Water bombing of fires: no magic solution

Contrary to popular imagination, a water-bombing aircraft doesn't dump its tank load on top of a fire, extinguishing this in one fell swoop. Only the smallest of fires could be affected that way.

An experimental drop of retardant from the DC–6.

A high-intensity fire, around 10 000 kW per m.

Actually, water bombers seek to spread their load of retardant in a line at the edge of the advancing fire, creating a fire-break — just as ground crews try to do.

Rather than putting the fire out, the best that a bomber can do is hold it for perhaps an hour, giving ground crews more time to get to the scene and contain it. By interrupting the fire's spread in its early stages, the bomber may prevent it becoming an uncontrollable monster.

That's a valuable accomplishment — but can fire-suppression bombers achieve it often enough to make the technique worth while? If the fire is small, ground crews could probably contain the outbreak; if it's large, a bomber is ineffective. Given the logistical constraints, can the aircraft usually get there before the regular fire-fighters? In short, can its high operating costs be justified?

This was a major question that scientists involved in CSIRO's Project Aquarius undertook to answer. Recently, the National Bushfire Research Unit published their results: a cost–benefit study of aerial suppression of bushfires.

The study looked at about 900 summer fires that broke out in Victoria between 1978/79 and 1982/83 and, using a computer model of fire behaviour, it compared the damage the fires inflicted with the damage that might have resulted had particular water-bombing aircraft been available. The difference was tabulated against the operating cost of each type of aircraft.

The scientists concluded that the advantages of water bombers are very marginal, giving a satisfactory result only when quite small fires can be caught before they get out of control. A DC–6 aircraft gave the largest annual savings ($660 000 gross), but this still only represented about 3% of the estimated annual losses caused by bushfires. After deducting operating costs of $524 000, the team calculated the net saving as $136 000.

And the savings depended heavily on success in a small number of fires. For the DC–6, 93% of gross savings came from an average of eight fires a year. Only for less than two fires a year, on average, did the gross benefits amount to $100 000 or more. Its particular abilities would probably have been called upon for about 50 fires a year, and for about 16 of these the costs would have outweighed the benefits.

According to the modelling exercise, the DC–6 would have made its main contributions in the severe 1982/83 fire year. However, this aircraft, and all the others considered, would have been helpless against the devastating Ash Wednesday fires that year.

On such days of extreme fire danger (high temperatures and high winds), fire easily jumps fire-breaks, whether made by bulldozers and ground crew or by aircraft using water or other fire-retardants.

Experimental fires lit by the Project Aquarius team showed that a medium-intensity blaze of about 3000 kW per metre of fire front would be about the most severe that a strip of retardant could hold. This limit roughly matches that for a bulldozer and trained ground crew. The intensity of the ferocious Ash Wednesday fires has been estimated at up to 100 000 kW per m.

Indeed, the narrow range of applicability of air-tankers can be viewed as a compliment to the high efficiency of ground crews in suppressing fires. The principal advantage of aircraft is faster access to fires that ground crews cannot reach quickly. The cost–benefit study therefore also looked at the benefits of spending money on more fire-fighters instead of on aircraft. According to the computer model, this course of action would produce about the same savings as the best fire-suppression bombers.

An extra crew of nine in each of the 45 Victorian fire districts, equipped with a bulldozer, tanker, and light support units, would save \$115 000 a year; an extra crew of six in each district equipped only with hand tools would save \$63 000.

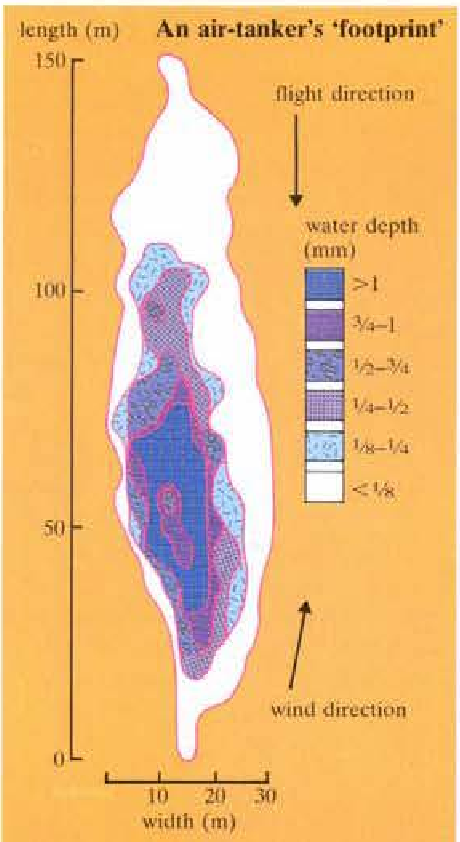
This compares with the DC–6's \$136 000, and the savings of other aircraft that operated in the black: two Bell 212 helicopters (\$78 000); six Thrush Commander agricultural aircraft (\$77 000); four Bell 206 helicopters (\$28 000); and a single old DC–4 (\$8000). Aircraft that would have cost more to operate than they would have saved were a Grumman Tracker (−\$74 000); a Canadair CL–215 water scooper, which scoops up water in flight from lakes to recharge its tanks (−\$278 000); and a Hercules transport aircraft (−\$373 000).

