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Paper 7D

HOW CAN TWO WRONGS MAKE A RIGHT?

The wall of flame model - the theory behind the BMO

INTRODUCTION

The Royal Commission (VBRC, 2010) analysed the WMO and AS3959 planning scheme systems and was very critical of both. It also had evidence that neither had any mitigating influence on house loss in the Black Saturday fires. It asked that the name WMO be changed to BMO and that a single risk mapping system be organised so that new house development can be discouraged in highest bushfire risk areas. Since then, the bureaucracies have developed a single mapping system but it is not a risk map and they have amalgamated both criticised planning schemes into a new BMO system. This paper therefore asks two questions. In regard to bushfire risk mapping, did the government deliver what the Royal Commission wanted? This question is addressed in Appendix 1 of this Paper. In regard to the amalgamation, our question is - **how can two wrongs make a right?** The amalgamated system is very similar to the NSW RFS system. Thus, if the amalgamation of two Victorian wrongs generates an equivalent to NSW system, we may also ask - does that make the NSW system a right or another wrong?

The BMO is technically an amalgamation of the WMO and AS3959, but the WMO and AS3959 derived from the NSW RFS system. All are designed to regulate new houses in bushfire areas. The major outputs of the BMO are defendable space and BAL via its "Table 1" in the planning document Clause 52.57. It is almost identical in structure and scope to the current NSW RFS Table (NSW RFS 2012). Douglas (2010) developed "Table 1" for Victoria after having been the co-author of the quantification of the NSW RFS and AS3959-2009 systems (Tan et al, 2005). New house construction in both Victoria and NSW is now based on the same model – the wall of flame model and its associated concepts, process and equations. Our grave concern is that the model does not achieve our aim of protecting the house or the community against bushfire.

Paper 7A has analysed the BMO scheme, 7B has analysed the WMO and 7C has analysed AS3959. This Paper now examines the wall of flame model that the amalgamated BMO is based on. In particular we examine the science behind it and whether the model is a relevant indicator of bushfire threat or protector against house loss – either the new house or the community of existing houses. We observe with great concern that the authorities approved the amalgamation process with uncritical acceptance of the concepts, processes and equations of its parent systems.

METHOD

The first part of the paper examines the wall of flame model per se, as used in the amalgamated BMO. We use published documents to deduce the science behind the concepts and processes and the equations. We deduce what it deems as threats to the new house and we deduce the science behind its threat mitigation concepts and on site specifications. In particular, we ask whether the wall of flame model neutralises its own deemed threats.

The next part of the paper asks - how relevant is the wall of flame model to the protection of the house or the community. In particular, does it address the known causes of house loss and neutralise the known causal agents?

The facts are gathered together in the Results section and they are analysed in the Discussion section.

THEORY

A reasonable starting point for assessing the effectiveness and value of planning tools in reducing bushfire-caused damage is to identify an underlying logic or philosophy. The root logic of damage prevention is found in the following common sense threat management principles – identify threats and if risk of damage is too high, neutralise or mitigate threats down to an acceptable level of risk so that damage is minimised or prevented. We can apply this principle to bushfire as follows - if we recognise that a bushfire attack has causal elements that inflict damage on lives and property, and if we can identify these **causal elements** and **neutralise** them, we can **prevent the damage** they cause in bushfires. Almost all the damage in bushfires can be traced back to heat. Other damage is caused by wind force and by smoke. This paper looks only at heat related causes.

We also know from observation that almost all damage is caused during the destructive period of the bushfire attack. Therefore, these observations can be articulated as a damage minimisation theory:
If causal elements inflict damage during the destructive period of the bushfire attack, damage is prevented when those causal elements are neutralised during the destructive period.

RESULTS

Historically, both BMO parent systems (WMO and AS3959) were based on NSW RFS system (2001), which clearly identified that piloted ignition was the major threat to the house. In the fire protection industry, piloted ignition refers to ignition by a spark or flame of pyrolysis gases on a preheated surface. In the RFS case, the source of the threat is the artificial wall of flame in "nearest vegetation". It provides all the ingredients for piloted ignition. The wall of flame provides the radiation that preheats the surface and the ignition mechanisms are its flame or live embers.

The wall of flame protection model can be expressed as follows: ***The fire front ignites the "nearest vegetation" and generates a wall of flame that is the source of radiation, flame contact and ember attack on the new house. Piloted ignition time (by flame or ember) is a function of radiation load, eg, it occurs more rapidly when radiation load is higher. Therefore, reducing radiation protects the house by slowing piloted ignition time. The model by reduces radiation by maximising the distance between flame and house (defendable space) and reduces impact of radiation by fortifying the house with fire resistant materials and designs (BAL).***

The BMO system is concerned with "nearest vegetation" within 150m of the house site, whereas WMO, AS3959 and RFS assessed the surrounding 100m.

The threats

We can deduce that the core science behind the BMO is similar to that of its antecedents (WMO and AS3959) and the RFS system. We can apply the structure in Paper 8 to identify the threats from first principles. The originating factors that have to coincide to cause a bushfire are weather (hot, dry, windy), flammable fuel and ignition source. The wall of flame

model assumes worst case weather and deems the nearest vegetation is the fuel and the fire front is its ignition source. It deems the nearest vegetation has peak fuel load which generates a wall of flame with peak flame height. It deems the wall of flame is the source of the threat agents. The threat agents are flame and embers which imperil the house with three causal agents (flame contact, radiation and ember attack).
We can therefore deduce the house is vulnerable to three types of ignition due to proximity to fire front and to one that is independent of distance to fire front:
(1) Proximity to fire front

- auto ignition by radiation from fire front
- piloted ignition by flame impingement (= hot ignition, heated and ignited by flame)
- piloted ignition by embers (= hot ignition, pre heated by radiation)

(2) Independent of fire front:

- cold ignition by embers

In regard to auto ignition, RFS (2001, 2006) and CFA (2012) accept that non piloted ignition occurs after 3 minutes at approx 30 kW / sq m radiation. Paper 3A (Fig 4) confirms this agrees reasonably with lab tests for thermally thick timber. Auto ignition time is also a function of radiation load, eg, it occurs at lower radiation, but requires longer exposure time, but if radiation is higher, ignition time is shorter. Paper 3A also notes that auto ignition in thermally thin timber is much faster than thermally thick timber at the same radiation level.

In regard to ignition by flame contact, Paper 3A (Fig 4) shows that ignition of thermally thick timber by impinging flame takes half the time of piloted ignition (ember) at the same irradiation level, eg, if incident radiation is 29 kW / sq m, impinging flame causes surface ignition after 25 sec and piloted ignition takes 60 sec. Paper 3A also notes that ignition time by direct flame contact on thermally thin timber or flammable fine fuels is almost instantaneous.

In regard to preheating or "hot ignition", RFS (2001, 2006) and CFA (2012) provide examples of industry data that piloted ignition is more rapid when radiation is higher. Paper 3A (Fig 4) confirms lab tests that show piloted ignition occurs on thermally thick timber after 60 sec if incident radiation is 29 kW / sq m, and if incident radiation is less than 20 kW / sq m, piloted ignition takes longer than 3 minutes. Thus, when BMO increases defendable space, it is aiming to reduce incident radiation, which delays ignition time. How long should the delay be? The deemed duration of the fire front in the wall of flame in nearest vegetation is 2 minutes.

In regard to "cold ignition" by embers, BMO documentation is not so illuminating, but due to the close similarities, we can comfortably quote rationale and explanations from the NSW RFS (2001, 2006) documents. RFS (2001 and 2006) states: "Embers can also cause spotting in advance of the bush fire and provide piloted ignition to building elements". In regard to the 100m limit, RFS (2006) says - "experience from the Canberra 2003 fires suggests that house losses are greatest in the area up to 250 metres from the bush interface. Distances of less than 100 metres are particularly vulnerable to flame contact, radiant heat and ember attack. Hence it is within this distance that efforts should be made to prepare for the onslaught of major bush fire events."

Threat mitigation

Douglas was very clear that both predecessor systems (WMO and AS3959) calculated radiation from the wall of flame. He has assumed the wall of flame was the bushfire front. He said "In both cases this modelling is an estimate of the radiant heat flux which may be received from a bushfire front, relative to a given point. This estimate of radiant heat flux is then used to determine defendable space and the required construction level (BAL)" (Douglas, 2011).

Reduce radiation

The BMO system (as does the NSW RFS system) identifies radiation level as the key threat to be managed to protect the house - "reduce radiant heat on a building … to a level where the building is unlikely to be ignited during the passage of a fire" (PN65). RFS (2006) states "Overall the intention of bush fire protection measures should be to prevent flame contact to a structure, reduce radiant heat to below the ignition thresholds for various elements of a building, to minimise the potential for wind driven embers to cause ignition and reduce the effects of smoke on residents and fire fighters".

How does the wall of flame model reduce radiation? Accepted science says that incident radiation reduces as distance to flame increases, or as the size of radiating surface decreases, or by installing a barrier. The wall of flame model chooses the first method and its mechanism is called defendable space. The wider the defendable space, the lower is the radiation on the house. The second mechanism is ruled out by the model's own definition that the wall of flame is at peak height. The third one is ruled out because it may be not be feasible in most situations.

