SELF DEFENCE AGAINST BUSHFIRE
A Systematic Approach

Denis O'Bryan
Red Eagle Bushfire Protection Services
Email redeagle@redeagle.com.au Tel: +61412710331

First published 2014 as "Protect a community against severe bushfire with defensive suppression"

ABSTRACT

This paper presents the case in favour of a substantially improved community protection policy using logic, bushfire behaviour science and threat management principles.

It explains that the current reliance on the fire brigade model (based on wet fire fighting) is unsatisfactory when embryonic bushfires can escape because its design capability is exceeded, resulting in fierce bushfires rushing headlong into unprotected communities that cannot be protected by the fire brigade model. Why? Because its design capability is exceeded. The consequence is an unacceptable death and house toll. This was the outcome of the Black Saturday fires in Victoria in 2009. Despite the very high toll and the obvious design capability issues, the Royal Commission jurists deliberated on the evidence provided to it and chose to fine tune the same model and increase funding to it. The concern is that the same ingredients remain in place for another Black Saturday tragedy.

This paper proposes defensive suppression (based on dry fire fighting) as an alternative model because it neutralises the threats in worst case bushfire attack by separating them and allowing each to be managed safely. It outlines the principles and science behind defensive suppression and shows how its threat management strategies are founded on solid foundations. It describes three bushfire attacks on communities that met the passive defence components of defensive suppression, but the authorities failed to recognise them, and were unable to prevent the subsequent damage toll. It also describes the successful protection of a property using the defensive suppression model.

The seven-point diagnostic list allows people to assess the infrastructure and preparation that needs to be in place for successful protection of a community or a property with the defensive suppression model. These principles also provide residents and fire authorities alike with tools to assess whether a property or community is bushfire-exposed or bushfire-protected. Sensitivity analysis indicates whether success will be compromised or not if the elements of the model are sub-optimal.

INTRODUCTION

This article is an attempt to persuade fire authorities and the government to recognise that the fire brigade model, which is based on wet fire fighting, has a peak design capability that is well below what is needed for community protection, and to urge them to apply a model that can neutralise a severe Black Saturday bushfire attack, a model based of dry fire fighting.

The Victorian government relies on its two lead agencies to protect its citizens against bushfire, as it did in the Black Saturday fires of February 2009. The Country Fire Authority (CFA) is responsible for suppression on private property and Department of Sustainability and Environment (DSE, now Department of Environment and Primary Industry, DEPI) on public land. Many Black Saturday fires began on private property, jumped into public land and then back into private property. CFA deployed its volunteer fire brigade model to protect private property. DSE focused on public land, but assisted in towns where public land was nearby.

The previous evening, the Premier assured Victorians that its fire authorities were “the best prepared ever” to deal with tomorrow’s extreme weather. The next day, the government watched on as its fire brigade model was helplessly unable to prevent the loss of 173 lives and 2000 houses within a few hours. The trucks and aerial water bombers were powerless against the large flames and the perimeters of the numerous spot fires outran their control line attempts (VBRC, 2010 – evidence presented). The “best prepared ever” model was clearly inadequate for the task. Furthermore, the scale and intensity of the fires unfairly exceeded their design capability. Yet the subsequent Royal Commission, which relied heavily on the evidence presented to it, and despite unmistakeable evidence that the fire brigade model was consistently overwhelmed, recommended the model be given more technical and financial support. All stakeholders supportively agreed that everybody did their best, and explained it away as Mother Nature’s fury. The root causes of the overpowering were not addressed, eg, the Royal Commission did not canvass the design capability issue.

Technically, the fire brigade model is a statewide contingent of volunteer fire fighters using wet fire fighting. It is designed for rapid response and for small scale, short term fires. Eg, it copes well with slow to medium pace running fires in where truck access is good and with houses that burn one at a time. Thus, it can be seen that the physical capability of the fire brigade is limited by their ability to access and deliver water to kill the live edge. As it happens, the volunteers can stop most outbreaks in severe weather, but despite their best efforts, some fires have escaped. When this happens, any number of extra trucks cannot catch them. This can be proven by doing the maths: If a grassfire runs through a flat paddock at 10 kph (which happens in normal hot dry weather when wind is only 30 kph, like the recent Epping fire), its perimeter grows at least 20 km per hour. If a large fire truck can drive up to the fire edge and can extinguish 1 km in an hour before it runs out of water, each hour they will need 20+ new trucks at work on the edge just to keep pace with bushfire perimeter growth. This is a logistical challenge for one fire in an unfenced, open driveable paddock. Add in real life access difficulties, topography, breakdowns and queuing, and add in multiple fires, it becomes a logistical nightmare. It is proposed that for planning purposes, the fire authorities acknowledge that fire brigade model capability peaks at FDI 30 when winds are strong, and that some fires will escape from the first attack crews and run with the wind into unprotected communities. [FDI is the logarithmic Forest Fire Danger Index scale from 1 to 100+ (CSIRO Forest Meter, Mark V). Total Fire Ban days are generally declared at FDI 50]

The corollary issue is whether this limited capacity fire brigade model can be safely deployed to protect an unprepared community when the escaped bushfire bears down on it. The reasonable answer is no, it is futile and dangerous. Making a stand is the high risk strategy where a line of tankers apply water against the advancing flame. It can be achieved if the flame is low, if there are enough trucks for the entire width of the front, and if the fire fighters are themselves safe within a fuel free area, either an existing one or a freshly burnt out one. But even if they can prepare their defence before the attack and lower the flame height, it may be counter productive if the aim is to protect the houses of the community. The fire fighters would be occupied spaying the flame and, in the meantime, embers are thrown over their heads into the houses, but there are no spare resources to defend them.

The issues of concern in this chapter however are not the limitations of the fire brigade model, but that the communities engulfed by the escaped fires on Black Saturday were unprotected, that the government did not require the fire authorities to protect them above their design capability (eg, FDI > 30 in high winds). The Royal Commission did not canvass these issues significantly. These issues are yet to be addressed and are still causing house loss and deaths in the fire seasons since Black Saturday, fires in much less severe weather. Eg, in 2013 - Carngham (6 houses, FDI in the high 30's), Dereel (16 houses, FDI in the high 40's) and Seaton / Glenmaggie fires (1 death, a few houses, FDI in 20's), and in 2014 - the Mickleham / Kilmore fires (4 houses, FDI 60's, after the change FDI in 20's and 30's, another 13+ houses over a few days) and Gisborne fires (at least 2 houses, FDI in 30's). The pre Black Saturday conditions of unprotected communities and reliance on the limited-capacity fire brigade model remain unchanged. This concern is reinforced by the government tolerating an inexplicably feeble and unaccountable aim of the fire authorities "to reduce the impact of fire".

The purpose of this chapter is to propose that the continued reliance on the fire brigade model alone, ie, wet fire fighting and its associated limited design capability, is no longer an appropriate strategy because it provides the same ingredients for another Black Saturday tragedy. It is proposed that fire authorities acknowledge that bushfires will escape in severe weather and cannot logistically be stopped, and that they should focus on effective preparation of threatened communities in their path. It is proposed that a defensive suppression model based on the principles of dry fire fighting is an appropriate method to protect communities from advancing bushfires. It is proposed that the potential benefit of the defensive suppression model is to eliminate house loss rate.