Project Aquarius

At first sight it may appear strange that Australia, which is acknowledged as having probably the worst wildfire problem in the world, should not have aerial water tankers.

Large-scale aerial attack on forest fires, with water or chemical retardant, has been common in the United States and Canada for more than two decades. Most other countries with a forest-fire problem — France, Spain, Greece, and Chile, for example — use medium or large air-tankers.

This is the drop pattern made by a Thrush Commander. Every aircraft has a different 'footprint'.



In Australia, only the Victorian Department of Conservation, Forests and Lands has regularly used such bombing. This effort, extending back nearly 20 years, was confined to the use of light agricultural aircraft until a few years ago, when helicopters were introduced for fire suppression.

The only operational use of a large air-tanker in Australia occurred in the summers of 1981/82 and 1982/83, when the Victorians experimented with a Hercules C–130, hired from the RAAF, and carrying retardant in a bolt-on unit hired from the United States. These experiments suggested that the system was not cost-effective.

Bushfire-fighting units in Australia operate on tight budgets, and they have not considered large air-tankers to be within their means, or even to be particularly well suited to eucalypt fires. The normal requirements for attacking a fire are: a water tanker; a bulldozer or men with hand tools to construct a fire-break; and cunning to fight fire with fire, using back-burning from a road or prepared fire-break.

Recently, however, pressure has been strong for governments to buy air-tankers. In 1981, Prime Minister Fraser asked CSIRO to evaluate aerial bushfire suppression.

So CSIRO established Project Aquarius, beginning a 3-year investigation into both the physical effectiveness of bombing fires and its costs and benefits in terms of dollars. A staff of 11 — covering many disciplines, including economics — were recruited to the CSIRO Division of Forest Research.

Scientific experiments provided much of the missing information for the economic study. Project Aquarius undertook:

- studies in 1982/83 of high-intensity-fire behaviour in Western Australian jarrah forest (described in *Ecos* 38)
- trials in 1984 of the effectiveness of a DC–6 air-tanker, hired from Canada, on experimental fires near Nowa Nowa, Victoria
- further studies of fire behaviour and water bombing by helicopter and agricultural aircraft at Nowa Nowa in 1985

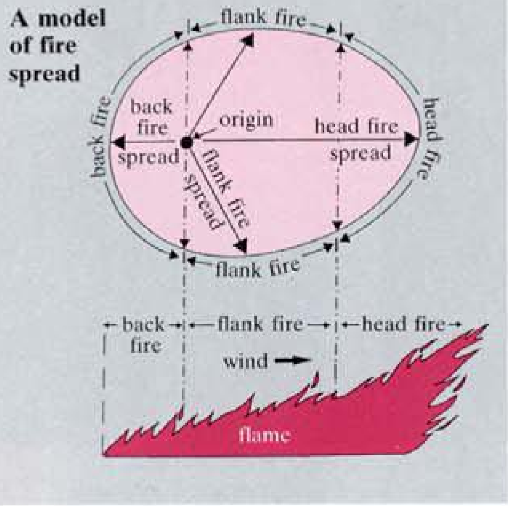
Ground crews, using rakes and hoes, construct a fire-line against a low-intensity fire. Researchers time how quickly the job can be done.