How does science explain the correlation between reducing radiation and preventing ignition? Science says that reducing radiation load increases the time required for piloted ignition to occur. It delays ignition time. It prevents ignition if the time to ignition is greater than radiation exposure time. Thus, we can deduce that if the BMO's fire front passes over in shorter time than a thermally thick timber can ignite, ignition is prevented. The BMO / AS3959 systems deem the wall of flame lasts 2 minutes, which suggests they believe radiation exposure time is less.

We can refer to the AS3959 testing procedure for verification. BAL 29 allows Appendix F timbers. The AS3959 test for these timbers is done in the lab under exposure of 25kW / sq m for ten minutes in calm conditions. But, the test is for mass loss rate (ie, rate of burning), not for time to ignition. We hope BMO authorities have access to other tests that confirm time to ignition. The authorities were well aware that inappropriate testing was roundly criticised by the Royal Commission.

Fortify the house

The BMO system also incorporates fortification as another mechanism to prevent ignition on the house, called the BAL. It prescribes increasingly fire resistant materials and design criteria as radiation level rises. Thus a BAL 12.5 house has less fire resistance than BAL 40.

The BMO system believes there is equivalence between defendable space and BAL fortification. The same concept applies in NSW RFS. This is applied in cases where the distance between new house and nearest vegetation is fixed, because defendable space is also fixed. For example for forest vegetation on flat land:

- BMO's Table 1 shows defendable space is 40m and BAL 29 has same protection level as 69m and BAL 12.5, and 31m and BAL 40.
- NSW Table 3 shows defendable space is 25m and BAL 29 has same protection level as 48m and BAL 12.5, and 19m and BAL 40. The NSW table allows "less than 19m" for BAL Flame Zone.

The BMO system relies on the theory that narrow defendable space and high BAL rating reduces piloted ignition to the same extent as wide defendable space and a low BAL rating. We hope BMO authorities have access to tests that confirm time to ignition in thermally thick timber is greater than 2 minutes across the BAL range. If they do not, the BAL system is simply hope without credibility.

Summary, so far: The BMO and RFS systems identify the major threat as radiation from wall of flame. They seek to neutralise its effects by managing separation gap and fortifying the house. The two BMO threat mitigation tools that protect the house from the wall of flame threat agents are width of defendable space and fuel reduction within it, and fortification of the house with fire resistant materials according to BAL.

Threat mitigation tools in theory

Defendable space

Defendable space refers to separation gap between flame and house. We can deduce that BMO authors wanted defendable space to have several aims – reduce radiation, prevent flame contact and reduce ember attack. To have an influence on radiation and flame contact, we must assume that this gap is fuel free and specifically, that the wall of flame stops at the edge of the vegetation. When the gap width exceeds the flame stretch, flame contact is prevented on the house. It is well known that when gap width increases, incident radiation reduces. This reduces the potential of auto ignition and it also reduces the level of preheating. BMO authors also believe a wider defendable space protects the house by absorbing more embers from the wall of flame and causing more embers to self extinguish as they cross it.

In regard to ember attack, the inner zone of defendable space aims to "reduce ember attack on the building by reducing the amount of potential fire brands" and the outer zone reduces the wall of flame from crown to ground thereby preventing the building from flame contact, excessive radiant heat and ember attack" (ie, from the wall of flame) (PN65). AN44 Appendix 3 says "compromising defendable space will result in an increased exposure to the effects of heat, flame and ember attack". These beliefs agree with the WMO concept. Defendable space is said to absorb the embers and this protects the house. "The WMO has been designed to reduce dwelling ignition from ember attack rather than direct flame and radiant heat (which are addressed through the Building Code of Australia). The WMO does this by introducing a number of vegetation and siting requirements aimed at increasing setbacks to create enough distance to ensure that a dwelling is likely to be clear of wildfire's ember attack zone". (Buxton, 2009 quotes CFA staff Maughan and Krusel (2005)).

By contrast, some official government documents regard defendable space as simply an area of land around a building where vegetation is modified to reduce the effects of flame contact and radiant heat associated with bushfire (AN44). Its forerunner, the WMO also saw it as an ember absorber and a safe working area for fire fighters because it required access and water supply. The RFS equivalent of BMO defendable space is Asset Protection Zone. Its sub sets are inner protection area, outer protection area and defendable space. Defendable space is defined as a workable area in which firefighters, emergency services personnel, residents and others can undertake property protection after the passage of a bush fire (NSW RFS 2006). It is a surprisingly nebulous concept, not defined by size of location, but it lies somewhere within the IPA "The IPA is critical to providing a defendable space and managing heat intensities at the building surface."

Fire resistance / BAL

We can deduce that BMO identifies thermally thick timbers as vulnerable to piloted and non-piloted ignition if the wall of flame is too close and produces too high radiation. Therefore, BMO specifies fire resistant materials and designs to mitigate potential for ignition by prescribing fire resistant timbers according to calculated incident radiation level = BAL.

BMO uses the AS3959 standards. They have general specifications for maximum size of gaps or vents or openings to prevent ember entry. They have specifications for parts or all of the following areas of the house to protect materials against piloted ignition by auto-ignition or piloted ignition by flame or embers - Subfloors and elevated floors, External walls, Windows and doors, Roof, Veranda and decking. It is a step by step specification, eg, BAL29 allows fire resistant species, based on the belief that they will not ignite in the heat from the wall of flame. As BAL becomes very high, timber is excluded.

AS3959 theory seems to be this - the higher the radiation loading, the less surface area of combustible material is to be exposed, the fewer sites will be available for piloted ignition, and therefore the less chance of ignition occurring.

We can make the following observations about BAL standards:

- Specifications exist for the nominated components. If not nominated, there is no specification. Therefore, BMO assumes that no other combustible cladding or material exists on the house.
- They focus on the house itself, not on the fine or other flammable fuels near or on the house (known as urban fuel)
- They do not distinguish thermally thick from thin, even though time to radiation is very different.
- They assume the specified condition remains forever – never splits / cracks/ shrinks / gets damaged

The following INSET indicates that many flammable elements are not addressed by BMO

INSET

What is flammable on or near a house? Red circles are addressed by BMO

Cladding thermally thick, thermally thin, fine fuel debris build-up in corners and crevices
Entry points for embers joinery gaps, vent gaps, sub floor, open windows and doors, roof gaps,
Ignition sites rough sawn surfaces, cracks, broken or damaged sites, re-entrant corners, ledges
Near a house fine fuel debris, grass, garden beds, shed, nearby house

In summary, AS3959 nominates particular components with specifications of the house but if not nominated, there are no specifications. Thus, one AS3959 key success factor is that all ignitable components on the house are nominated. This is critically important because it does not have specifications for ignitable elements close to the house.

In regard to managing threat of cold ember ignition, BMO requires a minimum BAL of 12.5 if it is within a bushfire prone area, and BAL12.5 has some useful ember prevention specifications. If it is outside the bushfire prone area, it adopts the NSW RFS approach where, if the wall of flame generate less than 12.5 kW / sq m of radiation, BAL is low and the house needs no protection - "Minimal attack from radiant heat and flame due to the distance of the site from the vegetation, although some attack by burning debris is possible. There is insufficient threat to warrant specific construction requirements." NSW RFS (2012). NSW RFS (2006) also stated - "Extensive ember attack can occur beyond 100 metres ahead of a bushfire, however, distances are limited to a maximum of 100 metres for class 1, 2, 3 and Class 4 parts of buildings". Thus, there is no concern about embers coming from more than 100m away.

Threat mitigation tools in practice

Defendable space specifications

Douglas (2011) was the author of BMO's "Table 1". He calculated the inner zone using the same FDI and flame temperature inputs as AS3959 (FDI 100 and 1090^0K). It is almost identical to the NSW RFS (2012) Table 3. He calculated the outer zone using FDI 120 and 1200^0K, the same inputs as WMO. He acknowledged these figures were CFA policy decisions, ie, they have no scientific backing. These figures add an extra 50% distance.

The outer zone specifications require low fuel load, eg, grass height less than 10cm and low density shrub and tree cover. The inner zone requires minimal fuel on the ground, eg, grass less than 5cm and lower density shrub and tree cover.

The perceptive reader will note that the specifications do not deliver a fuel free zone, which raises the question – how does the BMO envisage the wall of flame stops at the edge of "nearest vegetation"? The answer is simply that it assumes the flame will stop. In reality, the low fuel load in the defendable space allows a low flame, up to 1m tall, and it allows fuel bed continuity, which means it can run unrestricted between vegetation and house.

BAL specifications

The said purpose of BAL specifications is to prevent ignition on the house during severe bushfire conditions. One category of timbers in AS3959 is graded by density and the other two categories are graded on resistance to spread rather than ignitability. Tests are done in cone calorimeters under calm conditions. The Royal Commission was critical that tests did not match the windy conditions of a bushfire, and recommended they be changed. AS3959 tests are done on thermally thick timber, and BAL is based in them. AS3959 overlooks thermally thin materials, but Paper 3A shows that they ignite much more rapidly than thermally thick materials.