METHOD

This chapter firstly clarifies the terminology for defence options to ensure misunderstandings are avoided. It then clarifies the bushfire threat to be targeted. Thirdly, it describes the key principles of dry fire fighting of relevance to defensive suppression of a community. Finally, it outlines the scientific principles behind defensive suppression. This then establishes the context to examine some recent examples of attacks by severe bushfires where defensive suppression has been applied, both deliberately and accidentally, and analyses the reasons for successes and the failures. The attacks occurred on three communities and one property.

Terminology

Essentially, there are two options for bushfire defence – active and passive.

Active defence is the urgent physical effort during the bushfire attack of extinguishing the flame or cutting a path to stop the flame spreading. It requires adequate people (preferably trained) and equipment. In the literature it includes direct attack when the flame is extinguished (usually by water) and the dead edge becomes the control line, and indirect attack where the flame is at some distance from the defenders' control line. In Australia, the most common form of direct attack is known as wet fire fighting, and indirect attack is known as dry fire fighting. Direct attack and indirect attack fit into the categories of offensive and defensive suppression respectively.

Passive defence is the infrastructure put in place prior to the bushfire attack that determines where flame is allowed or not allowed, how tall the flame is on each area, where people and vehicles can access, where water delivery can reach to, and the type of fortifications used on buildings.

In the context of defending a community from the bushfire threat, two types of response can be described - offensive and defensive.
- Offensive suppression refers to direct attack on the running edge, typically done by fire fighters via a truck or aircraft. Technically, however, extinguishing any flame is offensive suppression, eg spot fires or stationary flames in a garden.
- Defensive suppression uses passive defence to facilitate active defence, ie to create a safe workplace and to reduce flame size to match the capability of the defenders. Specifically, the defensive suppression model in this chapter utilises the proven principles of dry fire fighting, a successful fire fighting strategy developed by foresters over many decades. It evolved in forests where water and access were scarce, and where defenders also had to make full use of fuel bed management and topography (eg, down slope runs and lee slopes) to reduce the flame to manageable size.

Luke and MacArthur (1978) confirm that indirect attack can be effective where direct attack against a severe head fire is not advisable. Cheney and Sullivan (1999) note that under extreme conditions, stopping head fire attack in grass fires by direct attack is rarely possible. In these circumstances, they recommend the use of indirect attack. In these scenarios, the control line is set up away from the fire edge. By the above definitions, this is defensive suppression.

The bushfire threat
This chapter divides the major bushfire threat into two types, One Day Inferno fires and Multi-day Campaign fires.

The **One Day Inferno fire** runs unchecked throughout the day and threatens houses and towns in its path. It typically occurs on a Total Fire Ban day or on milder summer days when the wind is very strong. If it escapes the control of first attack fire crews and reinforcements, it runs out of control towards towns and settlements. The death toll and the house loss toll can be huge, eg, most Black Saturday fires.

The **Multi-day Campaign fire** runs unchecked for days or weeks.

- Sometimes it originates in mild weather and resists control because of terrain or other access limitations, eg, Victorian alpine fires 2003, 2006, 2013, Grampians fires 2006, 2012,
- Sometimes it originates from the One Day Inferno, which grows so large in the wind on Day 1 that its perimeter requires days or weeks to be controlled. Typically, the weather is milder after Day 1. Consequently, the damage toll is very high during Day 1 phase, but negligible during the campaign fire phase, due to the milder weather and the abundance of fire fighting resources on hand to quell potential flare ups. Eg, Blue Mountains fire 2013, Ash Wednesday 1983, many Black Saturday fires.

When the Multi-day Campaign fire runs for several days or weeks, the normal summer weather cycle of severe weather returns and a large uncontrolled perimeter can change from a quiet edge into a raging inferno, eg, Canberra fire 2003, Black Friday 1939. This can lead to a high death, house and damage toll.

It is reasonable to deduce that most damage to houses occurs in the One Day Inferno fires. Therefore, to minimise house loss, defensive suppression must be able to neutralise bushfire attacks on such days.

The concept of two categories of severe bushfires was raised by Chen and McAneney (2004) This chapter names and characterises two types after their namesakes, both of which the author has experienced or inspected and closely examined - the Ash Wednesday attack category and Duffy attack category.
The **Ash Wednesday attack category** is a fearsome combination of flame, smoke and ember attack, which occurs because there is no fuel free barrier to stop the flame's run. The author was on site to see the Ash Wednesday attack (Victoria, 1983) and its aftermath in the Macedon area. By comparison, the **Duffy attack category** (Canberra, 2003) is an ember only attack, made possible because the flame's run has been stopped upwind. The author was on site at Duffy immediately after the attack, and has closely examined unedited footage of the attacks by the several spot fires into the firebreak that protected Duffy.

There were similarities and differences. Both fires happened in very severe weather, and both fire authorities knew a huge fire was in their vicinity and that a powerful wind was pushing the fire mass into the communities. Both attacks ran into wide fuel free barriers. The Macedon fuel free barrier was the 50m wide Calder Highway. It clearly stopped the run of the flames, but embers started multiple spot fires downwind. The residential area of Macedon, which was mostly low density large blocks, was immediately adjacent but the spot fires ran between the houses. Just to the north of Macedon, the spot fires ran through the uphill forest into even more dispersed Mt Macedon township. Mt Macedon was the site studied by Wilson and Ferguson (1984), and is the basis of the Ash Wednesday attack category.

The author was at nearby Gisborne during this attack. He observed some of the major spot fires progressing steadily across the landscape. Afterwards at Macedon, he saw that the area was peppered by embers, that there was no massive single fire front. He saw the burnt houses in the vacant high density residential areas, among the discontinuous fuel beds dissected by streets and driveways that allowed only stationary flames. He saw where one neighbour stayed and put spot fires out on his house and four other houses before collapsing with exhaustion. Beyond the residential area, most was continuous fuel bed. Spot fires grew larger with distance travelled. They ran into unprotected houses. They ran into accidentally protected houses. The author observed where flames ran through the continuous forest fuel beds with massive flames that stopped at 200m wide bare paddocks and hurled embers at houses like machine gun fire. One occupant stayed to put the spot fires out and saved the house. Another fled, and lost his house and vehicle and irreplaceable family heirlooms. The house loss rate of vacant houses was more or less consistent as the fire fronts proceeded between them, flame and embers attacking together.

The Duffy fuel free barrier was a 35+ m firebreak of short grass and the 8m wide road. It separated the suburb from the very flammable unthinned unpruned 20m tall pine plantation. The flames reached 30+m. The crown flames stretched 20m into the firebreak. The fire break had 20 – 40cm flame height. The firebreak flame stopped at the road. The firebreak design stopped the runs of these large fierce spot fires dead. The embers hurled across the firebreak and peppered the high density well maintained residential area. There was no running flame. Houses were attacked by embers only. The stationary flames were ignited by the embers. Most people had been evacuated. The author clearly observed that the house loss rate of vacant houses reduced with distance from the firebreak.

