire at very competitive rates, especially when suitable filling points for helicopters are greater than 2 km from the fire.
- The selection of smaller helicopters based on lower hourly running costs is a false economy that will result in larger fires, because larger helicopters can deliver greater volumes of water than smaller ones.
- Dip-filling will enable a helicopter to deliver the greatest volume of water and suppressant at the lowest cost, provided adequate filling points are located near the fire and the aircraft has the capacity to inject foam concentrate when needed.
- Delays in filling due to poor filling point management and/or the use of lower volume pumps will result in considerable "opportunity costs".
- The use of buckets that are below the safe carrying capacity of a helicopter will result in considerable "opportunity costs".

While not covering every individual aircraft operated in New Zealand, this FTTN extends FTTN 8 by providing cost-effectiveness information for more aircraft makes and models, using data from a wider survey of aircraft owners and operators. This information will help fire managers to estimate:

- Which aircraft types and models deliver the most water to the fire at the cheapest rate.
- The number of filling points required to service the aircraft at a fire.
- The hourly rate of water and additive usage.

Method

<u>Performance data</u>

Estimates of aircraft performance were obtained from a survey of most aircraft owners and operators used by the Department of Conservation and other forest and rural fire authorities throughout New Zealand. Of the 53 people surveyed in October 1996, 41 (77%) responded.

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Respondents were asked to provide the following performance information for their aircraft:

- Maximum hook load and average hook load based on owner/operator experience when firebombing in warm and windy conditions.
- Average flying speed with a loaded and unloaded bucket.
- Hourly operating cost (GST excluded).
- Maximum wind speed for suppression operations with and without a bucket under slung.

Performance data summarised by averaging the responses for each make and model of aircraft in the survey. Because not all aircraft are charged out at an average rate, or carry an average load at an average speed, the performance summaries also include a measure of the variation above and below the average value using a measure called the 'standard deviation'. One standard deviation either side of the average is the area in which at least two out of three (or 66%) of the responses are likely to fall.

Figure 1 shows how the distribution or shape of survey responses often looks. This shape is called a "bell-shaped curve" and is properly termed a normal distribution. Even though we have only a small number of responses for each aircraft model, we are assuming that if we had say 100 responses, they would look like this bell-shaped curve. When more than three responses were received for a given model, an estimate of one standard deviation is included in the performance data summary. Figure 1 shows an example using the 13 responses received for a Hughes 500D, which has an average hook load of 494 kg, but 66% of the responses actually fall within 58 kg above or below this value. The average hook load for a Hughes 500D is therefore represented as 494 kg (±58 kg) in the performance summary.

Appendices 1a to 1d show the performance data for different helicopters. These are categorised into one of four load/speed (L/S) ratio classes (2-4, 4-6, 6-8 and 8-10). The L/S ratio is derived by dividing the average hook load by the average cruise speed (when a bucket is attached). Appendix 1e provides the same information for fixed-wing aircraft.

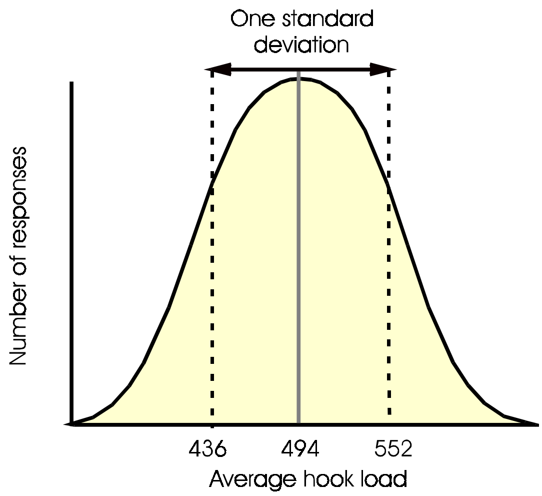

Figure 1. A normal distribution showing one standard deviation either side of the average value, and the average hook load (494 kg) plus and minus one standard deviation (±58 kg) for a Hughes 500D.

Helicopter makes and models were grouped into different classes using the L/S ratio. Even though horsepower was reasonably well correlated with the rate of water delivery, some helicopters such as the MD 530F and AS350 B2 Squirrel were able to carry significantly more water than other helicopters with similar horsepower (Figure 2a). The load/speed ratio overcame these discrepancies (Figure 2b).

Fire managers are able to account for local differences that might occur due to pilot skills or alterations to aircraft (e.g., reduction of water carrying capacity due to the addition of permanently fixed search and rescue equipment) by getting estimates of average hook load and flying speed from their local pilots.

<u>Cost of delivery, rate of water delivery and time spent at the filling point</u>

To assist with the comparison of different makes and models of aircraft, the cost of delivering 1000 litres of water and the hourly rate of water delivery were calculated for each aircraft make and model when filling at distances 0.5 km to 10 km from the fire. The calculations used the average estimates for flying speed, drop volume (i.e., average hook load minus bucket weight), refilling time and operating costs, provided by the survey respondents. The following assumptions were made:

- filling is done using a pump with an output of 1400 litres per minute;
- deceleration, positioning and acceleration at the filling point add 20 seconds to a helicopter refill;
- landing, positioning, and take-off add one minute to an aeroplane refill; and
- drop assessment and aircraft alignment above the fire add 20 seconds to each drop.

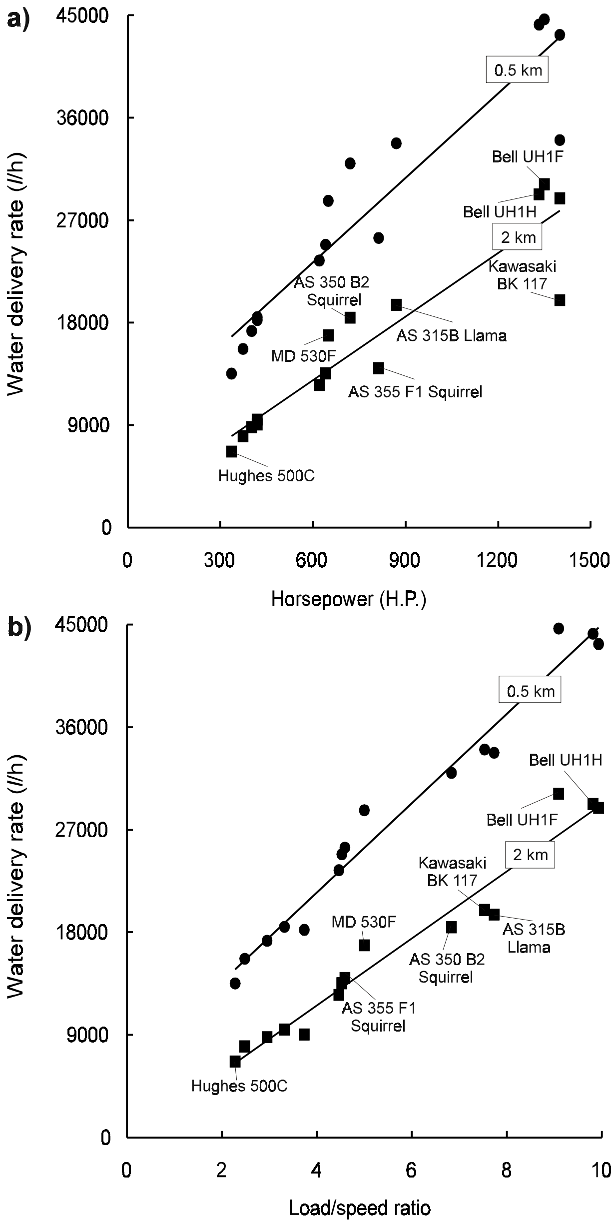

Figure 2. The hourly rate of water delivery (*l*/h) versus: **a)** helicopter horsepower output; and **b)** helicopter load/speed (L/S) ratio, for aircraft filling 0.5 km and 2 km from the fire using a 1400 *l*/min pump.