The minimum BAL in bushfire prone areas is 12.5 by law. If the wall of flame is distant, BAL remains at 12.5. BAL 12.5 is useful against ember entry because it requires gaps and vents to be less than 2 – 3mm. It allows non resistant timber on most of the cladding. It assumes cladding will not ignite readily because it is not preheated. The only way to increase BAL is if the wall of flame is closer. Higher BAL reduces the amount of non resistant and fragile materials.

Calculation process

Defendable space calculations

Typically, defendable space is deemed as the distance between the vegetation and the house site. Because "nearest vegetation" generates the artificial wall of flame, defendable space is the distance between the wall of flame and the house site.

BAL calculations

The nearest vegetation is deemed to generate a wall of flame, which generates incident radiation onto the house, based on a calculated height and a distance equal to the width of defendable space. This radiation load determines the BAL. The wall of flame is deemed to be 100m wide and have a deemed duration of 2 minutes. It is assumed to be a thick continuous flame with emissivity of 0.95. Douglas (2011) assumed the face of the wall of flame to be thick and continuous, yet he wrote this: "forest flames have significant discontinuities, and have highly variable flame temperatures across the fire face. This is exaggerated when flame geometry is based on tree canopy in addition to litter/understorey fuels".

The height of wall of flame is calculated by a series of equations from AS3959 based on vegetation type as defined in AS3959. The equations calculate rate of spread adjusted for slope, which then calculates Byram’s fire line intensity, which then calculates flame length, which is adjusted for tilt to determine flame height. Douglas (2011) said “The objective of rate of spread modelling is to provide the inputs required for fire intensity calculation and flame length modelling”.

AS3959 equations for forest and woodland
Calculate rate of spread with **R = 0.0012 *FDI*W**,
Adjust rate of spread for slope with **Rslope = R X exp (0.069 x slope)**
Calculate flame length with Z **= (13 x Rslope + 0.24 x W) / 2**
Calculate radiation from flame length or height using View Factor equations

AS3959 equations for shrub and scrub
Calculate rate of spread **R = 0.023 x wind^1.21 x veg height^0.54**
Adjust rate of spread for slope with **Rslope = R X exp (0.069 x slope)**
Calculate Byram’s Fireline Intensity - **BFI = H x fuel load x Rslope**
Calculate flame length with **Lf = 0.0775 x BFI^0.46**
Calculate radiation from flame length or height using View Factor equations

Paper 7C finds the process of determining flame length / height from rate of spread has no scientific support, and regards the equations as scientifically invalid or inappropriate. Appendix 1 of Paper 7C shows that the equations have an undisclosed built in safety factor ranging from underestimated to 50 – 100 times actual radiation load.

DISCUSSION

Wall of flame model per se

This section clarifies what the model identifies as the threats, how it treats them and assesses how effective the treatments are.

Identified threats and their mitigation

The BMO system / wall of flame model identifies piloted ignition as the threat to the house. It believes the wall of flame provides the heat and the ignition sources for “hot ignition”. It is treated by the rather risky strategy of delaying piloted ignition time, either by reducing radiation or using fire resistant materials.

We have deduced that there are four ignition mechanisms in the wall of flame model. The model’s threat mitigation strategy ignores the “cold ignition” mechanism, but addresses the three that are associated with “hot ignition”. The model proposes that if radiation load onto the house is lower, the time for piloted ignition is longer, and if it exceeds the duration of radiation exposure from the fire front (wall of flame - deemed as 2 minutes), no ignition will occur. The key success factor for the wall of flame model can be called ***ignition delay theory***.

This ***ignition delay theory*** relies on the assumption that wall of flame duration is not more than 2 minutes. If the patch of nearest vegetation is isolated, we can presume from Project Vesta (2007) findings that residence time of a flash flame is likely to be 30 seconds. But if the house is surrounded by burning forest, (as the planning models originally envisaged) the heat persists much longer than 2 minutes. The BMO concept borrows from AS3959, whose aim is to protect the house from ignition while the fire front passes. The Royal Commission (VBRC,

2010) reported that the expected time for the fire front to pass is 15 minutes, but Black Saturday fires were found to take much longer.

Thus the success of the ***ignition delay theory*** depends on the duration of heat source. The above observations suggest that prediction of heat duration from a fire front is not readily quantified, which makes the wall of flame model / ignition delay theory a high risk strategy.

How does the wall of flame model propose to reduce radiation load? It is well known that a wider gap reduces radiation load. If the gap can be increased by vegetation clearance, radiation can be reduced as required. This allows ***ignition delay theory*** to operate effectively.

But in most situations, the gap cannot be changed because the distance between nearest vegetation and house is fixed. Therefore, the model is forced to deal with higher radiation, which it does by prescribing a higher level of fire resistant materials via the BAL specifications. The model assumes that ***ignition delay theory*** works as protectively with fire resistant timbers, eg, BAL 29 specified timbers do not ignite during the passage of a fire front.

We have already observed that AS3959 timber categories are based on rate of burning and not on ignitability (also see Paper 3C). The assumption that fire resistance and wood ignitability are equivalent has not been established by AS3959 or BMO authors. Data based on an assumption technically qualifies as unreliable. Yet, research data may be available. Eg, it is known that wood products can be treated with fire retardants to improve their fire performance, eg, delayed ignition, reduced heat release rate, and slower spread of flames (Forest Products Laboratory. 2010). This means the government has allowed unreliable AS3959 specifications for timbers to be used in government policy. Before incorporation, specific verifiable ignitability tests should have been done to match bushfire conditions.

Based on such unreliable data, BMO's Table 1 assumes a narrow defendable space and a high BAL rating is as protective as a wider defendable space and a low BAL rating. But this is not supported by CFA: "If a building is within close proximity to vegetation, the flame length from the burning vegetation will directly impact on the building. Nearly 20% of house loss in bushfires occurs where houses are located directly adjacent to bushland. It is extremely difficult to effectively design a building that can withstand the conditions of flames directly impacting upon it. Designing to flame zone is very costly with uncertain outcomes" (CFA, 2012).

The focus on thermally thick timbers means BMO overlooks thermally thin timbers and fine fuel in debris on or near the house, whose piloted ignition rate is much faster. The model assumes thermally thick timbers are ignited by the wall of flame itself or its embers, and nothing else. It overlooks the threat of other sources of ignition. It overlooks the threat of "cold ignition" by embers. However, these oversights combine to generate other overlooked sources of ignition that can ignite the thermally thick timbers of the house.

So far, the BMO / wall of flame model can be seen as a risky concept that identifies surprisingly few of the potential ignition threats to the house and addresses the identified ones with unreliable tools. Its whole success to date depends on one thing – that the wall of flame keeps its distance from the house. This is controlled by the BMO specifications for defendable space. What are the BMO specifications? They allow continuous flammable fuel between flame and house. But we can see that this totally undermines the BMO's / wall of flame model's aim. It means the wall of BMO / flame model denies the house of reliable protection.

Calculation process

There are two issues of concern within the calculation process, the variable and often excessive built in safety factor and the government's acceptance of seriously misrepresented science.

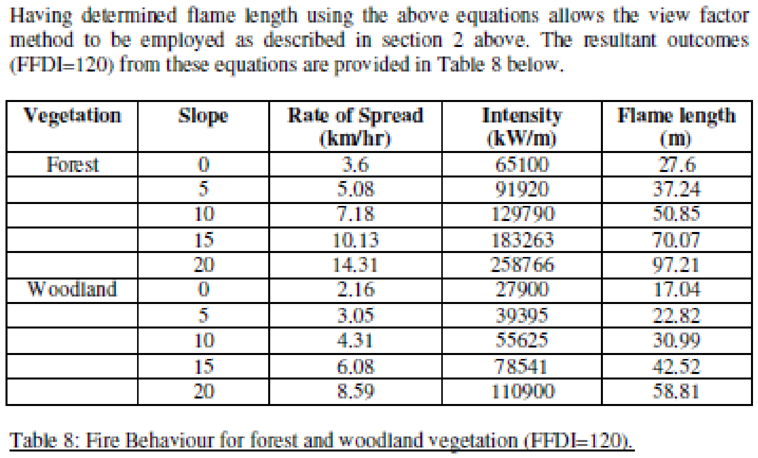
The BAL calculation process for the BMO system is based on the narrative of the new house in the middle of a long unburnt forest or other vegetation and is protected by defendable space. The fire front makes a bee line for the house and the radiation load is calculated using a wide flame face (100m), the tallest possible flame height and a thick flame. Using peak flame height therefore builds in a safety factor for the house. As Paper 7C suggests, this scenario may occur rarely, but the common scenario is a patch of remnant forest that is narrower than 100m and may not even be part of the fire front, eg, it might be up hill or down wind of the actual fire front. But the calculation process remains unchanged. This means the built in safety factor can increase enormously, but it is not quantified. Appendix 1 of Paper 7C shows that the standard flame length for each vegetation type has an inconsistent and very variable safety factor. It occasionally underestimates the radiation in each of the AS3959 sub types, but most often overestimates considerably, even up to 50 – 100 times. The unstated BMO assumption is that a large and undisclosed / unquantified safety factor is a good thing for building design. We disagree, and believe actual flame height should have been used to calculate radiation, and a know safety factor added later.