Summary of casualty toll:
Macedon / Mt Macedon area had 750 houses over 13 sq km (1981 census data), of which 350 were destroyed (46%). 7 lives were lost (EMA web site). Part of this area was studied by Wilson and Ferguson (1984). Within their study area, 229 of 450 houses (51%) were lost and five people died.
Duffy residential area had approx 1200 houses within the ember attack area over 1.5 sq km, of which 206 (16%) were destroyed (Chen and McAneney, 2010). Three lives were lost within Duffy (EMA web site).

The obvious point of difference is that the flames running towards Duffy stopped at a 10m wide fuel free barrier and the houses were attacked by embers only. The Ash Wednesday running flames stopped at a 50m wide fuel free barrier, but the ember attack spawned battalions of spot fires downwind that attacked houses with flame and embers. This chapter explains how the defensive suppression model converts the bushfire-exposed Ash Wednesday scenario into a bushfire-protected Duffy scenario.

The principles of dry fire fighting

Dry fire fighting was developed many decades ago by foresters in areas where water was not available (eg, Luke and McArthur (1978). It is effective because it creates a bushfire-protected environment at the fire control line. The author has personally deployed it many times on the fire line, when the advancing flame has been close and distant, and has witnessed and examined its successes and failures at many other bushfires, including forest, heath and grass. It has definable pre-requisites for success as follows:

The first one is a clear aim to stop the advancing fire at a nominated control line. This sets the basis for success or failure. Successful dry fire fighting requires fire fighters to widen a (usually) narrow control line into a wide fuel free barrier between them and the advancing fire edge. In forest areas where there is no control line, fire fighters have to create a new track (control line) with rakehoes or bulldozers before burning can commence. The fuel free barrier is commonly done by burning. In Australia, there are two variations of the burning process - burning out and back burning.

The fuel free barrier is essential for stopping the fire and for the safety of fire fighters. The fuel free barrier needs to be wide enough to deal with the danger elements of the moving flame as follows:

- Ensure barrier width exceeds flame rollover / stretch distance so the flame does not stretch across it. This means the moving flame stops at the barrier.
- Keep the moving flame well away from the fire fighters. This means the risk of danger due to flame contact and radiation is eliminated.

Fire fighters are alert for spot fires beyond the control line that are ignited by the embers that continue to blow across the fuel free barrier. They constantly patrol the control line to ensure spot fires do not take hold and escape beyond it. The success of dry fire fighting depends on availability of sufficient numbers fire fighters and their alertness during patrols. The numbers required depend on the expected intensity of spot fires. This can be quantified as numbers of fire fighters per km of control line.

Table 1 summarises the principles of dry fire fighting, indicating that it deploys both direct and indirect attack methods in a two step process.

Table 1 Principles of dry fire fighting

Scenario	Objective	Strategy	Tactic
Step 1 Flame has expanding perimeter	Halt spread of perimeter flame at a designated control line	**Indirect attack** Prepare a fuel free barrier between designated control line and fire edge	Remove on-ground fuel between control line and fire perimeter (usually done by burning out). Use an existing control line or create a new one.
Step 2 Ember throw occurs downwind.	Extinguish spot fires that have ignited downwind of control line	**Direct attack** Patrol control line, extinguish spot fires down wind using direct attack	Patrol the control line and extinguish spot fires down wind.

In essence, successful dry fire fighting has three core fundamentals –

- a defined control line
- an adequate fuel free barrier (eg, burnt out area)
- adequate, alert and equipped and trained defenders who extinguish spot fires

How does dry fire fighting influence an advancing bushfire?
No matter how large the running flame is, when it hits a low fuel area, the flame keeps running but its height reduces. When it hits a wide enough fuel free barrier, it stops and the flame soon fades to nothing. The embers continue to fly across while the flame is large, but their supply gradually subsides.

These fundamentals and principles can be juxtaposed into the defensive suppression model of protecting a community from an advancing bushfire. Preparing the barrier is passive defence and extinguishing spot fires is active defence.

Passive defence components
Defined control line This is the defence line where the moving flame will not enter. Spot fires are extinguished downwind of it. It is the starting point for the fuel free barrier.

Fuel free barrier It extends upwind from the control line towards the incoming flame. How wide? If the expected height in the flame area on a worst case day is high, the width needs to be greater than if the flame height is short. This leads to an additional principle – height in flame area upwind.

Flame height upwind Flame height upwind of fuel free barrier is managed by reducing fuel height or load for an appropriate distance. This ensures the flame cannot stretch across the gap and reduces its radiation loading on defenders. For example, the CSIRO Grassland Meter indicates that a maximum flame height on a worst case day will be 1m if grass height is less than 10 cm, and 3m if 50cm tall.

Active defence components
Team of defenders The defenders patrol within the bushfire-protected community for spot fires within and extinguish them when small.

Work place is a fuel free zone The defenders patrol and extinguish small spot fires in a safe work environment. This is achievable when the fuel bed is highly discontinuous.

The principles for the defence of a community are summarised in Table 2.

Table 2 Principles of defensive suppression for the defence of a community

Scenario	Objective	Strategy	Tactic
Flame approaches community	Protect community from damage by flame	**Infrastructure already in place** provides adequate on-the-ground fuel free barrier	Fuel free barrier installed before bushfire occurs. It is wide enough to exceed predicted horizontal flame stretch and to ensure low radiation levels
Embers attack community	Protect community from ignition by embers or nearby stationary flames	**Direct attack** Patrol and extinguish spot fires within discontinuous fuel bed	Extinguish spot fires on and near community, eg, by wetting

It is important to note that a basic feature of both dry fire fighting and defensive suppression is to separate the flame and ember threats and allocate resources to deal with each separately. This chapter now examines the underlying science of defensive suppression.

LITERATURE REVIEW

It has long been known that the theory behind wet fire fighting is that water cools the flame base and as evaporation saturates the combustion zone water with water vapour it excludes oxygen from the fuel mixture thereby preventing combustion (Byram, 1959). Once evaporation is complete, however, the fire can resume as before. The impact on water on a given flame is a direct function of area of the flame base influenced by the water spray and inversely related to width and depth of flame base. This means that a flame with a small base requires less water to extinguish it, whereas a running bushfire with a depth of 50m or more will be largely immune to fire tanker hose sprays and aerial water drops. This theory helps to explains why wet ire fighting has a limited capability.

The core theory behind dry fire fighting is that removing fine fuel from a given site prevents the flame occurring on that site, and when the fuel free gap is wide enough, flame spread stops because it cannot cross it (eg, Luke and McArthur, 1978). Removing fuel and creating gaps is part of fuel bed management, which is the combination of fuel bed composition on a site and fuel bed discontinuity. Fuel bed composition includes fuel bed load, fuel bed type, fuel bed height, fuel particle size ranges. Fuel bed discontinuity is defined by location, size and arrangement of fuel free gaps.

The defensive suppression model combines several corollary theories and logical deductions from the foregoing as follows:
Fuel bed composition on a given site controls ember ignition success and flame size, and because flame size is related to uplift force, it controls ember generation potential.
Fuel bed discontinuity controls where flame is allowed or not, where embers are allowed to ignite or not and whether the flame spreads or not. Wind is known to tilt the flame into the gap, but wind is not controllable. The defensive suppression model reduces flame tilt by reducing flame size.