The comparative cost and water delivery rate for the four helicopter L/S ratio classes and fixed-wing aircraft are shown in Appendices 2a to 2e. Because these values were derived using a single pump discharge rate, the rate of delivery information does not help plan air-attack operations when using different pumps.

The volume of water delivered every hour and the time at the filling point was calculated for the mid-range value for each L/S ratio. Estimates of the hourly rate of water delivery were produced for different pump discharge rates and distances from the fire using average bucket volume, the average cruise speed, time for positioning at the filling point, and drop assessment time (see equation 1, Appendix 3). Appendices 4a to 4e show the hourly rate of water usage for the four helicopter L/S ratios and for fixed-wing aircraft.

A similar approach was used to determine length of time spent at the filling point every hour (see equation 2, Appendix 3). This considers the effect of pump discharge rate and bucket volume on actual filling time, time for entry and exit from the filling point, and the number of times an aircraft visits the filling point when ferrying water over a range of distances. Appendices 5a to 5e show the length of time spent at the filling point every hour for the four helicopter L/S ratios and for fixed-wing aircraft.

Discussion and Results

Performance data

The information presented in this FTTN provides guidance on how to optimise aircraft and filling point performance. Appendices 1a to 1e and 2a to 2e provide fire managers with comparative information about the performance of a range of aircraft types, makes and models. The average figures quoted for factors such as load, flying speed, operating cost, cost of water delivery, and the rate of water delivery all incorporate wide variation. Summary information that includes more than 3 responses can be used more confidently when selecting the best aircraft for aerial suppression operations.

Appendices 1a to 1e also include an estimate of the maximum wind speed in which aircraft can conduct firebombing operations and other aerial operations. This should not be confused with the maximum wind speed in which firebombing is effective. As discussed in FTTN 11, drop effectiveness is dependent on many factors, including flight and delivery characteristics, drop coverage, additive properties, vegetation type, fire behaviour and drop placement. Air operations should be continually monitored and adjusted to ensure that they are being effective.

Water delivery and additive usage

The volume of water delivered every hour (Appendices 4a to 4e) provides managers with a tool for planning aerial operations. If for example, four helicopters (say a Hughes 500D, a Jet Ranger II, AS 350 B2 Squirrel and a Bell 205) are being filled by a pump (averaging 800 *l*/min) at a distance of 2 kilometres from the fire, their total hourly rate of water usage would be 54,710 litres (see Table 1). Appendix 6 can then be used to estimate the volume of foam or retardant used every hour. For this example, 275 litres of foam (assuming a 0.5% mix ratio), or 5500 litres of retardant (assuming a 10% mix ratio) would be needed every hour.

Appendices 4a to 4e also help fire managers to assess the impact of using different pumps for filling, and of filling from different distances from the fire. For example, if a higher volume pump (say 1600 *l*/min) was used, the rate of water usage for our example increases to 65 950 *l*/h, and the amount of foam (325 *l*/h) and retardant (6500 *l*/h) required also increases.

Helicopters with larger L/S ratios deliver more water than ones with smaller ratio values. Table 1 shows that for our example scenario, machines similar to a Bell 205 would deliver 2.5 to 3 times more water every hour than the Jet Ranger II and Hughes 500D. Fire managers should consider assigning these priority when they arrive at a filling point at the same time as a helicopter with a lower L/S ratio.

Filling point management

Queuing is a problem commonly encountered when pumps are used at helicopter filling points. Appendices 5a to 5e, which estimate time at the filling point for aircraft in each L/S ratio, provides guidance on how to optimise filling point performance. If the helicopters from the previous example were operating 2 km from the fire and being filled by an 800 *l*/min pump, it is estimated that the total time they would occupy the filling point is more than 90 minutes every hour. This means that 30 minutes of queuing would occur (Table 2). The estimates of the amount of time that the helicopters spend at the filling point every hour (Appendices 5a to 5d) do not include the effect of time out for refuelling. Even if the impact of this was accounted for, it is likely that significant queuing would still occur.

Table 1. Hourly rate of water, foam (0.5%) and retardant (10%) usage for four helicopters being filled by pumps with an 800 and 1600 *l*/min delivery rate at a distance of 2 km from the fire.

Helicopter	L/S Ratio	Pump delivery: 800 *l*/min			Pump delivery: 1600 *l*/min		
		Water usage (*l*/h)	Foam usage (*l*/h)	Retardant usage (*l*/h)	Water usage (*l*/h)	Foam usage (*l*/h)	Retardant usage (*l*/h)
Jet Ranger II	3.0	8250			9030		
Hughes 500D	3.3	8250			9030		
AS 350 B2 Squirrel	6.8	16990			20650		
Bell 205	9.9	21220			27240		
Total		**54710**	**275**	**5500**	**65950**	**325**	**6500**

*This example assumes that only foam or retardant are being used in all aircraft.

Table 2. Time at the filling point for four helicopters being filled by pumps with an 800 and 1600 *l*/min delivery rate at a distance of 2 km from the fire.

Helicopter	L/S Ratio	Time at filling point (minutes:seconds/hour) (pump delivery rate: 800 *l*/min)	Time at filling point (minutes:seconds/hour) (pump delivery rate: 1600 *l*/min)
Jet Ranger II	3.0	17:00	13:00
Hughes 500D	3.3	17:00	13:00
AS 350 B2 Squirrel	6.8	26:50	19:40
Bell 205	9.9	31:30	23:30
Total		**92:20**	**69:10**

The obvious solution is to assign no more than 60 minutes of total helicopter filling time at each point. However, each of the helicopters operating from the filling point would have different airspeeds and flying distances during each run, so some queuing would still result. To minimise queuing, aerial operations managers should ensure that total filling times are less than the maximum capacity (say 50 to 55 minutes). Even though the filling point may be under utilised, aircraft costs ($5813/h for this example) usually exceed filling point costs (approximately $180/h to $400/h).

From our example, Table 2 shows that even if a 1600 *l*/min pump was used, it would reduce, but not eliminate, queuing. When significant queuing is likely to occur due to a lack of pumping capacity and/or space to establish additional filling points, aerial operations managers should stand down excess aircraft. If drops from all aircraft are effectively containing fire spread, those with lower L/S ratios should be stood down first.

Another option more commonly employed is the use of two 800 *l*/min pumps at the same filling point to fill separate helicopters. Even though this reduces queuing, each helicopter would spend approximately 25% less time at the filling point if they were filled with a 1600 *l*/min pump). Using one pump (or filling one helicopter with two 800 *l*/min delivery rate pumps) reduces congestion at the filling point and increases the amount of water delivered to the fire. This is important in steep terrain where multiple helicopter filling is not possible.

<u>How far should they fly?</u>

Can the aircraft specifications and performance information be used to determine when distance from the fire to the filling point makes firebombing inefficient? A conclusive answer to this question may only be obtained using operations research techniques, which are beyond the scope of this study. One approach (see Figure 3) is to compare the opportunity cost[1] of operating from distances greater than 0.5 km with the costs of running two different types of filling point[2]; these are:

- where water is pumped from a static water source (costing $180/h); and
- where water is delivered by two bulk water carriers (costing $400/h).

When a static water point is used, the opportunity cost is greater for all types of aircraft filling more than 1 km from the fire. When water is supplied by two bulk water carriers, then the opportunity cost is greater when the filling distance is greater than 1.5 km. Even if only one helicopter is working a fire, once the average distance is greater than 1.5 km, then the cost of establishing a second filling point to reduce the average filling distance to 0.75 km will be largely offset by the reduction in opportunity cost. Once two or more helicopters are operating, significant savings will be made.