The use of AS3959 equations seems to be unnecessary for the purpose of the BMO. Presumably their purpose is to achieve some consistency for each vegetation type. They could have deemed the flame height for each vegetation type and enshrined it as law. (Appendix 1 of Paper 7C shows that none of the AS3959 diagrams reproduce the calculated flame heights.) Instead, the government has implemented policy based on calculations with equations that were invalid and inappropriate and were scientifically misused and extrapolated. This is very disappointing. When the Royal Commission asked "to ensure that the mapping used to determine building and planning controls is based on the best available science", it probably assumed the best available science would also be used in the planning and building controls.

We wish to highlight the work of one collaborator in the BMO amalgamation process. He presented some outlandish data and some disappointing misquotes in his report. Our concern is not so much his work, but the fact that his government supervisors accepted it as normal and scientific and then incorporated it into government policy that has forced new house builders to pay for expensive fire retardant materials that were not necessary. It heightens our concern that the BMO amalgamation occurred without scrutiny, checks and due diligence.

Outlandish data

Douglas (2011) presented the following Table of calculated rates of spread and flame lengths for forest and woodland by slope. They were extraordinarily high and yet they were presented as if they were normal or possible. They purported to derive from the McArthur Meter but they seriously exceeded it. The McArthur Meter data peaks at 14m flame height, which means the figures have no credibility. It appears that even Douglas (2011) realised this - "A limitation of the McArthur's formula though is that it is appropriate for lower intensity fires not involving the canopy."



Having determined flame length using the above equations allows the view factor method to be employed as described in section 2 above. The resultant outcomes (FFDI=120) from these equations are provided in Table 8 below.

Vegetation	Slope	Rate of Spread (km/hr)	Intensity (kW/m)	Flame length (m)
Forest	0	3.6	65100	27.6
	5	5.08	91920	37.24
	10	7.18	129790	50.85
	15	10.13	183263	70.07
	20	14.31	258766	97.21
Woodland	0	2.16	27900	17.04
	5	3.05	39395	22.82
	10	4.31	55625	30.99
	15	6.08	78541	42.52
	20	8.59	110900	58.81

Table 8: Fire Behaviour for forest and woodland vegetation (FFDI=120).

Douglas's (2011) Table 8 also showed that rate of spread doubled as slope increased by 10 degrees and that therefore flame length also doubled. He did not check if linking slope to flame length to rate of spread had scientific backing. In fact, it has no relation to McArthur Meter, which makes allowance for rate of spread in a litter bed to double. Paper 7C explains how McArthur knew there was a complex relationship between rate of spread and flame height and that his research was based on litter bed layer, not elevated layers. We regard this table as a misrepresentation of valid science.

Disappointing misquotes

Douglas (2011) said "the Commission's Report recommended a review of the 100 metre assessment zone criteria used in both AS3959-2009 and the current WMO (see p.223, VBRC, Vol.2). But this is a significant misquote. The Commission said it "supports the view that the 100-metre margin should be reviewed", but it was referring to the ember buffer margin around mapped WMO areas, not to site assessment systems.

Douglas (2011) says "the Commission's Report has identified that the current maximum distances used in AS3959-2009, are based on an 80-85% loss of dwellings (and other buildings) within a 100 metre distance from the fire front, principally due to the impact of ember attack". But this is a combination of several misquotes. The Royal Commission was not referring to AS3959 but to the buffer strip around mapped WMO areas. It did not say "from the fire front", it said "from vegetation". If 80 – 85% loss of dwellings means 80-85% of houses were destroyed, it is a misquote of the Ahern and Chladlil study, which found a cumulative total of 80 – 85% of destroyed houses were within 100m of vegetation (see Paper 6B). The actual Royal Commission quote was as follows - "The distance of 100 metres appears to have been chosen initially as a convenient margin and was retained when a 1999 study by Ahern and Chladil found that 85 per cent of houses were destroyed within 100 metres of vegetation".

Douglas (2011) said "It has been identified that a level of protection to 90-95% of dwellings can be achieved at a distance of 140-150 metres (Ahern & Chladil, 1999; Douglas et al, 2009)". This misquote is a reference to Ahern and Chladil's chart where they show a cumulative total of 90 – 95% of destroyed houses were within 140 - 150m of vegetation (see Paper 6B). It is an attempt to promote that application of the BMO system out as far as 140 – 150m will be so effective that 90-95% of houses will be protected. It assumes that the BMO system will protect houses where it is applied.

Summary of wall of flame per se

The BMO / wall of flame model identifies piloted ignition as the threat and treats it using a risky strategy of ignition delay theory, ie, it wants the time to ignition on thermally thick timbers to be greater than the duration of exposure to radiation from the wall of flame. It is an even more risky concept because the treatment relies on unreliable AS3959 tools, eg, timber materials should have known times to ignition under each BAL, but they are tested for burning rate only. As BAL becomes high, timber is excluded, but this has to be seen in perspective. If a building element is not nominated, there is no specification, and AS3959 assumes that no other combustible cladding or flammable material exists on or near the house.

The whole success of the wall of flame's risky radiation management model depends on the wall of flame keeping a distance from the house. This is controlled by the BMO specifications for defendable space. But they allow continuous flammable fuel between flame and house, which means the effectiveness of the model is fatally compromised.

The major concern about the calculation process and equations is not that they are invalid and inappropriate, but that the government allows their use in policy that may requires citizens to pay unjustifiable and unnecessary extra costs, and yet at they same time implies it uses the best science.

Is wall of flame model relevant to actual bushfire threat?

The wall of flame model identifies the danger to the house as the nearest vegetation, which generates a wall of flame, which is regarded as the fire front (Douglas, 2011). Yet readily available research shows there are two sources of danger to the house, the moving fire front and the urban flame, both of which generate flame and embers that cause substantial damage (See Paper 3A). If the wall of flame does not fall into these categories, it does not rate as a cause of house loss. The following INSET lists four potential causes of house loss and their relative loss rates.

INSET
Source of danger / potential causes of house loss in severe bushfire attack

Moving fire front wall of flame, embers ← Causes 80 – 90% of house loss

Urban flame wall of flame, embers ← Causes 10 – 20% of house loss

Flame in defendable space running flame

BMO's wall of flame If not up wind or down hill from house site - not a threat

The fire front is a moving flame that may be one of numerous separate spot fires, or may be a large single front. Each fire front moves through continuous fuel bed in the direction of wind or under the influence of slope. It generates flame and embers. Often the flame does not reach the house, but its embers do if the house is downwind. Ember attack is known to cause more than 80% of house loss. Urban flame burns in any flammable fuel that is within a few metres of the house. It generates flame and embers very close to the house. Urban fuel is ignited by embers and its flame and embers can cause up to 20% of house loss.

If readily available research has shown that radiation from the fire front is a very minor cause of house loss (See Paper 3A), why does the BMO system believe that radiation from the artificial wall of flame is the cause of damage to the house? It relies on three assumptions, which seem to verge on dogma. It assumes proximity of vegetation measures risk of house loss, ie, closer vegetation means higher risk. It assumes this vegetation inevitably generates a wall of flame of maximum height. It assumes this wall of flame is the fire front advancing onto the house. The BMO and its parents the WMO and AS3959 are based on this concept, as is its grandparent, the NSW RFS system. They all base their mitigation treatments on radiation level, ie, defendable space and building fortification.

But all three assumptions fail to pass scrutiny. (1) Paper 6B shows that proximity to vegetation and house loss is a coincidental correlation, not a causal one. For example, X% of houses are destroyed within Y m of vegetation because X% of houses occur within Y m of vegetation. (2) The automatic maximum flame excludes the feasible option that the vegetation’s owner can reduce bushfire hazard. (3) Papers 7A, 7B and 7C show that the wall of flame in nearby vegetation uncommonly qualifies as the fire front because it is neither up wind nor down slope of the house site.

We conclude that the BMO system / wall of flame model has no relevance to actual causes of house loss. It fails the damage minimisation theory test because the wrong causal elements are identified for treatment. Its focus on treatment of artificial radiation level is puzzling because radiation is known to be a minor cause of house loss. The disregard by BMO system / wall of flame model of “cold ignition” by embers is astounding because it is well known as the predominant cause of house loss. “Research conducted after major fires indicate that up to 80% of house losses are due to ember attack” (CFA, 2012). Yet the same authorities advise the public that “the planning system addresses ember attack through the requirement of construction standards, defendable space and vegetation management” (CFA, 2012).

If it has no relevance to causes of house loss, its treatments are also irrelevant. This raises two issues. If house builders believe the BAL treatments deliver lower bushfire risk, they are being misled by government. If people pay extra for BAL treatments that have no impact, they are also being misled by government.