Table 3 summarises how the core risk management principles of the defensive suppression model trace back to a core fire behaviour principles or theory. They are divided into two areas – upwind of the bushfire-protected community and within the community. It is expected that extreme fire weather events such plume induced mini tornados and lightning strikes obey these theories, eg, a tornado cannot be fire filled unless it is sourced on a fuel bed with flammable fuel; lightning cannot ignite a fuel free gap.

Table 3 Core risk management principles of the defensive suppression model

Fire behaviour principle or theory	**Risk management principle**
Upwind of bushfire-protected community	
Flame occurrence Flame cannot ignite or spread where flammable fuel is absent	Identify areas where flame is allowable and not allowable and manage fuel bed presence or flammability accordingly
Flame size Manage flame height by managing fuel bed on-the-ground parameters	Determine what flame height will occur on each site
Flame rollover Flame rollover / stretch into a fuel free gap is proportional to flame height	Create fuel free barrier to exceed flame rollover by acceptable margin
Ember generation Ember volume and density increase with flame size and volume of loose fire brand material at the source property	Identify source properties to be managed to reduce ember threat
Within the bushfire-protected community	
Ember management Embers ignite quickest on flammable fuel beds	Identify areas where spot fires are allowable and not allowable and manage flammability accordingly

The major strength of the defensive suppression model is its capability to convert a raging bushfire of any size into controllable status. It is able to isolate the two causal agents and allows them to be managed separately. It does this by stopping the run of the flame and thereby neutralising it, and allowing defenders to neutralise the ember attack.

The first part of this section amplifies on the above theories and principles with the research findings about the moving flame as it approaches the fuel free barrier. The second part deals with the science behind ember ignition.

Moving flame

A fuel free barrier is effective in stopping a moving flame provided its width is greater than the flame's rollover or stretch distance. Cheney and Sullivan (1999) concluded that a head fire in severe weather can be stopped if it runs into a substantial barrier, eg, a wide firebreak or road. They found that when the head fire reaches a fuel gap, winds push flames into the break and blows superheated air, ash and flame across it for up to a few minutes. They advised that design of an effective break must be wide enough to allow fire fighters to suppress spot fires beyond the break as soon as they occur.

How wide? Byram (1959) specifies that an effective firebreak is at least 1.5 times the flame length. Luke and MacArthur (1978) state that a firebreak will stop a moving flame if flame stretch is considerably less than width of the break. They caution that firebreaks provide insignificant defence against ember attack. The caution about embers is addressed below, but defenders can have confidence knowing the moving flame has been stopped. They know they can then deal with the spot fires in safety.

The two dangers that emanate from the flame upwind of the fuel free barrier are radiation and flame contact.

Radiation Luke and McArthur (1978) pointed out many years ago that most of the heat from the flame is radiant, not to be confused with superheated air from the flame. It is long known that incident radiation from a heat source can cause damage to skin or to a wood surface if thermal load thresholds are exceeded. Thermal load is a function of incident radiation and exposure time (eg, Vines (1981)).

The factors that influence incident radiation are long known. Incident radiation increases with flame size and flame width and decreases with distance from heat source Byram (1959). Therefore, incident radiation from a given flame height and width is managed by varying the width of the fuel free gap because this determines the separation distance from the heat source. View factor analysis (eg, McGrattan et al, 2000) provides a useful tool for assessing flame height and separation gap combinations can achieve appropriate incident radiation levels. Thus the elements that determine destruction potential, ie, the flame height - separation gap balance can be readily quantified to assure safety.

Flame contact Flame contact across a fuel free barrier is the result of flame stretch, also called flame rollover. Byram (1959) measured flame stretch as a multiple of flame length. Byram measured flame length from the centre of the depth to the flame tip (Catchpole et al, 1993), and because flame depth is proportional to wind speed, flame length in a strong wind can be up to half its depth, yet flame height may be low, and the flame's rollover beyond the gap may be short as well. It seems reasonable to measure flame rollover as a multiple of flame length or flame height. Based on numerous measurements from photographs of rollover distances in grass, litter and shrub fires, the author concluded it is rare for flame rollover to extend into the gap beyond flame height on flat terrain. Nevertheless, to allow for the impact of superheated air from the flame tip, the defender can plan for a minimum gap width of 1.5X to 2X flame height as recommended in the classical literature, or incorporate an even greater safety margin.

Thus it can be concluded that for a given flame height, both flame contact and the level of incident radiation on an object can be controlled by varying width of fuel free gap. The next section shows that incident radiation and flame rollover can also be controlled by managing flame height in the upwind zone.

Flame height

It has been long known that at a given distance from a flame, incident radiation is related to flame height (eg, Tassios and Packham (1984)). Butler and Cohen (2000) more recently proposed a fire fighter safety zone of 4X flame height as acceptable (this reduces incident radiation levels to 7 kW / sq m). It has also been long known that flame height is manageable, eg, in some cases it is proportional to fine fuel load (eg, McArthur 1967), or to fuel bed height Cheney and Sullivan (1999). Therefore, incident radiation on an object can be managed by designing maximum flame height on the upwind side of the fuel free gap for worst case weather.

The techniques of managing fuel load on the upwind side of the firebreak have long been known. Reduction of fine fuel load can be done by burning or mowing, or raking or scraping. Luke and MacArthur (1978) promoted fuel reduction burning in forests as a protection tool because major benefits are that flame heights are lower and less ember generation occurs.

Planning for flame height can be done on the basis of predictions (eg, CSIRO Grass Fire Meter and McArthur Forest Meter provide useful estimates for low fuel loads). What flame height prediction is relevant? It is reasonable that predictions be made for the most severe fire danger weather. This means the flame height predicted will be the maximum expected. The pragmatic defender can define a maximum acceptable flame height and adjust fuel load accordingly.

How wide is upwind flame zone? Wide enough to prevent the unmanaged upwind fuel bed causing radiation concerns to the defenders or flame rollover to breach the control line.

Ember ignition

The foregoing principles of flame height and duration and fuel free gap width provide a reasonable basis for infrastructure design to stop an approaching flame at a designated location. It will not stop ember attack because embers leap across any sized barrier. However, the defender has a safe environment to focus on ember attack and controlling the spot fires they ignite.

Ember attack is also called spotting. The descriptions in Luke and MacArthur (1978) help identify three types of spotting, based on distance ahead of the fire front – short distance (up to a few hundred metres ahead), medium distance (1 – 4 km ahead) and long distance (10 – 20+km) spotting. They suggest that ember volume is determined by time since last burnt, fuel type or species, and age of vegetation. Clearly, no firebreak can reasonably claim to stop spotting. Therefore, unless ember source can be neutralised, ember attack must be regarded as a constant feature in property and control line defence.