To optimise aircraft performance, aerial attack managers should adopt the “2 × 2” rule. This rule of thumb suggests that when two or more helicopters are in use, and the average distance from the filling point to the firebombing zone exceeds 2 km, additional points should be established closer to the fire. The distance has been extended because establishing additional filling points requires effort during hectic suppression operations, and because the “2 × 2” rule is easier to remember than the “1.5 × 1.5” rule.

Figure 3 shows that the rule is most critical when high cost but high performance L/S ratio 6-8 and 8-10 helicopters are in use. To ensure that it is safe and practically possible to establish additional filling points, pilots should be consulted on how the fire can be divided into logical zones (based on topography and/or fire flanks) to establish independent and identifiable flight paths.

1 If inefficient aircraft management results in a reduction in the amount of water delivered to the fire, the lost productivity can be quantified using a measure termed the “opportunity cost”. For example, when hauling 0.5 km from a fire and using a 1400 l/min pump, a Bell 205 can deliver 41 030 litres of water per hour. When the distance is increased to 2 km, only 26 180 litres of water is delivered. By assigning a value to the lost productivity, the opportunity cost can be calculated. In this instance there is a loss of 14 850 litres of water, and the average cost of water delivery is $0.068/l, so the opportunity cost is $1011/h. The average cost of delivery per litre is determined using equation 3 of Appendix 3.

2 Both filling points have a boss and 5 crew members.

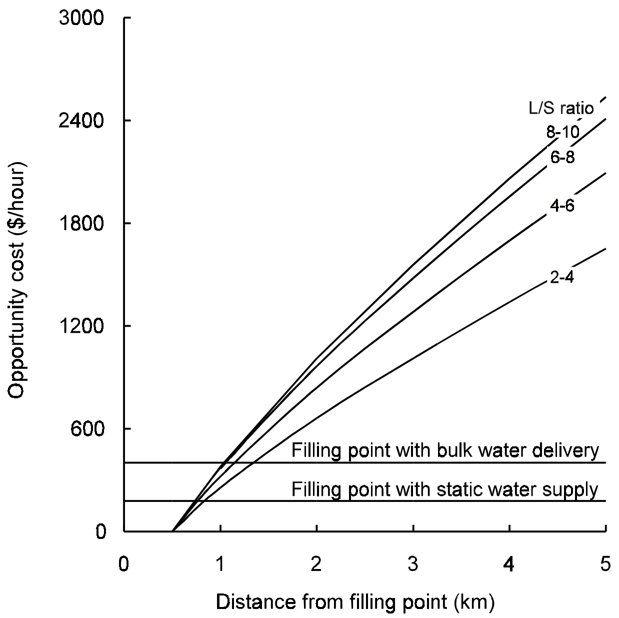

Figure 3. The "opportunity cost" of haulage distances greater than 0.5 km from the fire for each helicopter L/S ratio class compared with the cost of operating two types of filling point.

An example

A Filling Point Management Form (Appendix 7) provides a framework for managing filling point operations. An example of its use is shown on Appendix 7b. There are two filling points in use and we have assumed that the same aircraft from our earlier example are working from filling point 1. The information entered into Appendix 7b for filling point 1 is the same as for Table 1 and Table 2 when a 1600 *l*/min pump is being used, except that the Jet Ranger II and the Hughes 500C are delivering 0.5% foam solution, and the two larger helicopters have 10% retardant added.

If a filling point has a static capacity of say 100 000 litres, then with a water delivery rate of more than 55 000 *l*/h (assuming one of the smaller helicopters has been assigned to a different filling point because the total time at the filling point exceeds 50 to 55 minutes), it will be pumped dry within 2 hours and additional water supplies will be needed. Appendix 6 uses the water usage rate and the mix ratio to estimate the hourly rate of foam and retardant usage, even when different additives are being used. At a 10% mix ratio, the Squirrel and Bell would use 4789 litres of retardant every hour.

The Filling Point Management Form can also be used to manage fixed-wing operations. For example, a Cresco (08600 750) and Aures Turbo Thrush (T34DC) filling from filling point 2 (10 km from the fire) would deliver approximately 26 500 litres of water every hour and require 132 litres of foam. The total rate of foam usage for all aircraft is 222 *l*/h.

From Appendix 1 we are able to determine the L/S ratio for each aircraft. Fuel usage has also been included because:

1. Aircraft occasionally run out of fuel before their support crews arrive.
2. When several aircraft are operating, their ground support can increase congestion in the limited suitable areas for marshalling firefighters and managing the fire.

Managers could consider using a local contractor to refuel all aircraft.

Conclusion

The information on the cost and performance of some commonly available aircraft makes, models and types will help fire managers to select and better utilise aircraft for aerial fire suppression operations. Methods for estimating when a filling point is likely to be over-utilised, and the rate of fuel, water and additive usage have been developed. In doing so, the following general conclusions were also drawn:

- Aircraft with higher load/speed (L/S) ratios should have priority for filling.
- The total time that a filling point is utilised (as estimated from Appendix 4) should not exceed 50 to 55 minutes per hour.
- When the available filling capacity has been exceeded, aircraft with the lowest L/S ratios should be stood down.
- The "2 × 2" rule should be adopted as a general rule of thumb. This suggests that when 2 aircraft are flying more than 2 km to the firebombing zone, additional filling points should be established closer to the fire.

Perhaps the best way to summarise this FTTN and FTTN 8 is to say "*fly em' close and fill em' fast*".

References Cited

Fogarty, L.G.; Smart, P.N. 1996. Comparison of the cost-effectiveness of some aircraft used for fire suppression. *Fire Technology Transfer Note* 8. (June 1996). 6 p.

Robertson, K; Fogarty, L; Webb, S. 1997. Firebombing effectiveness - where to from here? *Fire Technology Transfer Note* 11 (April 1997). 12 p.

Appendix 1a. Aircraft performance specifications. Helicopters, load/speed ratio: **2 - 4**.

Helicopter make/model	Units	Hughes 500C	Bell 206 Jet Ranger III	Bell 206 Jet Ranger II	WASP	Hughes 500D	Hughes 500E
Horsepower	hp	336	374	401	685	420	420
Load/speed ratio		2.3	2.5	3.0	3.2	3.3	3.7
Maximum hook load	kg	400	508	525	636	605	700
Average hook load[a]	kg	356 (± 43)	417 (± 26)	457 (± 53)	363	494 (± 58)	513
Cruise speed without monsoon bucket	km/h	204 (± 13)	198 (± 9)	194 (± 9)	148	228 (± 11)	232
Cruise speed with loaded monsoon bucket	km/h	135 (± 19)	128 (± 19)	130 (± 19)	93	132 (± 19)	111
Cruise speed with empty monsoon bucket	km/h	128 (± 17)	154 (± 17)	141 (± 17)	93	133 (± 17)	130
Fuel consumption	*l*/h	90	115	115	not stated	135	140
Flying duration before fuel refill	min	108 (± 32)	143 (± 44)	80 (± 28)	60	92 (± 31)	50
Cost per hour (excl. GST)	$/h	838 (± 85)	972 (± 63)	934 (± 53)	not stated	929 (± 74)	875
Minimum diameter helipad	m	18	23	19	60	20	24
Maximum wind speed for firebombing[b]	km/h	76 (± 50)	72 (± 19)	61 (± 19)	93	74 (± 20)	93
Maximum wind speed for aerial operations[c]	km/h	89 (± 41)	81 (± 26)	87 (± 15)	93	93 (± 24)	93
Number of responses		4	6	7	1	13	2

[a] Average hook load for warm, windy day.
[b] Refers to situation where a monsoon bucket is being used.
[c] Refers to other aerial operations such is air attack supervision.