Is wall of flame model relevant to protection of community?

NO. Consider this litmus test. If the nearest vegetation was identified as a threat to the community, surely a responsible action would be to alert the neighbours to protect existing houses. Do the authorities alert surrounding existing house owners to this newly discovered danger? No. Do the authorities request the owner of the hazard of the threat and order him to reduce the risk, as their Act allows? No. But ample case law exists to show that if a person owns a hazard on his property, it is his responsibility to prevent harm to the community.

Is the BMO system legally fair?

The BMO and its predecessors identify a community danger (nearby vegetation) and a victim (new house owner) but they put the onus of protection onto the victim. This seems to be because all planning systems assume the wall of flame is a natural disaster - inevitable and unmanageable. The planning scheme actually groups bushfires with erosion and flooding. Paper 8A shows that managing the causal elements of a natural disaster is impossible, and the only practical response to mitigate damage is to fortify the house. The authorities seem to have applied this model to bushfires, whereby the new house owner is asked to fortify the house against the wall of flame.

Yet Paper 8A also shows that bushfire flame is not a natural disaster because its critical causal elements are manageable. When authorities recognise this, they will realise that the owner of the “nearest vegetation” is responsible for the condition of that vegetation. If the nearest vegetation or any other area is truly a threat to the victim, the authorities can apply the spirit of the CFA Act and reduce the hazard and thereby protect the victim.

If the authorities acknowledge that common law requires the owner of a danger to take responsibility to protect the community, they will realise they have another management option – require the owner of the land to mitigate the danger at his cost to protect the new house and indeed the entire community. When authorities realise this, they have more effective means of providing community with lasting protection against house loss in severe bushfires.

CONCLUSION

The BMO system and its predecessors are based on the wall of flame model. The analysis of the model per se reveals the following observations:

- The success of the wall of flame model relies on the ***ignition delay theory***, which is very site specific, is high risk and will fail on many sites
- The fire resistance specifications are not reliably scientific
- The model provides protection against a limited range of ignition mechanisms
- The model disregards the threat of "cold ignition" by embers

In the final analysis, the success of the wall of flame model relies on keeping the wall of flame at a distance from the house. The expectation is a fuel free barrier. But BMO does not understand this need, and allows defendable space to be a continuous bed of flammable fuel. Thus, the BMO concept of preventing hot ignition by auto ignition and piloted ignition by flame contact and embers is fatally compromised by its own specifications.

The use of invalid and inappropriate equations to determine flame height and radiation levels is castigated for two reasons. Firstly, the calculated built in safety margins are inconsistent and range from underestimates to excessive, eg, 50 to 100 times. Secondly, the authorities have allowed government policy to be based on junk science.

The wall of flame model is clearly seen to have no relevance to actual cause of house loss. It chooses to target radiation as a danger, yet radiation is a very minor cause of house loss, and it chooses to disregard "cold ignition" by ember attack from the moving flame, yet it is the predominant cause of house loss. Furthermore, BMO regards the wall of flame as the fire front, even though in most cases it is neither upwind nor down slope of the house.

The question of legal fairness is raised. The BMO identifies a danger (the nearest vegetation which generates the wall of flame) and a victim (the new house owner), yet it requires the victim to fortify against the danger. The rationale is presumably because bushfires are regarded as natural disasters by planning authorities. In real life, the opposite is true because most of the causal threat elements are manageable by the owner of the nearest vegetation. When authorities realise this, they have more effective means of providing community with lasting protection against house loss in bushfires.

Nevertheless, we can argue long and hard that the choice of equations has no scientific credibility or that the BMO process does not deliver what the Royal Commission wanted, but in reality, the government can deem what it wants to. It has already deemed into law that all BPA must be minimum BAL 12.5. This assumes the government believes BAL 12.5 is usefully protective against bushfires. The government could deem that any given area should have minimum BAL, eg, Dandenongs will be a blanket BAL 29, perhaps include an opt out process, eg, property owner has onus to prove otherwise.

By specifying, it can be seen as applying a safety net, similar to legislating for seat belts and licence tests for road safety. Nevertheless, whatever the government deems as a prescription, has to have some evidence or scientific truth. Otherwise, people are being asked to pay extra for non-existent protection or people assume there is protection when there is none. This makes the government appear false and misleading. This paper has shown that the BMO falls into the false and misleading category because it uses the wall of flame model.

Can two wrongs make a right? The continued support of the flawed BMO system by the authorities is of great concern to us.

Glossary of acronyms

BMO	Bushfire Management Overlay	RFS	Rural Fire Service
WMO	Wildfire Management Overlay	BAL	Bushfire Attack Level
AS3959	Australian Standard 3959	FDI	Fire Danger Index
CFA	Country Fire Authority		

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APPENDIX 1

DOES THE AMALGAMATED BMO SYSTEM ACHIEVE WHAT THE ROYAL COMMISSION WANTED?

Official documents misleadingly suggested that the Royal Commission either wanted or sanctioned the amalgamation. Part 1 asks this question - Does the amalgamated system achieve what the Royal Commission wanted? Part 2 explains why BFI is not suitable as measure of bushfire risk or threat and proposes an alternative system of bushfire risk assessment and management.

PART 1

DOES THE AMALGAMATED SYSTEM ACHIEVE WHAT THE ROYAL COMMISSION WANTED?

Government departments give the impression that the Royal Commission is the authority for the change of policy to the amalgamated BMO and associated Table 1. Eg, "New defendable space requirements have been developed in response to the 2009 Victorian Bushfires Royal Commission" (AN44). But this is a misrepresentation of the facts because the system was designed by the bureaucracy. This section takes a step back and looks at what the Royal Commission wanted, and what the government departments delivered, and finds they are different. The Royal Commission made some specific requests as follows, but they were not delivered.

What the royal commission wanted:

(1) The Royal Commission's oft repeated request was that new development should be discouraged in highest risk areas (eg, Recommendations 39 and 40). To achieve this required a mapping system that differentiates risk levels. Thus the Royal Commission wanted a mapping system with graduated risk areas based on the improved mapping criteria.

(2) The Commission was very critical of the planning scheme framework (WMO), but wanted it to be improved (eg, Recommendations 39, 40). It said "the WMO has serious limitations and should be revised and strengthened". It urged a name change – that "Wildfire Management Overlay be renamed the Bushfire-prone Overlay and that it be comprehensively reviewed in order to redress the shortcomings detailed in Table 6.2"

(3) The Commission was very critical of the building scheme framework (AS3959) but wanted substantial improvements (Recommendations 47, 48, 49). It said that AS3959 "building standards do not and cannot guarantee a home will not burn down". The Commission also notes that "even if a house is built to the relevant building standard, this standard is not designed to ensure survivability without active defence".

(4) The Commission was told the departments were exploring a single site assessment method for assessing bushfire risk for building purposes and planning purposes on a new building site. It urged them to "finalise the alignment of site-assessment methods for planning and building purposes, taking into account bushfire risk to human safety as well as to property" (Recommendation 37)

What government departments delivered instead:

They delivered a mapping system showing what they describe as "bushfire hazard" for vegetation types that still exclude grass areas. They specifically say it is not a map of risk. The mapping system has one level of hazard that is a rather low level. The measure of hazard is Byram's fireline intensity (BFI), which can be shown to be an inappropriate measure of fire behaviour (see next section in this Appendix). They combined (2), (3) and (4) and applied the AS3969 site assessment method to WMO and amalgamated the defendable space tables of the WMO and the BAL calculation tables of AS3959 into a single tabulation – "Table 1"- a joint tabulation of defendable space and BAL, which has now become the centrepiece of a new planning system called the Bushfire Management Overlay – BMO.

Does the amalgamated system achieve what the Royal Commission wanted?

Does the new system deliver the major Royal Commission request that new development be discouraged in highest risk areas (Recommendations 39 and 40)? The answer is NO.

Firstly, there is no map of bushfire risk areas or grading of risk levels. The government departments delivered a mapping system showing what they describe as bushfire hazard for vegetation types that still exclude grass areas. They specifically say it is not a map of risk. The BPA mapping system has one level of hazard that is a rather low level (AN46). Thus the mapping system precludes delivery of Recommendations 39 and 40.

Secondly, the new system does not deal with actual bushfire risk issues at all. It deems what risk is and it deems what the treatment will be to reduce that risk.
AN46 explains how BMO deals with hazard and risk:
1. The BMO map (now the BPA map) identifies bushfire hazard areas that need a planning permit.
2. A planning permit application includes a site specific bushfire hazard assessment
3. A planning permit application includes a risk assessment, which is an explanation of how it meets Clause 52.47 criteria.

We observe that the major performance guidelines in Clause 52.47 are the width of defendable space and BAL from "Table 1". "Table 1" assumptions are the same as WMO and AS3959, ie, that risk level is correlated with the distance between nearby vegetation and the house site and is quantified by radiation from the wall of flame in the nearby vegetation. This means the BMO process defines risk level by distance to nearby vegetation and deems that risk is reduced to an acceptable level by the defendable space and BAL combinations of "Table 1". This definition of risk is not consistent with the body of the Royal Commission's report, which includes the following concepts of risk - risk of bushfire occurrence, risk of damage, risk to peoples' safety and risk caused by vegetation hazard. But BMO and "Table 1" do not address any of these.