There is ample recent and historical evidence that houses burn down in residential areas by ember-generated flames (Eg, "Ember attack is the main cause of ignition and loss of buildings during a bushfire**" (**VBRC 2010 - CSIRO submission (Justin Leonard)). The success of defence on a property or a neighbourhood or a control line therefore depends on management of ember attack on the downwind side of the fuel-free barrier. Embers can be live or already extinguished, but it is safer for the defender to assume they are live, ie, capable of igniting a flammable substance. Embers can land on a structure, under a structure, above a structure, inside a structure. The surface can be flammable or non-flammable.

Ganteaume et al (2009) explain the influences that assist ignition in a litter bed and those that prevent ignition. They found that for a given litter bed, flammability increases with lower bulk density and lower fuel moisture content. They found dead grasses were the most flammable, followed by pine litter beds and then by eucalypt litter. The ember ignites quickest if heavy. It ignites quickly if flaming when it lands in calm air. It ignites slower if glowing and in light air flow. It ignites slowest if glowing and in no air flow.

Consider the following observations. If a live ember lands in a flammable fuel bed, it ignites as a small flame and then grows as it burns in the warm air flow. If it is a continuous fuel bed, the spot fire will run with the wind or run up slope. If it is discontinuous fuel bed, it will spread up to the fuel free gap and then stop spreading. If the fuel bed is flammable, the defender can make it non-flammable by saturation or by covering with a non-flammable barrier.

These observations suggest that when defending a designated area against embers, two key tasks are required to facilitate suppression efficiency. The first is to minimise the surface area of flammable sites available for ember ignition, and the second is to extinguish spot fires as soon as they develop, ie, while small. Rapid suppression of spot fires assumes adequate defenders are on site, which presupposes it is safe for the defenders to remain on site. Safety on site has already been determined by the size of the fuel free gap and the flame height expected in the adjoining upwind zone.

Ember generation

All embers originate from a forest or other source that is located on a property owned by a person. Ember volume and throw distance are directly related to the intensity of the flame on this property. Eg, a taller flame has a stronger uplift than a smaller flame because of buoyancy forces. (Albini et al, 2012). Furthermore, a forest that has not been burnt recently can have a large supply of potential firebrand material and tends to burn with a strong flame (Luke and McArthur, 1978). These observations indicate how ember generation can be controlled by managing flame intensity on the source site.

In summary, the defensive suppression model is supported by solid theory and a reasonable body of scientific findings that allow estimation and verification of its core tools - flame height, gap size, flame rollover distance, radiation loads and ember density.

RESULTS

The measure of success of the defensive suppression model is when the community is undamaged after a bushfire attack. This is achieved when passive defence infrastructure stops the running flame at edge of fuel free barrier and spot fires that ignite within the community area are managed by active defence, ie, extinguished before they cause damage. This is achieved when the five basic principles are applied – a defined control line, an adequate fuel free barrier, managed flame height upwind of the barrier, the presence of adequate, alert and equipped and trained defenders and a discontinuous fuel bed.

Sensitivity analysis
Can any of the basic principles be sub optimal and yet be compensated for by other elements, so that the chance of suppression success remains high?
- If fuel free barrier is narrow, and the upwind flame is not too large for safety of defenders on the line, numerous spot fires will cross the line. If defenders are present in large numbers, they will be able to access them safely and compensate for the narrow barrier.
- If defenders are in short supply, they may be able to achieve suppression success if the fuel free barrier is very large and the spot fires self-extinguish.

Can any of the basic principles be sub optimal and **not** be compensated for by other elements, meaning that the chance of suppression success becomes too low?
- If fuel free barrier is narrow, and the upwind flame is too large for safety of defenders on the line, nothing can compensate. The control line is breached and defender safety will be compromised.
- If the fuel free barrier is adequate, but the numbers of defenders is too low, chance of a spot fire growing too large and too damaging will be greater.
- If the fuel free barrier is adequate, but the attentiveness or diligence of defenders is too low, chance of a spot fire growing too large and too damaging will be greater.
- If the fuel free barrier is adequate, but the fuel bed is continuous where the defenders are expected to defend, spot fires will escape their control at the same time as ember attack is at its worst.

The foregoing analysis sets the context for a review of the outcomes of severe bushfire attacks on three communities that were prepared (knowingly or unknowingly) according to the passive defence part of the defensive suppression model.

1 Pre-planned defence of an urban townゃship – Duffy (Canberra Bushfire, 2003)

The Duffy residential area was adjacent to a 20m tall unthinned unpruned pine plantation. It was surrounded on the danger side (north and west perimeters) by a 30 – 40m wide fire break of short grass and a 10m wide bitumen road. The bushfire occurred in 2003 near Canberra, Australia. It has been widely analysed, eg, Chen and McAneney (2004).

The author attended the site one week after the attack and has also examined uncut footage (by a professional cameraman) of the entire bushfire attack. This allowed verification of actual flame heights in many places with flame height estimates that the author made from scorch heights. The following analysis uses the principles of defensive suppression to re-create aspects that would have been predictable before the fire attack.

Passive defence component
Defined control line: The boundary roads – Warragamba Avenue and Eucumbene Drive

Fuel free barrier: The fuel free barrier was the 8m wide road.

Upwind flame zone: Immediately upwind of the fuel free barrier is the 30 – 40m wide firebreak of short grass, and upwind of that is the 20m tall pine plantation.

Expected fire behaviour in upwind flame zone: It would have been foreseeable that in worst case weather, the pines would have flame height of up to 2X tree height, and the canopy flame would rollover up to 20m or so into the firebreak space. The firebreak itself would have a maximum flame height of 0.5m. This is the flame that would run into the road and stop because it cannot stretch across an 8m barrier. Thus, flame height adjacent to fuel free zone was substantially less that width of fuel free barrier.

The pine plantation would be expected to generate a mass of embers that would be thrown down wind across the fire break into the residential area and ignite anything flammable. If the bushfire originated a long distance away to the NW, it would run freely for tens of kilometres and would be expected to hit the firebreak / township with a wide front. Therefore, it should have been foreseen that the fringe few hundred metres of the residential area would be saturated with high density embers.

Active defence component
Resources: Evidence indicates that no significant consideration given to management of ember attack. This conclusion is based on the small number of fire fighters and pumper units allocated to defend the edge, the interview with the fire controller in the film footage and the subsequent panicked response. When asked about his strategy, he said they will let the fire run up to the firebreak and then they will stop it getting into the houses. Most of the residents had been evacuated.

Fuel bed within community area: Fuel bed was highly discontinuous within the residential area which means there can be no running flame. The house blocks are predominantly fuel free. Measurements by the author on aerial photos found that on average, 70-75% of the residential area is non-flammable at ground level. They have fine dry flammable fuel on up to 20% of it. The flammable areas are predominantly garden bed and dry grass and objects with flammable surfaces.

Expected fire behaviour within community area: The only flames will be the stationary flames that embers have ignited.

Verification
Film footage confirms that the running flame through the pines rolled about half way into the fire break, and then subsided without suppression assistance. The running flame on the fire break stopped at the bitumen road without suppression assistance. Embers poured densely across the fire break and road and ignited flammable garden beds and objects for up to a few hundred metres into the residential area.