Appendix 1b. Aircraft performance specifications. Helicopters, load/speed ratio: **4 - 6**.

Helicopter make/model	Units	AS 350 B Squirrel	AS 350 BA Squirrel	AS 355 F1 Squirrel	MD 530F
Horsepower	hp	620	641	813	650
Load/speed ratio		4.5	4.5	4.6	5.0
Maximum hook load	kg	755	813	800	900
Average hook load[a]	kg	656 (± 70)	698 (± 154)	717 (± 202)	800
Cruise speed without monsoon bucket	km/h	218 (± 6)	228 (± 11)	219 (± 6)	250
Cruise speed with loaded monsoon bucket	km/h	139 (± 28)	157 (± 19)	135 (± 46)	148
Cruise speed with empty monsoon bucket	km/h	130 (± 30)	126 (± 15)	148 (± 37)	185
Fuel consumption	*l*/h	160	170	210	130
Flying duration before fuel refill	min	120 (± 56)	160 (± 35)	180 (± 30)	80
Cost per hour (excl. GST)	$/h	1298 (± 81)	1300 (± 100)	1439 (± 54)	1000
Minimum diameter helipad	m	26	24	25	35
Maximum wind speed for firebombing[b]	km/h	80 (± 30)	89 (± 24)	80 (± 46)	74
Maximum wind speed for aerial operations[c]	km/h	98 (± 31)	124 (± 22)	93 (± 52)	93
Number of responses		11	3	3	1

[a] Average hook load for warm, windy day.
[b] Refers to situation where a monsoon bucket is being used.
[c] Refers to other aerial operations such is air attack supervision.

Appendix 1c. Aircraft performance specifications. Helicopters, load/speed ratio: **6 - 8**.

Helicopter make/model	Units	AS 350 B2 Squirrel	Kawasaki BK 117	AS 315B Llama
Horsepower	hp	720	1400	870
Load/speed ratio		6.8	7.5	7.7
Maximum hook load	kg	1200	1213	1100
Average hook load[a]	kg	1000	1100 (± 115)	1100
Cruise speed without monsoon bucket	km/h	222	241 (± 0)	185
Cruise speed with loaded monsoon bucket	km/h	139	144 (± 28)	130
Cruise speed with empty monsoon bucket	km/h	139	135 (± 39)	139
Fuel consumption	*l*/h	210	280	205
Flying duration before fuel refill	min	150	94 (± 43)	150
Cost per hour (excl. GST)	$/h	1500	2000 (± 283)	1695
Minimum diameter helipad	m	30	26	25
Maximum wind speed for firebombing[b]	km/h	93	80 (± 39)	111
Maximum wind speed for aerial operations[c]	km/h	148	104 (± 17)	130
Number of responses		1	4	1

[a] Average hook load for warm, windy day.
[b] Refers to situation where a monsoon bucket is being used.
[c] Refers to other aerial operations such is air attack supervision.

Appendix 1d. Aircraft performance specifications. Helicopters, load/speed ratio: **8 - 10**.

Helicopter make/model	Units	Bell UH 1F	Bell UH 1H	Bell 205
Horsepower	hp	1350	1333	1400
Load/speed ratio		9.1	9.8	9.9
Maximum hook load	kg	1800	1873	1800
Average hook load[a]	kg	1650	1675	1550
Cruise speed without monsoon bucket	km/h	204	207	213
Cruise speed with loaded monsoon bucket	km/h	167	152	139
Cruise speed with empty monsoon bucket	km/h	185	174	163
Fuel consumption	*l*/h	330	330	340
Flying duration before fuel refill	min	70	90	120
Cost per hour (excl. GST)	$/h	2500	2250	2450
Minimum diameter helipad	m	38	27	28
Maximum wind speed for firebombing[b]	km/h	93	104	80
Maximum wind speed for aerial operations[c]	km/h	93	104	80
Number of responses		1	2	2

[a] Average hook load for warm, windy day.
[b] Refers to situation where a monsoon bucket is being used.
[c] Refers to other aerial operations such is air attack supervision.

Appendix 1e. Aircraft performance specifications. Fixed-wing aircraft, load speed ratio: **6 - 8**.

Fixed-wing aircraft make/model	Units	Cresco 08600 750	Aures Turbo Thrush T34DC	Cresco 08600 600
Horsepower	hp	750	750	600
Load/speed ratio		6.5	6.9	7.6
Maximum load	kg	1843	1940	1800
Average load[a]	kg	1780 (± 24)	1500	1800
Cruise speed - empty	km/h	243 (± 9)	222	250
Cruise speed - loaded	km/h	220 (± 12)	213	222
Fuel consumption	*l*/h	250	200	200
Flying duration before fuel refill	min	140 (± 15)	120	180
Cost per hour (excl. GST)	$/h	938 (± 125)	1200	1000
Minimum length required for runway / airstrip - empty	m	175	300	150
Minimum length required for runway / airstrip - loaded	m	535	800	500
Maximum wind speed for firebombing	km/h	63 (± 11)	46	74
Number of responses		4	1	1

[a] Average load for warm, windy day.

Appendix 2a. Aircraft cost of delivery ($/1000 litres) and water delivery rates* (litres/hour). Helicopters, load/speed ratio: **2 - 4**.

Cost of water delivered		Helicopter make/model				
Distance	Units	Hughes 500C	Bell 206 Jet Ranger III	Bell 206 Jet Ranger II	Hughes 500D	Hughes 500E
0.5 km	$/1000*l*	48	47	42	39	37
1 km	$/1000*l*	70	67	59	56	54
2 km	$/1000*l*	113	106	95	88	86
3 km	$/1000*l*	157	146	130	121	119
4 km	$/1000*l*	201	186	165	154	151
5 km	$/1000*l*	245	225	200	186	183
6 km	$/1000*l*	289	265	236	219	216
7 km	$/1000*l*	333	305	271	252	248
8 km	$/1000*l*	376	345	306	284	281
9 km	$/1000*l*	420	384	341	317	313
10 km	$/1000*l*	464	424	376	350	346
Amount of water delivered						
0.5 km	*l*/h	13525	15681	17276	18499	18213
1 km	*l*/h	10070	11875	13095	14043	13612
2 km	*l*/h	6665	7995	8824	9477	9043
3 km	*l*/h	4981	6026	6654	7152	6771
4 km	*l*/h	3976	4835	5340	5743	5411
5 km	*l*/h	3309	4037	4460	4798	4506
6 km	*l*/h	2833	3465	3829	4120	3861
7 km	*l*/h	2477	3035	3354	3610	3377
8 km	*l*/h	2201	2700	2984	3212	3001
9 km	*l*/h	1980	2432	2688	2893	2700
10 km	*l*/h	1799	2212	2445	2632	2454

* Based on filling with a pump that has a discharge rate of 1400 *l*/min.

Appendix 2b. Aircraft cost of delivery ($/1000 litres) and water delivery rates* (litres/hour). Helicopters, load/speed ratio: **4 - 6**.