We also point out that if the nearby vegetation is NOT a threat to the new house, the "Table 1" provisions are treating the wrong threat. The real threat has not been neutralised.

Conclusion:

The amalgamated BMO prevents delivery of Recommendations 39 and 40, thus preventing delivery of what the Royal Commission wanted.

PART 2
WHY BYRAM'S FIRELINE INTENSITY (BFI) IS NOT SUITABLE FOR MAPPING BUSHFIRE HAZARD OR RISK

Background

One of the core concerns of the Royal Commission was to develop a bushfire risk map of different risk levels and to discourage new building and developments in highest risk areas. To do so required a central point of expertise in mapping bushfire risk. At that time, the CFA was coordinating map maker for WMO. The CFA used the data base of DSE (now DEPI) identify where tree cover occurred. After ground checking, a map of high potential fire intensity was prepared. Fire intensity was calculated using Byram's fireline intensity equation. The CFA regarded WMO areas as the highest risk areas. The Royal Commission wanted a broader measure of risk rather than just forest cover and wanted a more suitable department to coordinate it.

Now DEPI does the centralised mapping. It uses its vegetation data base and defines maximum fuel loads for each and calculates Byram's fireline intensity equation for each area. Although the method and map are very similar to the CFA method, authorities now call it a bushfire hazard map, not a map of bushfire risk (AN46). AN46 defines hazard as "the specific source of damage or harm". It defines risk as the chance of harm if exposed to the hazard. Thus the whole basis of the Royal Commission's saving plan is missing. There is no risk mapping to limit new house construction in highest risk areas.

[As an aside, the Victorian Risk Register purports to map risk for the municipal fire management planning process. It is based on the risk matrix in ISO 31000, which has two criteria, likelihood and consequence. The risk matrix concept may be theoretically useful at statewide level, but is totally inappropriate for managing the two simple bushfire threats on a property or within a shire – flame and embers. See Papers 8A and 8B. But it is now another source of confusion].

Thus:

- The Royal Commission said it wanted to discourage house construction in highest risk areas.
- But there is no map that specifies risk level
- The BPA map is a fire hazard map, not a fire risk map.
- Therefore the Royal Commission's reasonable wish has been defeated.

What is BFI?

BFI is average heat release rate (HRR) over unit depth of a long flame front (Byram, 1959). It is best understood by this equation.

BFI = H x w/t x d

Where H = heat content, usually 18,000 kJ / sec / sq m, w/t is average mass loss rate per sq m, which is more or less constant on a given fuel bed in severe weather, and d = depth of the fire front. BFI is a theoretical concept. It cannot be measured. It is the average HRR per sq m, averaged over the entire depth along a 1m wide strip of the fire front.

Because flame depth is proportional to wind speed, depth is the largest source of variation in the equation. For a given fuel bed type, a worst case weather day with 45kph wind will have a constant depth, therefore a constant BFI. A different fuel type will have a different depth and therefore different BFI. Refer to Figure 1. Therefore BFI is really a measure of flame depth for a given fuel type, which increases in proportion to wind speed.

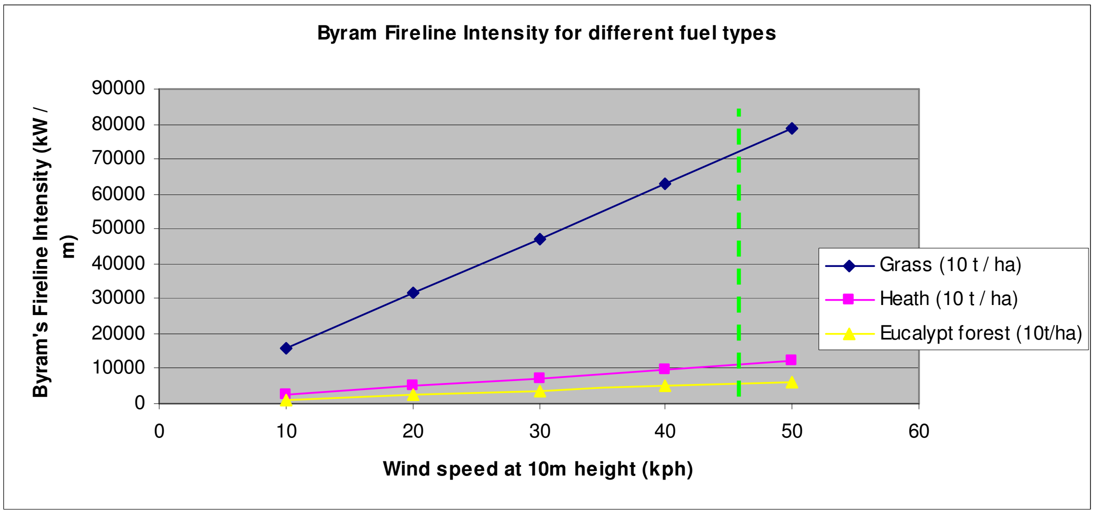

Figure 1 BFI for different fuel types with the same fuel loads consumed during the flash flame phase on a worst case weather day. Where the green line intersects is the value that goes on the BPA map.

Greater flame depth means greater uplift flow into the plume, which helps explain why Byram developed BFI. He was researching how to predict blow up fire weather days. He found that when the ratio of vertical power of the fire to lateral power of the wind at 330m was less than 1, the fire is wind driven, but the transition to plume driven occurred when the ratio is 1. Power of the fire was directly related to BFI and power of the wind was correlated with the cube of [wind speed less speed of fire]. BFI is the "rate at which the line (of fire) gives up heat to the atmosphere per unit length of (fire)" (Nelson 1993)

Byram was also working with actual fires. He changed the units to make it the familiar BFI = H x W x R, and sought to explain it by relating it to flame length. His example was a low intensity fire in a pine litter bed. He said the flame length equation did not apply to crown fire in that pine forest. He also said the correct interpretation of W was fuel load consumed in the flash flame phase.

Recent research in Australia found that in a litter bed, the moving flash flame runs across the surface and burns only the top 15-20cm (= 5 – 10 t / ha) (Project Vesta, 2007). In 1999, Neil Burrows showed that consumed fuel might be ¼ of the total fine fuel load. The flame in grass and heath fuel beds tends to consume total fine fuel load.

Thus, BFI in a given fuel type (ie, constant H and W) is proportional to rate of spread, which, on a severe weather day means BFI is proportional to wind speed. Wind speed is also proportional to flame depth.

The calculations have no obvious meaning with regard to fire behaviour. Flame length may increase with wind speed, but flame height often stays much the same at higher wind speeds. Radiation is calculated from flame height by the view factor method (Douglas, 2011), which means radiation levels tend not to increase in higher winds. Therefore the calculations have no obvious meaning with regard to fire behaviour risk or threat level:

Worldwide application of BFI

Byram's flame length equation was specific for a litter bed fire in a pine plantation in USA, and it was not applicable to crown fires. But it has been misquoted and misapplied around the world, much to the chagrin of Byram himself (M. Alexander pers comm).

BFI incorporates several factors of the fire environment into a single number useful in both wildfire suppression and prescribed burning, eg, it has been correlated with the likelihood of crown fire initiation and crown fire scorch and as a measure of post-fire tree mortality (Alexander and Cruz (2012a). Other uses have been noted as correlation with fire break effectiveness in grass fires, with difficulty of suppression and with maximum flame height (O'Bryan, 2005). Australian States appear to be unique in applying BFI to quantify bushfire hazard or risk.

Correlation with house destruction was attempted, but unsuccessfully. In the Ash Wednesday fires, Wilson and Ferguson (1984) reported "houses were exposed to fires of intensity ranging from 60 000 kW/m, where the fire entered from the uncleared forest on the western edge of town, down to about 500 kW/m within some other parts of the town", but they found no clear correlation between BFI and house loss or deaths. They calculated BFI 60,000 using estimated fuel load of 21 t / ha and averaged rate of spread of 6kph. Both figures can be regarded as excessive, fuel load because of Project Vesta findings about fuel consumption of the moving flame being much less and rate of spread because they confused ember leap frog rate with line of flame spread rate, which at 10pm would have been less than 1kph. Wilson (1988) later developed a guide for probability of house loss, with BFI as one of several inputs. It was doomed to fail because BFI is a measure of the line of fire itself. It is not next to the fire or near it. The fuel load is within the line of fire and the rate of spread is the fire itself. If the line of fire crosses the property, and any part of the house site itself has no fuel, its BFI is zero. If a garden bed is near the house, it is a stationary flame, which means rate of spread is technically zero, therefore BFI is zero. Fuel load cannot be averaged to estimate a BFI. That is an unauthorised extrapolation of Byram's work.