Film footage shows the defenders were professional fire fighters with several pumpers. It confirms that they were inadequate in numbers for the task at hand. It also shows the fire fighters being overwhelmed at the sight of multiple house ignitions and unable to perform significant suppression work. It shows some residents stayed and put out spot fires on their property. Some were dazed and were clearly not prepared for the fight.

Many scores of houses were destroyed in the area inspected by the author. Many garden beds and trees were observed to be not scorched or partially scorched. The film footage confirms that during the worst of the 15 – 20 minute attacks (by separate spot fires), darkness prevailed in mid afternoon. It confirms that the only flames within the residential area were stationary flames. They were confined by roads and pathways and other non-flammable fuel beds. It shows vehicles driving and people walking freely through the streets during the height of the ember attack.

In summary, the combination of fuel free zone width and upwind zone flame height met the passive defence component of the defensive suppression model. The active defence component was sub optimal and unable to be compensated for, and therefore the defensive suppression model was compromised. Thus the defence of Duffy failed, with three deaths and 206 houses destroyed within an hour or two.

Even though the Duffy community was deliberately and expertly protected from the advancing flame by the firebreak, the authorities did not realise it or apply it to protect the community. This suggests an apparent lack of common understanding between the managers of the government plantation who installed the firebreak and the Canberra fire service, which defended Duffy.

2 Accidental defence of a rural township – 2009 Black Saturday fires, Wandong

The East Kilmore fire started just before 11.50am, some 6 km NNW of Wandong township. Despite the strong N wind, it progressed slowly as it burnt though forest and pine plantations on the elevated plateau over the next 1.8 hours until the wind changed to NNW at 1.30pm. It then entered grassland and approached the 60m wide Hume Freeway strip at a sharp angle. The freeway strip runs between N- S and NE-SW in this area. This means the effective width of the fuel free break was much wider.

Four people perished in the fires around Wandong and 147 houses were lost. (The Age, March 27, 2009). Census data for Wandong - Heathcote Junction area, there were approx 1000 houses in 2009. This is a 15% house loss rate.

Passive defence component
Defined control line: The Hume Freeway roadways were the logical control lines, but, based on evidence to Royal Commission, there was no apparent decision to stop the fire there. Instead, the evidence suggested a belief it was unstoppable.

Fuel free barrier: The freeway strip comprised two 12m wide fuel free bitumen roadways flanked by short grass.

Upwind flame zone: Immediately upwind of the fuel free barrier is the 10-20m wide firebreak of short grass, and upwind of the firebreak are grazed paddocks with scattered trees for hundreds of metres.

Expected fire behaviour in upwind flame zone: It would have been foreseeable that in worst case weather, the grass flames would be 1 – 2+m and the fire break near the roads would have a maximum flame height of 0.5m. Thus, flame height adjacent to fuel free zone was substantially less that width of fuel free barrier.

It could have been foreseen that the flame would stop at the freeway, but strong winds could carry embers across the freeway toward the township. Apart from scattered trees, the main potential source of embers was the plateau at least 6km to the north. Therefore, it could have been foreseen that the township would be sprayed by low density embers.

Active defence component
Resources: Evidence indicates that no significant consideration given to management of ember attack. This conclusion is based on the evidence to the Royal Commission that suggested the response by individual fire trucks was based on attend-the-greater-need approach. It is not known how many residents had been evacuated.

Fuel bed within community area: The town streets were a grid pattern, which generated a discontinuous fuel bed, but the fuel bed in the outskirts was relatively continuous.

Expected fire behaviour within community area: Stationary flames will occur in the denser residential area. Combination of running flames, smoke and ember attack in the outskirts.

Verification
Media photos show fires behind shops along the main street. This confirms the whole town was showered with embers from the plateau during the first hour of the fire under the N wind. It was probably light ember attack because the plateau was the source and it was at least 6km to the north.
Other evidence given to the Royal Commission

- Before the wind change, fire trucks attended houses to the north of the town, but had to withdraw because they were exposed to flame, smoke and embers.
- After the wind changed to NNW at 1.30pm, spot fires ran across the paddocks into the forest on the eastern outskirts of the town. There were futile attacks by helicopter water bombing.

In summary, the combination of fuel free zone width and upwind zone flame height met the passive defence component of the defensive suppression model. The active defence component was sub optimal and unable to be compensated for, and therefore the defensive suppression model was compromised. Thus, the defence of Wandong was unsuccessful.

Thus, the community was accidentally protected from the advancing flame by the freeway strip, but the authorities did not seem to realise it. It can be concluded that because the town was surrounded by paddocks, it was essentially attacked by a grass fire flame which stopped at the freeway. Ember attack was probably light because, apart from scattered trees, the main potential source of embers was the plateau forest, some 6km to the north.

3 Accidental defence of a rural township – 2009 Black Saturday fires, Kinglake

The Kinglake township was attacked by embers from the SW at approx 6pm, very soon after the wind changed from NW to SW and converted the western edge of multiple spot fires into multiple fire fronts. The township was bordered on the south and west by a wide main road. Beyond the road to the west and south were wide paddocks with short grass. Beyond the paddocks, the forested slopes of the national park dropped down into the deep gullies.

Twelve people died within the township area (VBRC, 2010) – data base) and the house loss rate was 70% (derived from Chen and McAneney (2010)

Passive defence component
Defined control line: The Kinglake Whittlesea Road was the logical control line, but, based on evidence to Royal Commission, there was no apparent decision to stop the fire there.

Fuel free barrier: The road was 10m wide

Upwind flame zone: Immediately upwind of the fuel free barrier were grazed paddocks on a 300 - 500m wide flat. Upwind of that was the forested national park.

Expected fire behaviour in upwind flame zone: It would have been foreseeable that in worst case weather, the grass flames would be 1 – 2+m. Thus, flame height adjacent to fuel free zone was substantially less that width of fuel free barrier.

It could have been foreseen that the flame would stop at the roadway, but strong winds could carry embers across the freeway toward the township. The source of embers was National Park forest area. The slope was SW. The wind at the time of the attack was from the SW. Therefore, it could have been foreseen that the township would be attacked by high density embers.

Active defence component
Resources: Evidence indicates that no significant consideration given to management of ember attack. This conclusion is based on the evidence to the Royal Commission that suggested the authorities were unaware of the location of the fire edge. It is not known how many people evacuated, but based on the high house loss rate, it was probably high.

Fuel bed within community area: Residential area was medium density housing, with variable sized house blocks. The low road density was parallel to the SW wind. This means the fuel bed was continuous and therefore spot fires and smoke would run into and past the houses, at the same time as embers attack them.

Expected fire behaviour within community area: Combination of running flames, smoke and ember attack within the township

Verification
Inspection of the site by the author confirmed the damage was inflicted by unattended spot fires. Many yards had adequate fuel free areas for personal protection.

In summary, the combination of fuel free zone width and upwind zone flame height met the passive defence component of the defensive suppression model. The active defence component was sub optimal and unable to be compensated for, and therefore the defensive suppression model was compromised. Thus the defence of Kinglake failed.

It can be concluded that because the town was bordered by short grass paddocks, it was accidentally protected from the advancing flame by the road, but the authorities were unable to make use of this advantage. On this occasion, ember attack was heavy because the main potential source of embers was the forested slopes, only 0.4 km away.