Cost of water delivered		Helicopter make/model			
Distance	Units	AS 350 B Squirrel	AS 350 BA Squirrel	AS 355 F1 Squirrel	MD 530F
0.5 km	$/1000*l*	44	41	43	28
1 km	$/1000*l*	60	56	58	37
2 km	$/1000*l*	93	86	87	55
3 km	$/1000*l*	126	115	116	72
4 km	$/1000*l*	159	144	145	89
5 km	$/1000*l*	191	174	174	107
6 km	$/1000*l*	224	203	203	124
7 km	$/1000*l*	257	232	232	141
8 km	$/1000*l*	290	262	261	159
9 km	$/1000*l*	322	291	290	176
10 km	$/1000*l*	355	321	320	194
Amount of water delivered					
0.5 km	*l*/h	23450	24833	25444	28709
1 km	*l*/h	18166	19438	19987	23259
2 km	*l*/h	12522	13550	13987	16858
3 km	*l*/h	9554	10400	10758	13220
4 km	*l*/h	7723	8439	8740	10873
5 km	*l*/h	6481	7099	7360	9234
6 km	*l*/h	5583	6127	6356	8024
7 km	*l*/h	4904	5389	5593	7095
8 km	*l*/h	4372	4810	4994	6358
9 km	*l*/h	3944	4343	4510	5761
10 km	*l*/h	3593	3958	4112	5265

* Based on filling with a pump that has a discharge rate of 1400 *l*/min.

Appendix 2c. Aircraft cost of water delivery ($/1000 litres) and water delivery rates* (litres/hour). Helicopters, load/speed ratio: **6 - 8**.

Cost of water delivered		Helicopter make/model		
Distance	Units	AS 350 B2 Squirrel	Kawasaki BK 117	AS 315B Llama
0.5 km	$/1000*l*	38	52	57
1 km	$/1000*l*	49	68	79
2 km	$/1000*l*	72	99	122
3 km	$/1000*l*	95	131	164
4 km	$/1000*l*	117	162	207
5 km	$/1000*l*	140	194	250
6 km	$/1000*l*	163	226	293
7 km	$/1000*l*	186	257	335
8 km	$/1000*l*	208	289	378
9 km	$/1000*l*	231	320	421
10 km	$/1000*l*	254	352	464
Amount of water delivered				
0.5 km	*l*/h	31989	34035	33740
1 km	*l*/h	25698	27562	27177
2 km	*l*/h	18443	19967	19566
3 km	*l*/h	14383	15654	15285
4 km	*l*/h	11788	12873	12541
5 km	*l*/h	9986	10931	10632
6 km	*l*/h	8662	9498	9228
7 km	*l*/h	7648	8398	8151
8 km	*l*/h	6846	7526	7300
9 km	*l*/h	6197	6818	6609
10 km	*l*/h	5660	6231	6038

* Based on filling with a pump that has a discharge rate of 1400 *l*/min.

Appendix 2d. Aircraft cost of water delivery ($/1000 litres) and water delivery rates* (litres/hour). Helicopters, load/speed ratio: **8 - 10**.

Cost of water delivered		Helicopter make/model		
Distance	Units	Bell UH 1F	Bell UH 1H	Bell 205
0.5 km	$/1000*l*	47	48	53
1 km	$/1000*l*	56	57	67
2 km	$/1000*l*	74	76	93
3 km	$/1000*l*	92	96	120
4 km	$/1000*l*	110	115	147
5 km	$/1000*l*	128	134	173
6 km	$/1000*l*	146	153	200
7 km	$/1000*l*	164	172	227
8 km	$/1000*l*	182	192	253
9 km	$/1000*l*	200	211	280
10 km	$/1000*l*	218	230	307
Amount of water delivered				
0.5 km	*l*/h	44631	44186	43270
1 km	*l*/h	38478	37759	37128
2 km	*l*/h	30162	29251	28918
3 km	*l*/h	24802	23871	23681
4 km	*l*/h	21059	20163	20051
5 km	*l*/h	18298	17452	17385
6 km	*l*/h	16177	15384	15345
7 km	*l*/h	14496	13754	13734
8 km	*l*/h	13132	12436	12429
9 km	*l*/h	12003	11349	11350
10 km	*l*/h	11052	10436	10444

* Based on filling with a pump that has a discharge rate of 1400 *l*/min.

Appendix 2e. Aircraft cost of water delivery ($/1000 litres) and water delivery rates* (litres/hour). Fixed-wing aircraft, load/speed ratio: **6 - 8**.

Cost of water delivered		Fixed-wing aircraft make/model		
Distance	Units	Cresco 08600 750	Aures Turbo Thrush T34DC	Cresco 08600 600
0.5 km	$/1000*l*	22	31	24
1 km	$/1000*l*	25	35	26
2 km	$/1000*l*	30	43	31
3 km	$/1000*l*	34	50	36
4 km	$/1000*l*	39	58	41
5 km	$/1000*l*	44	65	46
6 km	$/1000*l*	49	73	51
7 km	$/1000*l*	53	80	56
8 km	$/1000*l*	58	88	61
9 km	$/1000*l*	63	95	66
10 km	$/1000*l*	68	103	71
Amount of water delivered				
0.5 km	*l*/h	37560	33620	37620
1 km	*l*/h	34450	30470	34550
2 km	*l*/h	29550	25680	29700
3 km	*l*/h	25870	22180	26050
4 km	*l*/h	23000	19530	23190
5 km	*l*/h	20710	17440	20900
6 km	*l*/h	18840	15750	19020
7 km	*l*/h	17270	14370	17450
8 km	*l*/h	15950	13200	16130
9 km	*l*/h	14810	12210	14980
10 km	*l*/h	13830	11360	13990

* Based on filling with a pump that has a discharge rate of 1400 *l*/min.

Appendix 3. Equations for estimating aircraft performance.

Equation 1. $\mathbf{w_r} = m_v \times l_n$; where

w_r = water delivery rate per hour (*l*/h)
m_v = monsoon bucket volume (*l*)
l_n = number of loads per hour delivered to fire (see equation 7)

Equation 2. $\mathbf{t_h} = \left(f_p + p\right) \times l_n$; where

t_h = time at helipad (min)
f_p = filling time (min) (see equation 6)
p = positioning time[1] per fill (min)
l_n = number of loads per hour delivered to fire (see equation 7)

Equation 3. $\mathbf{c_{tl}} = \dfrac{\left(\dfrac{h_h}{l_n}\right)}{m_v \times 1000}$; where

c_{tl} = cost of water delivered per 1000 litres ($/1000*l*)
h_h = aircraft hire rate ($/h)
l_n = number of loads per hour delivered to fire (see equation 7)
m_v = monsoon bucket or fixed-wing tank volume (*l*)

Equation 4. $\mathbf{t_t} = f_t + f_p + d_a + p$; where

t_t = turn around time (min)
f_t = flying time (min) (see equation 5)
f_p = filling time (min) (see equation 6)
d_a = drop assessment time[2] per drop (min)
p = positioning time per fill (min)

Equation 5. $\mathbf{f_t} = \left[\left(\dfrac{d_f}{s_l}\right) + \left(\dfrac{d_f}{s_e}\right)\right] \times 60$; where

f_t = flying time (min)
d_f = distance from fire (km)
s_l = flying speed with loaded monsoon bucket (km/h)
s_e = flying speed with empty monsoon bucket (km/h)

Equation 6. $\mathbf{f_p} = \dfrac{m_v}{p_r}$; where

f_p = filling time (min)
m_v = monsoon bucket or fixed-wing tank volume (*l*)
p_r = pump discharge rate (*l*/min)

Equation 7. $\mathbf{l_n} = \dfrac{60}{t_t}$; where

l_n = number of loads per hour delivered to fire
t_t = turn-around time (min) (see equation 4)

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1 Assumes a constant value of 20 seconds for helicopters, and 60 seconds for fixed-wing aircraft for each fill.
2 Assumes a constant value of 20 seconds per drop.

Appendix 4. Rates of water delivery (litres/hour) for different load/speed ratios, pump delivery rates and distances from the fire.

Appendix 4a. Helicopter load/speed ratio: **2 - 4**.