Alexander and Cruz (2012a) quote Cheney's 1990 conclusion that "Byram's fireline intensity is useful to quantify certain flame characteristics and to correlate with fire effects but **should not be used to compare fires in fuel types which are structurally very different**"

Byram (1959) used flame length in a low intensity litter bed fire of a pine forest in southern USA to describe what BFI meant in visual terms. His equation has now become famous
Lf = 0.0775 x BFI^0.46
He said this equation is better suited to low intensity fires than high, and was not applicable to crown fires in pine forest. Since then some researchers have said it is applicable to other fires, but Alexander and Cruz (2102a) found that "subsequent evaluations based on experimental fires conducted in the field and laboratory have shown both close agreement and considerable deviation". They also said its appropriate application is to surface heading fires.

We need to say two things about this equation. (1) Despite what many people have come to believe, flame length is coincidentally correlated to BFI, not causally. This can be readily explained because in a given fuel type, BFI is proportional to rate of spread, and there is no causal correlation between rate of spread and flame height or length. Thus in the charts below, we can use rate of spread as a proxy for BFI on the x-axis. (2) There is a well documented causal linkage between **peak** heat release rate and flame length. There can never be one between BFI and flame length because, as we described above, BFI is the average of an average HRR, and there is no correlation between average HRR and peak HRR.

Alexander and Cruz (2012a and 2012b) have become very concerned that the BFI equation has now come to be viewed as universally applicable to anything and everything, 'despite the fact that it was developed from a field study in a single fuel type'. They state firmly that "treating Byram's **Lf / BFI model** or its reciprocal as simple generic relationships is **not appropriate**. Application of these models needs to be done more judiciously than has been the case in the past. In this respect, authors should not only document their modelling assumptions but justify their use of specific fire behaviour models".

Alexander and Cruz (2012b) present charts showing that the Lf / BFI equation is anything but universal. They show the results of 19 different research studies where BFI was correlated with flame length for specific fuel types, and none of them correspond exactly to Byram's equation. Some are close, but most are wildly different. Their charts are reproduced below.

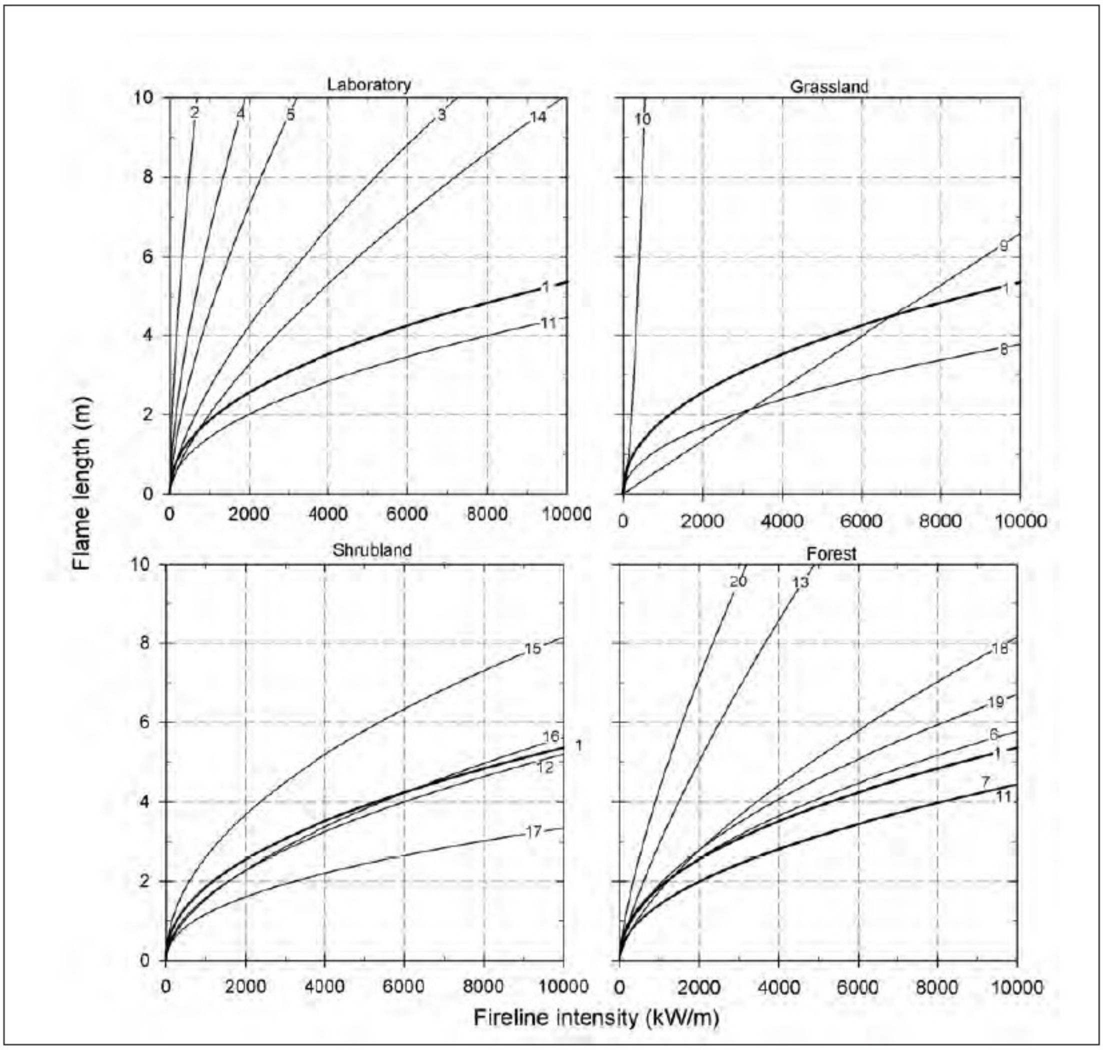

Fig. 3. Graphical representation of Byram's (1959) flame length – fireline intensity relationship for pine litter with grass understorey (represented by curve **1**) and other models (field and laboratory based) reported in the literature by four broad fuelbed types according to the listings given in Alexander and Cruz (2012b): **2** – wood cribs (Fons *et al.* 1963); **3** – wood cribs (Thomas 1963); **4** – lodgepole pine slash (Anderson *et al.* 1966); **5** – Douglas-fir slash (Anderson *et al.* 1966); **6** – general rule of thumb (Newman 1974); **7** – understory fuels (Nelson 1980); **8** – southern USA fuels (Nelson 1980); **9** – grasslands-head fire (Clark 1983); **10** – grasslands-backfire (Clark 1983); **11** – litter and shrubs (Nelson and Adkins 1986); **12** – fynbos shrublands (van Wilgen 1986); **13** – eucalypt forest (Burrows 1994); **14** – excelsior (Weise and Biging 1996); **15** – shrublands (Vega *et al.* 1998); **16** – shrublands (Catchpole *et al.* 1998); **17** – shrublands (Fernandes *et al.* 2000); **18** – 10-m tall jack pine forest-crown fire (Butler *et al.* 2004); **19** – maritime pine-head fire (Fernandes *et al.* 2009); and **20** – maritime pine-backfire (Fernandes *et al.* 2009). All of the relationships, unless otherwise specified, are for heading surface fires. The relationships represented by curves **7** and **11** are very similar but not truly identical.

They stress that "Byram established an empirical relationship between BFI and flame length for surface fires", and their charts are for surface fires, with one exception (see below). Their advice for people wanting to derive flame length from BFI is to either do specific research in for each fuel type or adopt a graph from their charts, but warn that "judgement will be required based on comparisons to fuel properties like size, shape, texture, quantity, and arrangement, including the presence or absence of ladder fuels".

Their one exception was #18 on their chart, a crown fire in forest "where *L* constitutes the free flame above the overstorey tree canopy… When this value is added to the average stand height (10m) it provides for an approximation of the height of the nearly vertical "wall of flame" typically associated with crown fires"

To highlight their point about variability between flame size and BFI, they quote Cheney's 1990 comparison of a 7500kW / m fire in grass and forest (Alexander and Cruz (2012a). The grass fire has a flame height of 4m and runs at 5kph and has 90% chance of being stopped at a 5m wide firebreak. The forest fire has a flame height up to 10m above treetops, runs at 1kph and throws embers up to 1km ahead and will be unstoppable by any means.

They gave another example to highlight differences in fuel type (Alexander and Cruz (2012a). Two fires in a pine forest had the same BFI (76 and 78 kW / sq m), but their flame heights were 0.3m and 3m. The first was in litter fuel bed. The second was in a clump of young fir saplings. There was a slight increase in fuel load consumed by the fire in the second, but a slight reduction in flame speed kept BFI more or less constant. The increased flame height in the second fire was due to increased fuel combustion rate in the elevated fuels, not to BFI.

Does BFI measure or indicate bushfire hazard or risk?