4 Defensive suppression on a property – 2009 Black Saturday, North Whittlesea

The same defensive suppression principles were applied to defence of a property by the author, during a severe bushfire attack on Black Saturday afternoon.

On Black Saturday, 2009, the author was present on a property by chance and remained on site during the bushfire attack in the role of coach and defender. More details are available in O'Bryan (2009). The property had not been consciously prepared according to above framework, but yet fell within the sensitivity analysis criteria.

Passive defence component
Defined control line: Outer edge of the fuel free barrier

Fuel free barrier: A bitumen driveway and bare earth areas (total width 15 – 25m) protected the danger side of the house and vehicles and a sandy stock yard for the horses was protected by a bare earth clearing of 10+m around it.

Upwind flame zone: The paddocks upwind of the fuel free barrier were ungrazed paddocks of native grass, 30cm tall, with a light to medium tree cover. 200m further upwind was dense forest.

Expected fire behaviour in upwind flame zone: The maximum flame height in the grassy paddocks was assessed at 1m near the horses and 2m near the house and in the isolated patches of scrub as maximum 6-8m. The trees were expected to have narrow trunk flames and perhaps occasional passive crowning. These estimates allowed for extra flame height because of the site’s steep up-slope. Calculations for radiation and flame rollover confirmed that safety and effectiveness of the fuel free zone was not compromised.
There was no infrastructure in place to stop the stopping the moving flame until it hit the fuel free zone. Nevertheless, due to terrain influences on fire behaviour, the initial flame attack was expected to be narrow spot fires, thrown well ahead of a main front. This burnt ground was assessed as extra protection for when the main front arrived, ie, the equivalent of a back burn.

Active defence component
Resources: After brief training and on going coaching, the defenders on site had knowledge, equipment and skill to patrol and extinguish spot fires and thereby protect assets during ember attack. Infrastructure was limited, but adequate for the task of extinguishing small spot fires. There was adequate petrol for pump and generator. In addition, a battle plan was formulated and practiced.

Fuel bed within active defence area: Predominantly fuel free on-the-ground, but had scattered garden beds (mulched). This area was predominantly fuel free, but the gutters, decking and the mulched garden beds were identified as vulnerable to ember attack. The building and vehicles were carefully assessed for gaps and openings for small embers. The water tanks were vulnerable because they were plastic and surrounded by dry grass.

Expected fire behaviour within active defence area: Stationary flames in garden beds

In summary, the combination of fuel free zone width and upwind zone flame height (predicted) was adequate, and defence team progressed rapidly from inexperienced to adequate because it accessed experience, knowledge and skills. Thus, the defensive suppression criteria were adequately met, although by coincidence rather than by deliberate planning. In this case, knowledge and skills compensated for sub-optimal preparation of fuel free zone and upwind zone and infrastructure planning. In planning terms, the chance of successful suppression was high.

Verification
The spot fires came first, as expected, commencing in the paddocks and ran up hill with the wind. Flame height was approx 2m in the grass. All observed flames heights corresponded with pre-fire assessments. According to the battle plan the spot fires that ran past were not to be suppressed. The ones that hit the fuel free zone flashed up and then burnt out. Thus, the moving flame was observed to stop at a safe distance and did not compromise safety of the assets or the defenders.

Meanwhile, the defenders were constantly extinguishing spot fires within the smoked-in fuel free barrier in the patchy flammable fuels and fuel beds and garden timbers. Total duration of the bushfire attack on the property was an hour. The main fire front did not arrive. Suddenly, the wind died down and the air cleared and visibility was restored.

The entire property except fuel free zone was burnt and blackened. Four people were safe and well. House was intact and undamaged. Horses were safe and uninjured. Vehicles were intact and undamaged by fire, except for wind-caused damage. High winds threw debris into vehicles causing damage to windscreen and panels. Conditions during the attack were uncomfortable at times, but never considered dangerous. The defenders were relieved that everything of value survived unscathed. The defensive work was tiring. It was concluded that defensive work would have been less tiring if the property had been prepared with a sprinkler network.

In summary, the combination of fuel free zone width and upwind zone flame height met the passive defence component of the defensive suppression model. The active defence component was but adequate. All nominated persons and property was protected. Therefore the defensive suppression model was successful.

This example indicates that the defensive suppression principles are relevant in assessing the condition of the property, in making the decision to defend and in conducting the defence in safety.

DISCUSSION

To some extent, this chapter breaks new ground in the bushfire protection world. It proposes a solution based on a theory rather than empirical finding. The theory of defensive suppression model is solid. The implementation failed in three examples because the practitioners did not know the theory, and succeeded in the fourth because the practitioners did know.

It is logical to propose that when the defensive suppression model converts an unprotected community from an Ash Wednesday attack scenario into a Duffy attack scenario, it has a much better chance of survival because it stops the moving flame well away from the houses and the houses have to deal with ember attack only. The above case studies show three communities that were bushfire-protected by the passive defence component of the defensive suppression model, but the fire authorities were apparently unaware or overlooked the significance. The fourth example applied the same principles to successful protection of a property under attack, and the defenders were very well aware of the threat-neutralising significance of both the passive and active defence components. Lack of knowledge of fire behaviour and fuel bed management was a major factor in the destruction of the three communities. This included failure to recognise that ember attack can be managed separately from the attacking flame.

These examples indicate that the principles of defensive suppression allow analysis before and after the event. The analysis also shows that they would have provided useful information to the planners in regard to preparing the community for protection, to the control team regarding the scale of the bushfire attack and to the residents in regard to making the personal decision to defend in safety.

This study began with five critical criteria for the success of the defensive suppression model, three in the passive defence area - nominated control line, fuel free barrier, flame height upwind and two in the active defence area – adequate resources and discontinuous fuel bed to ensure a safe work place. The above case studies suggest there are two additional criteria to add to the active defence list to ensure the success of the active defence component: acknowledgement and knowledge. They refer specifically to the supervising fire authorities. The four critical criteria for active defence are now listed as follows:

Acknowledgement The fire authorities have to be aware that the advancing flame will stop at the control line of a bushfire-protected community and that only embers can attack the bushfire-protected residential area.

Knowledge The fire authorities have to be aware what fire behaviour to expect in the upwind flame zone and within the bushfire-protected area. For example, a high density residential area has a highly discontinuous fuel bed which will generate only stationary flames, whereas a low density residential area is predominantly continuous fuel bed that allows the flame and dense smoke to run up to and past the house, at the same time as ember attack is occurring.
Discontinuous fuel bed The fire authorities have to ensure people have a discontinuous fuel bed to work within for safety, ie, ensure stationary flames only, and no running flames to endanger them.
Resources The fire authorities have to pre-organise adequate defenders, trained and equipped to deal with the spot fires.

When the supervising authorities learn to recognise that a community is bushfire-protected, they will be able to focus on a plan to manage ember attack. They will be confident that the work place is safe for the fire fighter, as well as the resident. They can then acknowledge the residents as a potential spot fire defence resource, rather than as a group to be saved by evacuation. Residents will be highly motivated to save their own house and to help the neighbours, and this frees the fire fighter from asset defence to chase the expanding perimeter.