Distance from fire (km)	Pump delivery rate (litres/minute)						
	800	1000	1200	1400	1600	1800	2000
	Water delivery (litres/hour)						
0.5	15 090	16 100	16 850	17 440	17 900	18 280	18 590
1	11 820	12 440	12 880	13 220	13 480	13 700	13 870
2	8250	8550	8760	8910	9030	9130	9200
3	6340	6510	6630	6720	6790	6840	6890
4	5150	5260	5340	5390	5440	5470	5500
5	4330	4410	4470	4510	4540	4560	4580
6	3740	3800	3840	3870	3890	3910	3920
7	3290	3330	3370	3390	3410	3420	3430
8	2940	2970	3000	3010	3030	3040	3050
9	2650	2680	2700	2720	2730	2730	2740
10	2420	2440	2460	2470	2480	2490	2490
11	2220	2240	2260	2270	2270	2280	2280
12	2050	2070	2080	2090	2100	2100	2110
13	1910	1930	1940	1940	1950	1950	1960
14	1790	1800	1810	1810	1820	1820	1830
15	1680	1690	1700	1700	1710	1710	1710
16	1580	1590	1600	1600	1610	1610	1610
17	1490	1500	1510	1510	1520	1520	1520
18	1420	1420	1430	1430	1440	1440	1440
19	1350	1350	1360	1360	1370	1370	1370
20	1280	1290	1290	1300	1300	1300	1300

Appendix 4b. Helicopter load/speed ratio: **4 - 6**.

Distance from fire (km)	Pump delivery rate (litres/minute)						
	800	1000	1200	1400	1600	1800	2000
	Water delivery (litres/hour)						
0.5	21 390	23 480	25 120	26 440	27 520	28 430	29 200
1	17 560	18 940	20 000	20 820	21 490	22 040	22 490
2	12 930	13 660	14 200	14 610	14 940	15 200	15 420
3	10 230	10 680	11 010	11 260	11 450	11 600	11 730
4	8460	8770	8990	9150	9280	9380	9460
5	7220	7440	7600	7710	7800	7870	7930
6	6290	6460	6580	6660	6730	6780	6830
7	5570	5710	5800	5870	5920	5960	5990
8	5000	5110	5180	5240	5280	5310	5340
9	4540	4630	4690	4730	4770	4790	4810
10	4160	4230	4280	4320	4340	4370	4380
11	3830	3890	3940	3970	3990	4010	4020
12	3550	3610	3640	3670	3690	3710	3720
13	3310	3360	3390	3410	3430	3440	3460
14	3100	3140	3170	3190	3210	3220	3230
15	2920	2950	2980	3000	3010	3020	3030
16	2750	2790	2810	2820	2840	2840	2850
17	2610	2640	2660	2670	2680	2690	2700
18	2480	2500	2520	2530	2540	2550	2550
19	2360	2380	2400	2410	2420	2420	2430
20	2250	2270	2280	2290	2300	2310	2310

Appendix 4. Rates of water delivery (litres/hour) for different load/speed ratios, pump delivery rates and distances from the fire (continued).

Appendix 4c. Helicopter load/speed ratio: **6 - 8**.

Distance from fire (km)	Pump delivery rate (litres/minute) 800	1000	1200	1400	1600	1800	2000
	Water delivery (litres/hour)						
0.5	26 000	29 160	31 720	33 860	35 650	37 190	38 510
1	22 090	24 330	26 100	27 520	28 700	29 690	30 520
2	16 990	18 290	19 270	20 030	20 650	21 150	21 580
3	13 800	14 650	15 270	15 750	16 120	16 430	16 680
4	11 620	12 220	12 640	12 970	13 230	13 430	13 600
5	10 040	10 480	10 790	11 030	11 210	11 360	11 480
6	8830	9170	9410	9590	9730	9840	9930
7	7890	8150	8340	8480	8590	8680	8750
8	7120	7340	7490	7610	7690	7760	7820
9	6490	6680	6800	6890	6970	7020	7070
10	5970	6120	6230	6300	6360	6410	6450
11	5520	5650	5740	5810	5860	5900	5930
12	5140	5250	5320	5380	5430	5460	5490
13	4800	4900	4970	5010	5050	5080	5110
14	4510	4590	4650	4700	4730	4750	4780
15	4250	4320	4380	4410	4440	4470	4480
16	4010	4080	4130	4160	4190	4210	4230
17	3810	3870	3910	3940	3960	3980	4000
18	3620	3670	3710	3740	3760	3780	3790
19	3450	3500	3530	3560	3580	3590	3610
20	3300	3340	3370	3400	3410	3430	3440

Appendix 4d. Helicopter load/speed ratio: **8 - 10**.

Distance from fire (km)	Pump delivery rate (litres/minute) 800	1000	1200	1400	1600	1800	2000
	Water delivery (litres/hour)						
0.5	30 030	34 330	37 940	41 030	43 700	46 030	48 080
1	26 380	29 640	32 300	34 510	36 380	37 980	39 360
2	21 220	23 280	24 890	26 180	27 240	28 130	28 880
3	17 750	19 170	20 240	21 090	21 780	22 340	22 810
4	15 250	16 290	17 060	17 660	18 140	18 520	18 850
5	13 370	14 160	14 740	15 190	15 540	15 820	16 060
6	11 910	12 530	12 980	13 320	13 590	13 810	13 990
7	10 730	11 230	11 590	11 870	12 080	12 250	12 390
8	9760	10 180	10 470	10 700	10 870	11 010	11 120
9	8960	9300	9550	9740	9880	9990	10 090
10	8270	8570	8780	8930	9050	9150	9230
11	7690	7940	8120	8250	8360	8440	8510
12	7180	7400	7560	7670	7760	7830	7890
13	6730	6930	7060	7160	7240	7300	7350
14	6340	6510	6630	6720	6790	6840	6890
15	5990	6140	6250	6330	6390	6440	6480
16	5680	5810	5910	5980	6030	6080	6110
17	5390	5520	5600	5670	5720	5750	5780
18	5140	5250	5330	5390	5430	5460	5490
19	4910	5010	5080	5130	5170	5200	5230
20	4690	4790	4850	4900	4940	4960	4990

Appendix 4. Rates of water delivery (litres/hour) for different load/speed ratios, pump delivery rates and distances from the fire (continued).

Appendix 4e. Fixed wing aircraft load/speed ratio: **6 - 8**.

Distance from fire (km)	Pump delivery rate (litres/minute)						
	800	1000	1200	1400	1600	1800	2000
	Water delivery (litres/hour)						
0.5	27 140	30 600	33 442	35 819	37 836	39 569	41 073
1	25 364	28 362	30 787	32 790	34 472	35 905	37 139
2	22 430	24 742	26 568	28 047	29 268	30 294	31 169
3	20 104	21 942	23 366	24 502	25 429	26 200	26 852
4	18 215	19 711	20 853	21 753	22 481	23 081	23 585
5	16 651	17 892	18 828	19 558	20 145	20 626	21 027
6	15 334	16 380	17 161	17 766	18 249	18 642	18 970
7	14 210	15 104	15 766	16 275	16 679	17 007	17 279
8	13 240	14 013	14 580	15 014	15 358	15 635	15 865
9	12 393	13 068	13 560	13 935	14 230	14 469	14 665
10	11 649	12 243	12 674	13 001	13 257	13 464	13 634
11	10 988	11 516	11 896	12 184	12 409	12 590	12 738
12	10 399	10 870	11 208	11 463	11 662	11 822	11 953
13	9870	10 293	10 596	10 823	11 001	11 142	11 259
14	9392	9774	10 047	10 251	10 410	10 537	10 641
15	8958	9305	9552	9736	9879	9994	10 087
16	8562	8879	9103	9271	9400	9504	9588
17	8200	8490	8695	8848	8966	9060	9136
18	7867	8134	8322	8461	8569	8655	8725
19	7560	7806	7979	8108	8207	8285	8349
20	7277	7504	7664	7782	7873	7946	8005

Appendix 5. Time at the filling point (minutes:seconds/hour) for different load/speed ratios, pump delivery rates and distances from the fire.