AIRPRO model

The basis of the economic analysis, carried out by Mr Bill Loane and Mr Jim Gould, was a large computer model originating with the Canadian Forest Fire Research Institute. The model, AIRPRO (from **air**-tanker **pro**ductivity), simulates the growth of individual fires selected from historical records, and models their suppression using the known abilities of particular air-tankers in laying fire-breaks. It then calculates costs and losses. Information fed into the model includes: size of the fire at detection, attack, and control; forest type; and property damage.

For the Australian application, AIRPRO's central routines for modelling physical fire growth and suppression were largely preserved, but extensive modification was needed for other factors. For example, existing equations for fire

Bulldozers preparing a fire-line.



The model used an elliptical shape of fire spread. Project Aquarius experiments had confirmed the validity of this pattern.

behaviour and retardant effect were replaced by others developed at the former National Centre for Rural Fire Research at Chisholm Institute of Technology.

Data relating to the 918 fires modelled in the study came from detailed records held by the Victorian Department of Conservation, Forests and Lands, and the Country Fire Authority of Victoria. Meteorological data from the Bureau of Meteorology were used to construct Fire Danger Indexes, so that each fire's intensity and rate of spread could be calculated for each phase of its life.

Time of arrival

A key variable is the size of the fire when first attacked, for this has a major bearing on whether air-tankers will be able to cope with it effectively.

For each fire, AIRPRO calculates the probable arrival time of each aircraft type, and how its use would affect the time taken to control the fire. Costs of damage calculated to have occurred if the aircraft had been used are then compared with the actual damage costs, and account is taken of operating costs. If the use of aircraft controls a fire earlier, this also saves costs associated with ground crews, and this saving is credited too.

Simulations of the impact of extra ground crews drew on the results of an experiment conducted to find out how rapidly ground crews could construct fire-break lines. This experiment, conducted by the South Australian Country Fire Services, indicated that a machine crew could construct up to 1100 metres of fire-break per hour. The rate of construction falls wih increasing fire intensity, and fires with intensities greater than 2000 kW per m exceed the line-holding abilities of any crew.

Options, and more options

In the cost–benefit study, AIRPRO first computed, as a bench-mark, the actual costs and losses associated with each of the fires considered and with their suppression. It then examined the likely impacts of additional ground forces and, finally, of air-tankers. For each run, the model tested the effectiveness of:

- 11 different models of air-tanker
- different numbers (from 1 to 4) of each model at different home bases
- three types of retardant (water and short- and long-term retardant — see the box on page 21)
- placement of the retardant in four different attack strategies (involving head, both flanks, and rear of the fire)

Ranking the cost of air-tankers

	number of home bases	optimal number of aircraft at each base	annual gross savings ($'000)	annual fixed costs ($'000)	annual net savings ($'000)
air-tankers					
DC-6	1	1	660	524	136
Bell 212 helicopter	1	2	306	228	78
Thrush Commander	3	2	237	160	77
Bell 206 helicopter	2	2	232	204	28
DC-4	1	1	344	336	8
Grumman tracker	1	1	227	301	–74
CL-215 water scooper	1	1	233	511	–278
Hercules MAFFS	1	1	415	788	–373
extra ground crew	no. of districts				
machine	45		713	598	115
hand	45		372	309	63

The computer model indicated that, averaged over the years, a DC–6 air-tanker would save the most. However, extra machine-equipped ground crews would produce nearly as good a result.

The value of human life

Loss of human life is seen by the community as the most important and terrible consequence of bushfires. Accordingly, any comprehensive study of the costs and benefits of fire suppression must somehow take account of the value of possible saving of lives.

'If air-tankers save only one life, then they are worth the expense — even if it's millions of dollars', some people may say. The cost–benefit study discussed various possible calculations for the value of human life, and ended up assigning a value of $200 000.

We will not go into the detail of the arguments here, except to note that air-tankers appear ineffective on high-intensity fires (such as on Ash Wednesday) when lives are lost. And so the value assigned to loss of life didn't change the saving for different air-tankers. In addition, it is worth sparing a thought for the poor air-tanker pilot.

Flying an air-tanker at low altitude through smoke is a dangerous undertaking. In executing a drop, the pilot has to control speed, number of tanks released, and delay between tanks. Often the pilot is helped by a 'bird-dog' — a small aircraft that directs the tanker to its target. Placement accuracy is vital; 10 m either way is significant. Retardant dropped inside the fire edge is wasted, but if it is dropped too far in front some will evaporate before the fire reaches it. For a deep coverage of retardant, slow speeds (about 100 km per h) are necessary, and they increase the risk of stalling.