Terminology can be confusing. In common English, hazard is a danger and risk is a chance of danger or damage occurring. However, the words hazard and risk are interchangeable. The forestry definition of bushfire hazard has for a long time been the fuel that enables the bushfire to burn. Thus, the hazard is the potential source of threat and the flame is the threat. We were trained with the simple notion that hazard's flame can generate the risk. If the hazard generated a flame that was within a forest asset or near any asset, it was a source of risk to the asset. If we manage the fuel, we reduce its potential intensity (= flame height), and we then reduce risk of damage. To add to the confusion, there are many types of specific bushfire risk in addition to risk of damage - risk of bushfire incidence, fire behaviour risk, risk of damage to assets, risk of crown scorch, risk of economic loss, risk of suppression success, risk of fire escaping, risk of economic loss, corporate risk, risk of injury or death (eg, O'Bryan 2006). Therefore, terminology and definitions are important because to target a specific risk requires specific threats to be managed, which requires specific hazard management.

Most of the references to hazard in CFA and RFS documents also regard it as the vegetation, even though RFS defines hazard as "the potential severity of a fire" usually measured as peak BFI by using maximum fuel load and rate of spread as the input variables (NSW RFS 2006). Their focus on vegetation runs the strong risk of excluding other hazards. CFA (2012) wants to mitigate bushfire risk, but it does not define risk. This is not helpful in defining which threats to target. RFS defines risk as chance of a bushfire igniting, spreading and causing damage to assets. Technically, this combines two types of risk – risk of fire incidence and risk of damage. In probability protocol, $Pr(A) + Pr(B) = Pr(A) \times Pr(B)$. Thus the probability of two different events occurring is lower than the probability of each one. Furthermore, occurrence and damage are not necessarily linked, eg, fire can occur, but no damage occurs.

Risk of fire occurring is very different from risk of damage occurring. This definition is not helpful in defining which threats to target.

AN46 defines hazard as specific source of damage or harm, and a bushfire hazard has three elements – vegetation, topography and weather. We assume they mean the sources of damage are flame and embers. Thus they regard hazard as the vegetation and its flame, and they measure hazard by peak BFI, which they then map. Their sole focus on vegetation excludes other hazards.

AN46 defines risk as the chance of harm caused by the hazard. But it is not referring to the mapped hazard. It refers to the "nearest vegetation" hazard. Risk of damage by a specific hazard is very different from risk of damage by any hazard. If the nearest vegetation hazard is not the casual hazard, this definition is not helpful in defining which threats to target.

Let's try to keep it simple. We know that in a bushfire, specific sources of harm are flame and embers.
(1) One "hazard" is the flame's size, ie, size of flame face = height x width
Some fuel types have a correlation between BFI and flame size, but some do not (Keeley, 2009). For the former, the correlation between flame length / height and BFI is fuel type specific, and has to be derived individually or empirically for each fuel type. BFI assumes a wide fire front. BFI does not indicate flame face continuity or flame thickness or flame duration or separation gap, all of which are relevant to calculating potential of radiation damage. It must be remembered that BFI in a given fuel bed is primarily an indicator of flame depth as wind speed changes, and flame depth is independent of flame height or length.

(2) The other "hazard" is ember attack. We consider the source of embers and the ignition of embers after their flight. Ember generation potential at the source fuel bed has no correlation with BFI because ember intensity is related to fuel bed type. For an ember generating fuel type, ember supply increases with time since last burnt, and if correlated with fuel load consumed, may be causally linked to BFI. Ember ignition potential in a fuel bed is unrelated to BFI but after ignition, it may generate a flame for which BFI can be calculated. .

Thus, BFI per se is not a reliable indicator of flame size or ember attack intensity or ignition propensity. It is therefore an unreliable measure of AN46's hazard or risk associated with fire behaviour. Whilst BFI is one measure of the aspects of fire energy, it does not provide information about other aspects, eg, heat release rate, temperature, residence time or radiation energy (Keeley, 2009). Many of these aspects have direct relevance to damage potential.

A personal note explains other concerns with BFI as a measure of risk or hazard. During my career, I once flirted with the idea that we could measure risk of damage by BFI and map it. But after a few applications, I realised that BFI had two problems – it was not measurable and it had no relevance to causes of damage, eg, flame size, proximity and duration. If anything it really only measures flame depth which is determined by rate of spread, which is determined by wind speed, ie, in a given fuel type, BFI is just a measure of wind speed. This is not useful when appraising risk of damage. Then the next problem was this - if an asset was next to a vegetation with BFI 10,000, BFI has to be converted into meaningful fire behaviour terms like flame size and proximity (to determine radiation or flame contact threat) and ember potential. So, I concluded it was better to keep things simple and direct, disregard BFI and simply map predicted (ie, not calculated) flame height.

In conclusion, the increasing popularity of BFI in isolation as a primary tool in government policy is very troubling because it is a very minor part of the fire protection picture. For example, it is not a reliable predictor of the causal damaging elements like flame contact, radiation and ember attack. It does not allow for appropriate on site adjustments of fire behaviour due to separation distance, slope and aspect and expected danger wind direction. Nor is it of use in suppression planning, eg, will running flame stop at the edge of vegetation without suppression action or will it throw embers downwind. Finally, it is designed for the moving flame, yet the stationary flame (eg, ignition of urban fuel near the house) is a substantial cause of house loss.

Mapping with BFI

A result will of course be obtained when using the BFI equation. Vegetation mapping typically shows a mosaic of different vegetation types interspersed. Each will have a different BFI, and as we know, BFI cannot be compared between different fuel types. For example, BFI of 10,000 for forest has a different fire behaviour meaning to 10,000 for shrubland that needs to be interpreted before application on a fire hazard or fire risk map. Otherwise a map that aggregates groups of BFI ranges, and then maps the groups, has scant technical meaning. If grassland is excluded from the vegetation map, the most flammable fuel bed of all is being discounted. This devalues the map. If non flammable areas are excluded from the map, the map has little technical value for bushfire protection planning.

AN46 describes how BFI maps bushfire hazard. Maps calculate peak BFI using maximum fuel loads and maximum rates of spread. Presumably this is done to build in a safety factor. That thinking has two drawbacks. The scale of the safety factor is not disclosed (eg, Appendix 1 of Paper 7C indicates the safety factor of the AS3959 vegetation types is very inconsistent and mostly excessive), and it precludes the possibility of managing the fuel load to reduce or eliminate the hazard. Yet, from the point of view of community bushfire protection, hazard reduction is desirable and achievable and legislation and case law even encourage it. We find this entire policy concept very troubling.

Initially, the AN46 described map was in two categories – [4,000 – 30,000] and [> 30,000]. Their map then surrounds these categories with 150m buffer zone, purportedly for ember protection. The lowest category [> 4,000] is not mapped. In recent months, legislation refers only to bushfire prone area, which means the map has one category, [> 4,000]. It does not include grassland areas, yet their BFI can exceed 50,000. It generates a 150m ember buffer around vegetation types that do not generate embers, and it disregards danger wind direction and generates 150m ember buffer in all directions, including up wind. In short, the map is little more than the location of native vegetation and its 150m surrounds. It has no practical relevance to fire protection or fire behaviour.

AN46 includes this quote: "The 2009 Victorian Bushfires Royal Commission recommended that a central point of responsibility for, and with expertise in, mapping bushfire be established to review mapping criteria used in the planning system based on the best available science". The mapping system it describes is a poor replica of the best available science.

In conclusion, Byram's fire line intensity (BFI) is an indirect measure and an unreliable stand-alone indicator of bushfire behaviour or bushfire hazard or risk. It is not based on the best available science, but borders on junk science. Our concern is that the government develops policy on dubious foundations.

ALTERNATIVE APPROACH
WHAT SYSTEM SHOULD BE USED TO IDENTIFY AN AREA AT RISK FROM BUSHFIRE?

In Red Eagle’s view, the entire Country Area of Victoria (including the grasslands) should be regarded as flammable and capable of a running bushfire, except for the many areas that are already non-flammable or bushfire-protected. Thus we have two broad categories for mapping, bushfire-exposed and bushfire-protected. The purpose of mapping is to change the whole approach and encourage the fire agencies to be accountable and protect people and houses on Black Saturday days. The fire agencies will be requested to adopt this measurable goal - to make all communities bushfire-protected against the Black Saturday one-day inferno running flame. It can so easily be done and the powers are within current legislation, but their current plan seems to be inadequate because it maintains status quo, leaving most communities bushfire-exposed. The fire authorities should have an annual rolling target to make X communities bushfire-protected per year. Then put them on a map so we can see their progress.

New houses within bushfire-protected areas would not require any more fortification than BAL 12.5, and their defence focus is on ember protection. If there is vegetation or other hazard near the new house or near existing houses, the authorities make sure it is treated to reduce risk for all houses, according to current legislation.

In bushfire-exposed areas, where vegetation or other hazard is nearby and generates a flame of ember hazard in a severe bushfire attack, the authorities will be required to ensure it is treated to reduce risk for all houses. This means a new house does not require any more fortification than BAL 12.5, and again their defence focus is on ember protection.

This approach will actually achieve the wishes of the Royal Commission, and ensure that new houses will not be built in high risk places because the fire agencies have done their job and reduced risk levels. It will also ensure that all houses are protected from the next Black Saturday.

For more information, see Paper 10.

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