Appendix 5a. Helicopter load/speed ratio: **2 - 4**.

Distance from fire (km)	Pump delivery rate (litres/minute)						
	800	1000	1200	1400	1600	1800	2000
	Time at filling point (minutes:seconds/hour)						
0.5	31:10	29:10	27:50	26:40	25:50	25:00	24:30
1	24:30	22:30	21:10	20:10	19:30	18:50	18:20
2	17:00	15:30	14:30	13:40	13:00	12:30	12:10
3	13:10	11:50	11:00	10:20	9:50	9:20	9:00
4	10:40	9:30	8:50	8:20	7:50	7:30	7:10
5	9:00	8:00	7:20	6:50	6:30	6:20	6:00
6	7:40	6:50	6:20	6:00	5:40	5:20	5:10
7	6:50	6:00	5:30	5:10	4:50	4:40	4:30
8	6:00	5:20	5:00	4:40	4:20	4:10	4:00
9	5:30	4:50	4:30	4:10	4:00	3:50	3:40
10	5:00	4:30	4:00	3:50	3:30	3:20	3:20
11	4:40	4:00	3:40	3:30	3:20	3:10	3:00
12	4:10	3:50	3:30	3:10	3:00	2:50	2:50
13	4:00	3:30	3:10	3:00	2:50	2:40	2:30
14	3:40	3:20	3:00	2:50	2:40	2:30	2:20
15	3:30	3:00	2:50	2:40	2:30	2:20	2:20
16	3:20	2:50	2:40	2:30	2:20	2:10	2:10
17	3:10	2:40	2:30	2:20	2:10	2:10	2:00
18	3:00	2:40	2:20	2:10	2:00	2:00	1:50
19	2:50	2:30	2:10	2:10	2:00	1:50	1:50
20	2:40	2:20	2:10	2:00	1:50	1:50	1:40

Appendix 5b. Helicopter load/speed ratio: **4 - 6**.

Distance from fire (km)	Pump delivery rate (litres/minute)						
	800	1000	1200	1400	1600	1800	2000
	Time at filling point (minutes:seconds/hour)						
0.5	36:50	34:30	32:50	31:20	30:10	29:10	28:20
1	30:10	27:50	26:10	24:40	23:30	22:40	21:50
2	22:20	20:10	18:30	17:20	16:20	15:40	15:00
3	17:40	15:40	14:20	13:20	12:30	12:00	11:20
4	14:30	12:50	11:40	10:50	10:10	9:40	9:10
5	12:30	11:00	10:00	9:10	8:30	8:10	7:40
6	10:50	9:30	8:40	7:50	7:20	7:00	6:40
7	9:40	8:20	7:30	7:00	6:30	6:10	5:50
8	8:40	7:30	6:50	6:10	5:50	5:30	5:10
9	7:50	6:50	6:10	5:40	5:10	5:00	4:40
10	7:10	6:10	5:40	5:10	4:50	4:30	4:20
11	6:40	5:40	5:10	4:40	4:20	4:10	4:00
12	6:10	5:20	4:50	4:20	4:00	3:50	3:40
13	5:40	5:00	4:30	4:00	3:50	3:30	3:20
14	5:20	4:40	4:10	3:50	3:30	3:20	3:10
15	5:00	4:20	3:50	3:30	3:20	3:10	3:00
16	4:40	4:10	3:40	3:20	3:10	3:00	2:50
17	4:30	3:50	3:30	3:10	3:00	2:50	2:40
18	4:20	3:40	3:20	3:00	2:50	2:40	2:30
19	4:00	3:30	3:10	2:50	2:40	2:30	2:20
20	3:50	3:20	3:00	2:40	2:30	2:20	2:20

Appendix 5. Time at the filling point (minutes:seconds/hour) for different load/speed ratios, pump delivery rates and distances from the fire (continued).

Appendix 5c. Helicopter load/speed ratio: **6 - 8**.

Distance from fire (km)	Pump delivery rate (litres/minute)						
	800	1000	1200	1400	1600	1800	2000
	Time at filling point (minutes:seconds/hour)						
0.5	40:60	38:40	36:50	35:10	33:50	32:50	31:50
1	34:50	32:20	30:10	28:40	27:20	26:10	25:10
2	26:50	24:10	22:20	20:50	19:40	18:40	17:50
3	21:50	19:30	17:40	16:20	15:20	14:30	13:50
4	18:20	16:10	14:40	13:30	12:30	11:50	11:10
5	15:50	13:50	12:30	11:30	10:40	10:00	9:30
6	14:00	12:10	10:50	10:00	9:20	8:40	8:10
7	12:30	10:50	9:40	8:50	8:10	7:40	7:10
8	11:10	9:40	8:40	7:50	7:20	6:50	6:30
9	10:10	8:50	7:50	7:10	6:40	6:10	5:50
10	9:20	8:10	7:10	6:30	6:00	5:40	5:20
11	8:40	7:30	6:40	6:00	5:30	5:10	4:50
12	8:10	7:00	6:10	5:40	5:10	4:50	4:30
13	7:30	6:30	5:50	5:10	4:50	4:30	4:10
14	7:10	6:10	5:20	4:50	4:30	4:10	4:00
15	6:40	5:40	5:00	4:40	4:10	4:00	3:40
16	6:20	5:30	4:50	4:20	4:00	3:40	3:30
17	6:00	5:10	4:30	4:10	3:50	3:30	3:20
18	5:40	4:50	4:20	3:50	3:30	3:20	3:10
19	5:30	4:40	4:10	3:40	3:20	3:10	3:00
20	5:10	4:30	3:50	3:30	3:20	3:00	2:50

Appendix 5d. Helicopter load/speed ratio: **8 - 10**.

Distance from fire (km)	Pump delivery rate (litres/minute)						
	800	1000	1200	1400	1600	1800	2000
	Time at filling point (minutes:seconds/hour)						
0.5	44:40	42:30	40:30	39:00	37:40	36:30	35:20
1	39:10	36:40	34:30	32:50	31:20	30:00	29:00
2	31:30	28:50	26:40	24:50	23:30	22:20	21:20
3	26:20	23:40	21:40	20:00	18:50	17:40	16:50
4	22:40	20:10	18:10	16:50	15:40	14:40	13:50
5	19:50	17:30	15:50	14:30	13:20	12:30	11:50
6	17:40	15:30	13:50	12:40	11:40	11:00	10:20
7	16:00	13:50	12:20	11:20	10:20	9:40	9:10
8	14:30	12:40	11:10	10:10	9:20	8:40	8:10
9	13:20	11:30	10:10	9:20	8:30	7:50	7:30
10	12:20	10:40	9:20	8:30	7:50	7:10	6:50
11	11:30	9:50	8:40	7:50	7:10	6:40	6:20
12	10:40	9:10	8:10	7:20	6:40	6:10	5:50
13	10:00	8:30	7:30	6:50	6:10	5:50	5:30
14	9:30	8:00	7:10	6:20	5:50	5:30	5:00
15	8:50	7:40	6:40	6:00	5:30	5:10	4:50
16	8:30	7:10	6:20	5:40	5:10	4:50	4:30
17	8:00	6:50	6:00	5:20	5:00	4:30	4:20
18	7:40	6:30	5:40	5:10	4:40	4:20	4:00
19	7:20	6:10	5:30	4:50	4:30	4:10	3:50
20	7:00	6:00	5:10	4:40	4:20	4:00	3:40

Appendix 5. Time at the filling point (minutes:seconds/hour) for different load/speed ratios, pump delivery rates and distances from the fire (continued).