The analysis indicates that protection of a community from severe bushfire attack is a premeditated decision that requires careful application of bushfire behaviour science and threat management principles, installation of infrastructure and organisation of the defence force. All of this preparation must be done before the bushfire attack. Because the timing of the attack cannot be forecast, it must be done each year. It is very different from the current model of arriving in the emergency team to an unprepared site, and relying on a team of water deliverers to extinguish a dangerous flame front.

The authorities have not yet realised the importance of preparation as a prerequisite for community protection, which explains why they still rely on the fire brigade model. Their recent actions may stimulate an early understanding. They have taken the initiative of identifying over 200 communities as very high or extreme risk. Their current policy is to evacuate them to a safer town during severe weather. This leads to two opportunities. Firstly they can learn to identify what features of the other town make it “bushfire-safe”, and secondly, residents will logically expect them to commence a program of reducing risk of each community to acceptable levels. When they are ready, authorities can apply the principles of defensive suppression.

The responsibility protection of a community ultimately rests with the supervisors of the fire authorities. The government acts on advice received. It is hoped that outlining the elements of defensive suppression opens the door to better quality advice for community protection, from scenario A to B.

A The fire brigade model is designed for emergency response, or in organisational management parlance – “to put out spot fires”. They attend an environment under threat from a fearsome ball of heat. People are suddenly in danger. They are caught by surprise. They are afraid. They panic. They do not know what to do. The fire fighters arrive, take charge, get people out of harms way and clean up the mess. When they leave, people deal with the injuries or deaths they did not want, with the ruins they did not want, and try to rebuild their lives. Why does this happen? Because the government is advised that bushfires will always be like this, and has not said to them - “We cannot accept that advice, come back with a plan to protect the innocent citizens”. In the meantime, it has faith in the fire brigade model, and funds it.

B The defensive suppression model recognises that bushfire is manageable risk. It stops the ball of heat before it enters the community. It knows the embers will fly in. It prepares the community by limiting the size and the location of the spot fires. It empowers people to deal with them with confidence and in safety. Why does this not happen? Because the government has not said to its advisers - "We cannot accept that advice, come back with a plan to protect the innocent citizens".

CONCLUSION

This chapter provides authorities with a mechanism to protect communities from the fires that escape the fire brigade model, both in mild weather and in severe weather. The purpose of the defensive suppression model is to bushfire-protect a community in a way that separates the two threat elements (flame and ember) and allows them to be managed independently. It is also shown to be effective in protection of an individual property. An unprotected community experiences the Ash Wednesday attack scenario and the bushfire-protected community experiences the Duffy attack scenario.

The core principles of successful dry fire fighting on the control line are converted into core principles for protecting a community using the defensive suppression model as follows – three in the passive defence area - nominated control line, fuel free barrier, flame height upwind and four in the active defence area – acknowledgement, knowledge, adequate resources and discontinuous fuel bed to ensure a safe work place (see Table 4). Protection levels can be improved further when ember-source properties apply passive defence measures to reduce ember generation density and uplift forces.

Table 4 The seven-point diagnostic list for successful protection of a community

Passive defence requirements	nominated control line
	fuel free barrier
	flame height upwind
Active defence requirements	acknowledgement
	knowledge
	adequate resources
	discontinuous fuel bed

These elements are found to be traceable to long known core bushfire behaviour scientific principles. All elements can be estimated and verified, particularly the elements that determine destruction potential, eg, the flame height, separation gap balance, flame rollover distance and radiation load.

In theory, both core elements of passive and active defence are all required for successful defensive suppression, but in practice, it is likely that one or more will be suboptimal. This question is addressed in a sensitivity analysis. It is possible that some elements can be suboptimal but compromise can be avoided because one element is stronger. It is also possible that an element can be too suboptimal that success is fully compromised. The important practical issue in this case is that the principles allow potential failure to be identified before the event so that alternative strategies can be made in time and that life and property is not put at risk.

The principles are proposed as a workable and scientifically valid approach to preparing a community or a property for successful defensive suppression. It also provides a diagnostic means of assessing or monitoring their condition before a bushfire attack and provides a diagnostic means of assessing and analysis and review after a bushfire attack.

REFERENCES

Albini FA, Alexander MA and Cruz MG (2012) A mathematical model for predicting the maximum potential spotting distance from a crown fire Int Journal of Wildland Fire 21, 609–627

Butler B and Cohen JD (2000) Field Verification of a Fire fighter Safety Zone Model Proc 2000 Int Wildfire Safety Summit International Association of Wildland Fire, Edmonton, Alberta Canada, October 10-12, 2000.

Byram G M (1959) Combustion in forest fuels In Forest Fires: control and use Ed. by K Davis McGraw-Hill, NY.

Catchpole EA, Catchpole WR and Rotherme1 RC (1993) Fire Behaviour Experiments in Mixed Fuel Complexes Int Journal of Wildland 3(1) 45 - 57

Chen K., McAneney K.J (2004) Quantifying bushfire penetration into urban areas in Australia**.** *Geophysical Research Letters* 31, L12212, doi:10.1029/2004GL020244.

Chen, K. and McAneney, K.J. 2010 Bushfire Penetration into Urban Areas in Australia: A Spatial Analysis Evidence to VBRC (2010), Witness statement CRC.304.001.0001 - 304.001.0032

Cheney P and Sullivan A (1997) Grassfires CSIRO Publishing, Victoria, Australia

EMA web site http://www.emknowledge.gov.au/category/?id=1 Emergency Management Australia

Ganteaume A, Lampin-Maillet C, Guijarro M, Hernando C, Jappiot M; Fonturbel T, Pérez-Gorostiaga P and Vega J A (2009) Spot fires: Fuel bed flammability and capability of firebrands to ignite fuel beds International Journal of Wildland Fire 18 (8) pp. 951-969

Luke RH and McArthur AG (1978) Bushfires in Australia Aust. Gov. Publ. Serv. Canberra

McArthur AG (1967) Fire behaviour in eucalypt forests Leaflet 107, For. Res. Inst., For. and Timber Bureau, Canberra

McGrattan KB, Baum HR, Hamins A (2000) Thermal Radiation from Large Pool Fires Nat Inst Standards and Tech, US Dept Commerce NISTIR 6546

O'Bryan DJ (2009) Beat the bushfire enemy with knowledge Red Eagle Victoria Australia

Tassios S and Packham DR (1984) An investigation of some thermal properties of four fabrics suitable for rural fire fighting Tech. Paper 1, Nat. Centre for Rural Fire Res., Chisholm Inst of Tech. Caulfield, Victoria

VBRC (2010) Victorian Bushfire Royal Commission Final Report Victorian Government, Australia

Vines RG (1981) Physics and chemistry of rural fires In Fire and the Australian Biota, Ed. by M H Gill, R H Groves, I R Noble Aust. Acad. of Science, Canberra

Wilson AAG and Ferguson IS (1984) Fight or flee? – A case study of the Mt Macedon bushfire Aust Forestry 47, 230 - 236