Drop height is important. Greater drop heights increase safety, but give rise to larger dispersion of the retardant, and hence decrease its effectiveness. For safety, the Forest Service of the United States Department of Agriculture recommends a minimum drop height of 150 feet, but in Canada drop heights are frequently below this.

In the United States, more than 50 air-tanker accidents, including 31 fatalities, were reported to the National Transportation Safety Board in the 11-year period 1964–74.

Water or chemical retardant?

The computer model tested three types of retardant.

- ▷ Water is obviously the cheapest, and is available at any airport without the need for mixing facilities. It has no adverse effect, but is the least effective.
- ▷ Short-term retardant is water with thickener added (for example, gum or clay) to reduce dispersion of the water when dropped.
- ▷ Long-term retardant such as diammonium phosphate (DAP) inhibits combustion of cellulose. About 12 kg of the powder is mixed with 100 litres of water. Gum thickener, corrosion inhibitor, anti-caking agent, and orange colouring are usually added.

One of the prime aims of Project Aquarius was to gather evidence on the effects that retardants had on the intensity of fires involving Australian eucalypt fuels. In the 1984 tests with a DC–6 at Nowa Nowa, the fires were of low intensity and easily stopped. In the following summer, using a helicopter and a Thrush Commander plane, the team encountered fires of higher intensity. The retardant checked some of these fires, while the highest-intensity fires jumped the retardant barriers and continued on virtually unaffected.

Some laboratory tests have given figures for retardant effectiveness, but more field tests are needed to confirm the results.

For the computer simulation, the depth of retardant in millimetres (Q) required to hold a eucalypt fire for an hour was taken to be $Q = rI^t$, where I is the fire intensity in MW per m. For water, $r = 0{\cdot}63$ and $t = 0{\cdot}89$; for long-term retardant, $r = 0{\cdot}24$ and $t = 0{\cdot}87$.

Considering all aircraft together, long-term retardant was responsible for 69% of the savings that showed up in the cost–benefit study, and water 27%. Situations where water was found more economic were those where it could be picked up from an airfield closer to the fire than the nearest retardant base, or where the fire was small and of low intensity, allowing water to do the job just as effectively.

In practice, a despatcher would play it safe and use long-term retardant wherever possible, just to be sure.

As to the ecological effect of a load of chemical dumped in the forest, DAP is a simple fertiliser and might not be expected to cause damage. However, vegetation exposed to high concentrations during fire bombing can be killed by DAP, and National Parks services have expressed concern at changes in vegetation types that may follow its use. Also, retardant may damage fish and aquatic life if dropped in or near streams.

Only those combinations passing preliminary tests were selected to go through the full simulation. This eliminated, for example, fires that were too small (where the maximum saving would be less than the cost of one load of retardant) and fires that were too intense for aerial suppression to have any worth-while effect.

Each fire was modelled as an expanding ellipse, the rate of growth of which depended on the Fire Danger Index prevailing at the time. The model calculated the time required for the aircraft to reach the fire. It assumed that the plane would dump its load in a strip along the line of the fire — the length of the strip and the depth of retardant depending on the air speed.

The depth of retardant for effective suppression ranges from less than a millimetre to several millimetres, depending on the retardant type and the fire intensity. Obviously, the greater the depth needed, the shorter will be the corresponding length of fire-break established. The larger aircraft have a clear advantage in their rate of fire-line construction.

Figures for this important variable were gathered from North American experience, from preliminary data on the effectiveness of different retardants collected during the Nowa Nowa experiments, and from each aircraft's estimated rapidity in refilling and completing a circuit.

The team based estimates of how long a retardant strip would hold a fire-break on the fire's intensity and the width of the strip; they made allowances for interception of the retardant by the tree canopy (preventing it reaching the understorey where fire normally progresses), the likely accuracy of placement, and evaporation of water-based retardants.

Big *v.* small

As stated earlier, several types of aircraft produced sufficient savings on an average long-term basis to cover their costs of acquisition and operation. Yet in most of the years none produced enough savings to cover costs.

The best results came from the simulation involving a single DC–6B stationed at Mangalore, a fairly central home base. It was assumed that retardant-loading facilities would be available at Mangalore, at Hamilton in the west of the State, and at East Sale in the east.