Appendix 5e. Fixed-wing aircraft, load speed ratio: **6 - 8**.

Distance from fire (km)	Pump delivery rate (litres/minute)						
	800	1000	1200	1400	1600	1800	2000
	Time at filling point (minutes:seconds/hour)						
0.5	50:20	49:10	48:10	47:20	46:40	46:00	45:30
1	47:10	45:30	44:20	43:20	42:30	41:40	41:10
2	41:40	39:40	38:20	37:00	36:00	35:10	34:30
3	37:20	35:10	33:40	32:20	31:20	30:30	29:40
4	33:50	31:40	30:00	28:40	27:40	26:50	26:10
5	30:50	28:40	27:10	25:50	24:50	24:00	23:20
6	28:30	26:20	24:40	23:30	22:30	21:40	20:60
7	26:20	24:20	22:40	21:30	20:30	19:50	19:10
8	24:30	22:30	20:60	19:50	18:50	18:10	17:30
9	23:00	20:60	19:30	18:20	17:30	16:50	16:10
10	21:40	19:40	18:20	17:10	16:20	15:40	15:10
11	20:20	18:30	17:10	16:10	15:20	14:40	14:10
12	19:20	17:30	16:10	15:10	14:20	13:40	13:10
13	18:20	16:30	15:20	14:20	13:30	13:00	12:30
14	17:30	15:40	14:30	13:30	12:50	12:10	11:50
15	16:40	15:00	13:50	12:50	12:10	11:40	11:10
16	15:50	14:20	13:10	12:10	11:30	11:00	10:40
17	15:10	13:40	12:30	11:40	11:00	10:30	10:10
18	14:40	13:00	12:00	11:10	10:30	10:00	9:40
19	14:00	12:30	11:30	10:40	10:10	9:40	9:10
20	13:30	12:00	11:00	10:20	9:40	9:10	8:50

Appendix 6. Foam and retardant[1] usage rates for different water usage rates (litres/hour) and mix ratios (%).

Water	Foam (%)									Retardant (%)		
(litres)	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	5	10	15
5000	10	15	20	25	30	35	40	45	50	250	500	750
10 000	20	30	40	50	60	70	80	90	100	500	1000	1500
15 000	30	45	60	75	90	105	120	135	150	750	1500	2250
20 000	40	60	80	100	120	140	160	180	200	1000	2000	3000
25 000	50	75	100	125	150	175	200	225	250	1250	2500	3750
30 000	60	90	120	150	180	210	240	270	300	1500	3000	4500
35 000	70	105	140	175	210	245	280	315	350	1750	3500	5250
40 000	80	120	160	200	240	280	320	360	400	2000	4000	6000
45 000	90	135	180	225	270	315	360	405	450	2250	4500	6750
50 000	100	150	200	250	300	350	400	450	500	2500	5000	7500
55 000	110	165	220	275	330	385	440	495	550	2750	5500	8250
60 000	120	180	240	300	360	420	480	540	600	3000	6000	9000
65 000	130	195	260	325	390	455	520	585	650	3250	6500	9750
70 000	140	210	280	350	420	490	560	630	700	3500	7000	10 500
75 000	150	225	300	375	450	525	600	675	750	3750	7500	11 250
80 000	160	240	320	400	480	560	640	720	800	4000	8000	12 000
85 000	170	255	340	425	510	595	680	765	850	4250	8500	12 750
90 000	180	270	360	450	540	630	720	810	900	4500	9000	13 500
95 000	190	285	380	475	570	665	760	855	950	4750	9500	14 250
100 000	200	300	400	500	600	700	800	900	1000	5000	10 000	15 000
105 000	210	315	420	525	630	735	840	945	1050	5250	10 500	15 750
110 000	220	330	440	550	660	770	880	990	1100	5500	11 000	16 500
115 000	230	345	460	575	690	805	920	1035	1150	5750	11 500	17 250
120 000	240	360	480	600	720	840	960	1080	1200	6000	12 000	18 000
125 000	250	375	500	625	750	875	1000	1125	1250	6250	12 500	18 750
130 000	260	390	520	650	780	910	1040	1170	1300	6500	13 000	19 500
135 000	270	405	540	675	810	945	1080	1215	1350	6750	13 500	20 250
140 000	280	420	560	700	840	980	1120	1260	1400	7000	14 000	21 000
145 000	290	435	580	725	870	1015	1160	1305	1450	7250	14 500	21 750
150 000	300	450	600	750	900	1050	1200	1350	1500	7500	15 000	22 500
155 000	310	465	620	775	930	1085	1240	1395	1550	7750	15 500	23 250
160 000	320	480	640	800	960	1120	1280	1440	1600	8000	16 000	24 000
165 000	330	495	660	825	990	1155	1320	1485	1650	8250	16 500	24 750
170 000	340	510	680	850	1020	1190	1360	1530	1700	8500	17 000	25 500
175 000	350	525	700	875	1050	1225	1400	1575	1750	8750	17 500	26 250
180 000	360	540	720	900	1080	1260	1440	1620	1800	9000	18 000	27 000
185 000	370	555	740	925	1110	1295	1480	1665	1850	9250	18 500	27 750
190 000	380	570	760	950	1140	1330	1520	1710	1900	9500	19 000	28 500
195 000	390	585	780	975	1170	1365	1560	1755	1950	9750	19 500	29 250
200 000	400	600	800	1000	1200	1400	1600	1800	2000	10 000	20 000	30 000

1 Retardant usage refers to Firetrol liquid, which is the most commonly used retardant in New Zealand.

Appendix 7a. Filling Point Management Form.

Filling points	Aircraft make/modele	S/L Ratio	Fuel usage (*l*/h)	Firebombing distance[1] (km)	Pump delivery (*l*/min)	Time at filling point[2] (min:sec/hour)	Water delivery (*l*/h)	Foam usage		Retardant usage	
								(%)	(*l*/h)	(%)	(*l*/h)
Filling point 1											
Subtotal 1											
Filling point 2											
Subtotal 2											
Filling point 3											
Subtotal 3											
Total											

[1] The “2 x 2” rule of thumb suggests that when two or more helicopters are in use and the average distance from the filling point to the firebombing zone exceeds 2 km, then additional filling point(s) should be established.

[2] Total aircraft time at each filling point should not exceed 50 - 55 minutes.

Appendix 7b. Filling Point Management Form - Example.

Filling points	Aircraft make/model	S/L Ratio	Fuel usage (*l*/h)	Firebombing distance[1] (km)	Pump delivery (*l*/min)	Time at filling point[2] (min:sec/hour)	Water delivery (*l*/h)	Foam usage		Retardant usage	
								(%)	(*l*/h)	(%)	(*l*/h)
Filling point 1	Jet Ranger II	3.0	115	2	1600	13:00	9030	0.5	45		
	Hughes 500D	3.3	135	2	1600	13:00	9030	0.5	45		
	AS 350 B2 Squirrel	6.8	210	2	1600	19:40	20650			10	2065
	Bell 205	9.9	340	2	1600	23:30	27240			10	2724
Subtotal 1			**800**			**69:10**	**65950**		**90**		**4789**
Filling point 2	Cresco 08600 750	6.5	250	10	1600	16:20	13257				
	Aures Turbo Thrush T34DC	6.9	200	10	1600	16:20	13257				
Subtotal 2			**450**			**32:40**	**26514**	**0.5**	**132**		
Filling point 3											
Subtotal 3											
Total			**1250**				**92464**		**222**		**4789**

[1] The "2 x 2" rule of thumb suggests that when two or more helicopters are in use and the average distance from the filling point to the firebombing zone exceeds 2 km, then additional filling point(s) should be established.

[2] Total aircraft time at each filling point should not exceed 50 - 55 minutes.