The net saving of $136 000 represented a rate of return on the annual fixed outlay of 26% — considerably higher than that for additional ground crews. In every year the DC–6 produced larger gross savings than any other aircraft, and its greatest savings (52% of the long-term average) came from severe fire seasons, of which the 1982/83 one was represented in the modelling. The other aircraft produced their best results in milder fire seasons. The DC–6, with its 12-compartment tank loaded with a long-lasting retardant (diammonium phosphate), had the greatest line-holding ability.

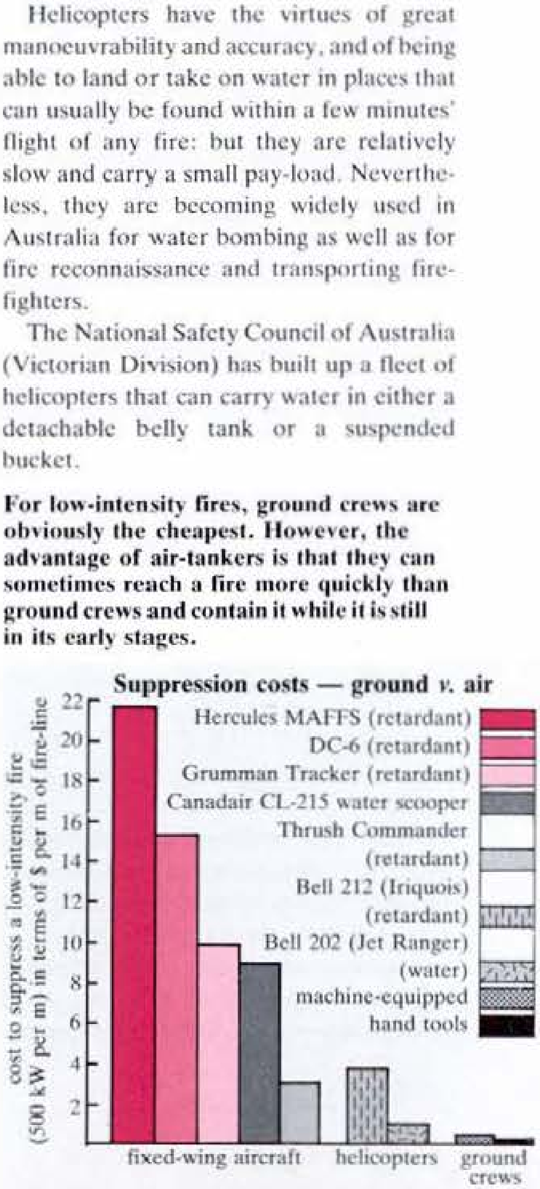
Light aircraft and helicopters were most useful in fighting small fires, against which the DC–6 was too expensive to operate. These aircraft also have the advantage of being multi-purpose, and so only part of their fixed costs needs to be counted against water bombing. They would be held on stand-by for bombing only on days of very high fire danger.

Helicopters have the virtues of great manoeuvrability and accuracy, and of being able to land or take on water in places that can usually be found within a few minutes' flight of any fire: but they are relatively slow and carry a small pay-load. Nevertheless, they are becoming widely used in Australia for water bombing as well as for fire reconnaissance and transporting fire-fighters.

The National Safety Council of Australia (Victorian Division) has built up a fleet of helicopters that can carry water in either a detachable belly tank or a suspended bucket.

For low-intensity fires, ground crews are obviously the cheapest. However, the advantage of air-tankers is that they can sometimes reach a fire more quickly than ground crews and contain it while it is still in its early stages.

Suppression costs — ground *v.* air

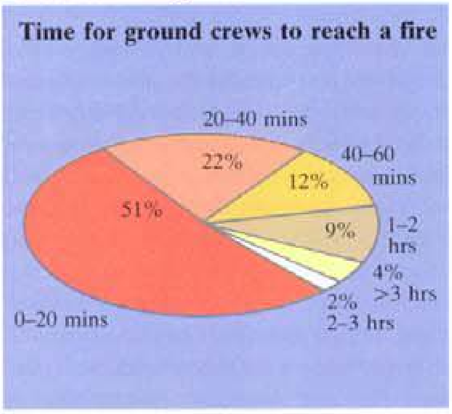


A medium-intensity fire — about 5000 kW per m. Such a fire can easily jump fire-lines constructed by aircraft or ground crew.

The type of helicopter that fared best in the study was the medium-size Bell 212, given the availability of two at their home base in the Latrobe Valley. Its effectiveness largely reflects the short distance, 6 km on average, between watering point and fire. Rates of fire-break construction — after the first drop — were therefore sometimes better than for the DC–6. Other factors that contributed to its cost effectiveness were its relatively long pattern length for its tank size, high accuracy, and low fixed costs attributable to bombing.

As for the Canadair CL–215 — the only one of the aircraft designed specifically for the purpose — it 'bombed' out completely, returning a loss in all circumstances tested. Drawbacks included its high capital cost (about $7 million new) and the fact that most fires occurred too far from water for it to fully exploit its main advantage — water scooping. (Lakes are much more abundant in its Canadian homeland.)

Ground crews arrive at nearly three-quarters of all fires within 40 minutes. The prime advantage of aircraft — speed — would only come into its own for the remaining 27%.



Insurance

Averaged over the long term, bushfires in Victoria burn out 150 000 ha and cause losses amounting to $25 million per year. The losses are concentrated heavily in the occasional severe season. Property damage averages $19 million a year, timber loss $4 million, casualties $1·5 million, and conservation considerations $1·5 million. One benefit of fire is an increase in water yields, valued at about $1 million a year.

Most of the losses result from high-intensity fires that break out on days of extreme fire danger. These cannot be suppressed by aerial tankers, nor by ground crews either.

In the end, the question that has to be addressed is what the community (or its politicians) is prepared to pay for fire protection. In most seasons, the cost of putting fires out actually exceeds the likely monetary loss that would result from letting them burn themselves out. However, we badly need the skills of fire-fighting crews in the 1 year in about 7 when extremely dangerous fire conditions prevail.

If the community feels safer with aerial fire-fighting tankers, then the cost–benefit study will provide pointers for choosing the most effective types. But it must be remembered that the amount of extra protection they can buy is small — at most, about a 3% reduction in losses.

According to Mr Phil Cheney, head of the National Bushfire Research Unit, greater benefits can be expected from reducing heavy fuel levels — and subsequent high-intensity fires — by prescribed burning. The lower the fuel level the more effective can suppression techniques be, particularly on days of high fire danger when fires can become uncontrollable. The Unit is working to understand the behaviour of intense bushfires, and how they can be moderated by reducing fuel levels.

New technology can allow fire-fighters to adopt more effective control strategies. Infra-red scanners can see through smoke and provide instant information about a fire's position and its rate and direction of spread. A computer model able to predict the future evolution of a fire front would also be of value.

Andrew Bell

More about the topic

'Aerial Suppression of Bushfires: Cost–benefit Study for Victoria.' I.T. Loane and J.S. Gould. (National Bushfire Research Unit: Canberra 1986.) (The report is available for $25 from CSIRO, P.O. Box 89, East Melbourne, Vic. 3002.)

National Bushfire Research Unit

Following the conclusion of Project Aquarius in 1984, CSIRO established the National Bushfire Research Unit.

The Unit is attached to the CSIRO Division of Forest Research in Canberra, but it will be investigating a wide range of problems created by bushfires in many parts of the country.

The head of the Unit is Mr Phil Cheney, former project leader of Aquarius. He and a group of nine staff based in Canberra will be working mainly on predicting fire behaviour, and ways of dealing with and suppressing fires.

Two other members of the Unit will be located in Melbourne at the site of the CSIRO Division of Atmospheric Research, where they will work with four atmospheric scientists on improving our knowledge of how weather conditions affect bushfires — such as how cool changes, or hilly terrain, influence wind speed and direction.

Many lives are lost in bushfires because people lack sufficient understanding of fire behaviour — even experienced fire-fighters can be deceived. Pioneering work on fire behaviour in eucalypt forest and in annual grassland was done by the late Mr Alan McArthur and others. Mr Cheney plans to refine this work and extend it to other fuel types in Australia.

Mr Cheney hopes the research will lead to a uniform nation-wide fire-danger rating system. This would allow fire behaviour in the tropics to be compared with that in temperate climates. The effects of particular factors could then be elucidated, and a fire-prediction model created.

The Unit conducted experiments near Darwin last July and August to clarify the factors contributing to the ferocity of a grassland fire. This work forms part of a collaborative project with the Northern Territory Bushfire Council, the Country Fire Services of South Australia, and the Country Fire Authority of Victoria.