Back to basics approach for bushfire behaviour research

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INTRODUCTION

In recent years, bushfire researchers have successfully muddied the waters of bushfire behaviour science in eucalypt forests. For decades, there was the McArthur model, whose core theory that rate of spread (ROS) is proportional to fuel load has long been disproven (eg, Burrows, 1999), but a loyal band of researchers and fire agency people persists. There is another group of researchers promoting the fire agency funded Project Vesta model to replace McArthur's Meter prediction system. Meanwhile, fire agencies are funding the Bushfire CRC, which is actively promoting a computer model called Phoenix Rapid-fire whose colourful moving graphics uses the disproven McArthur Meter prediction system, complete with fuel load. Undeterred, fire agencies are not only adopting the software, but are also training staff to deliver it. The puzzled bushfire manager asks - So, which system is accurate – McArthur, Vesta or Phoenix, or something else? Hence the need for the back to basics approach of this paper.

The bushfire manager invites the bushfire researcher to adopt the" back to basics" approach. The invitation derives from the Finney et al (2013) plea to focus on the how and why of bushfire theory to explain bushfire behaviour rather than eschew it in the quest to deliver a prediction model using whatever input variables deliver a reasonable match to bushfire ROS observations. A solid theory approach should be a win-win. Both parties need to know that the input variables derive from rock solid science, the bushfire manager because community safety is at stake, the bushfire researcher because trust and relevance come from good theory which comes from rock solid science foundations.

The bushfire manager now offers to re-arm the bushfire researcher with two basic due diligence tests as they walk together though a recent example of important bushfire behaviour research, Project Vesta (2007). On the one hand it has been hailed by research luminaries but on the other hand, it fails to pass the due diligence tests. This is a review with a positive outcome. The data is good, the correlations are good, and its interpretation can be rectified with a simple change of perspective.

Firstly, the plaudits. A contingent of bushfire research luminaries (Cruz et al, 2015) confirmed that the wind speed based Project Vesta model now predicts ROS in forest fires with old fuels run at 12 kph in severe weather at 60 kph wind at open station. This is a huge 20% of wind speed. They reported that its prediction accuracy was acceptable when assessed against well documented bushfires, and then declared the "McArthur Meter Mark V Model has been superseded by Cheney et al. (2012)". They concluded that despite constant usage for over 50 years in planning and operations in high and low intensity fires, McArthur's Meter model "might be an appropriate model to predict wildfire behaviour under relatively mild fire weather conditions in fuel types without significant near-surface and elevated fuel layers".

Next, the due diligence tests. The bushfire manager urges that henceforth all bushfire research be transparently rooted in first principles, that researchers raise the priority of a new data correlation test – UFLCS test (user friendly, logical, common sense), and that all past research to be re-assessed and updated accordingly. For ROS research to meet the first principles approach, two key proofs are essential - nominate what spread mechanism is under study, articulate the core theory that is being tested.

It is axiomatic that …

- Merits of an ROS model cannot be rationally discussed without first clarifying what fire spread mechanism it is designed for.
- Bushfire managers need to know how the bushfire is spreading (= the spread mechanism) before they can apply the prediction tool that the researchers have developed.

DUE DILIGENCE TESTS

First principles approach

A successful fit-for-purpose fire behaviour prediction tool will tick each of the following boxes.

Mechanism Define the spread mechanism under investigation.
[See Appendix for list of ROS mechanisms and the rules of engagement relevant to this Project Vesta review]
The mechanism concept is the assurance that research is rooted in solid scientific principles. The mechanism clarifies how the tall flash flame transfers heat, ignites unburnt fuel and how the flame spreads.
- Heat transfer mechanism and ignition mechanism combine to generate an observable flame spread mechanism
- The heat transfer mechanism and ignition mechanism can be technically described from first principles - from laws of thermodynamics and gas laws to molecular level, to fluid physics, etc.
- Flame spread mechanism can be described and measured, eg, wind causes leading flame to hinge at the base, tilting and slapping onto unburnt fuel 1m ahead of flame base, etc.

Theory Specify theory being tested.
It may be an established theory from the amalgam of laws, theories and principles that constitute fire behaviour science, or a variation, or a new concept.
Eg, ROS in a fuel bed is proportional to wind and inversely proportional to FMC (Fuel Moisture Content).

Experimentation Purpose of trial fires is to quantify correlations between ROS and causal input variables that are relevant to the specified spread mechanism. If anomaly data arises, conduct specific trials to test other theories and be open to possibility that another spread mechanism is involved. If so, revise theory and data interpretation.

Verification Test correlations against own data and similar data

Model development - extrapolation Test model against stronger winds and more severe fires Refine model to fit data Retest

Sale and monitor feedback Sell model to customer as fit-for-purpose. Eg, the CSIRO Grassfire Meter is designed to predict wind driven ROS in grass paddocks in all weather conditions using standard weather and fuel bed inputs that are causally related to ROS.

UFLCS test (user friendly, logical, common sense)
This test is designed to make ensure tools based on research outputs are relevant and relatable to the end user. It includes a number of simple down to earth questions, a double check of underlying assumptions, re-examination of evidence in the light of the first principles approach.

APPLICATION of DUE DILIGENCE TESTS

Application of the UFLCS test

Is the prediction output realistic?

Specific question: Based on the assumption that ROS is proportional to wind speed, is Vesta's ROS of 12 kph physically possible in a litter bed or understorey within a tall forest, when maximum sub canopy wind speed is around 15 kph?
To the bushfire manager's knowledge, there is no known record of wind driven fires in tall forest exceeding 2 – 3 kph. Research in wind tunnels suggests it is physically impossible.
Therefore, the answer is NO.
Next step is to return to the first principles checklist – check another mechanism and associated spread theory, reassess data with this perspective.

Check spread mechanism and vegetation type for each data source before comparing, amalgamating or extrapolating

During extrapolation process, Vesta used several bushfires to test its algorithm beyond trial limits. Under rules of engagement, Vesta can only extrapolate to other wind spread mechanism fires. Some examples follow:

The Deans Marsh fire reference said "the average ROS in the forest was about 10 kph" (Rawson et al, 1983), but the accompanying map and description of spot fire locations and times make it very clear the spread mechanism was spot fire spread, probably leap frog spotting. Conclusion - invalid comparison.

Vesta used the leap frog spot fire spread rate (3 kph) in McArthur's (1967) Daylesford example, yet McArthur clearly stated that the mother fire front ran uphill at 0.75 kph in the first hour and made it clear that the average spread rate of the leading spot fires was three times the rate his model predicted for the continuous mother fire front. McArthur (1967) said about spotting ROS - "the apparent rate of spread can be very high, but does not represent the movement of a true front". Luke and McArthur (1978) said "the apparent rate of spread can be very high but does not represent the movement of the true flame front" (P 106). Conclusion - invalid comparison, should use 0.75kph instead.

Cheney et al (2012) added a few recent bushfires to the Projects Vesta (2007) list, including them on their updated verification chart. The Kilmore East fire of 2009 was quoted as 4.08 kph between 2 and 3pm. The author observed the lone leading spot fire approach Mt Disappointment at 3pm. It was approx 8 km from where the first spot fires entered the forest at Wandong at 2pm. It was clearly a long distance spot fire with an apparent ROS of say 8 kph, and at 3pm was several kilometres ahead of the nearest smoke plume base. Of interest is that the spot fire itself was spreading by the wind spread mechanism. For over 30 minutes, the author observed the base of the pot fire's plume travel continuously through tall eucalypt forest at approx 1 kph. Conclusion - invalid comparison.

Check accuracy of bushfire data source before comparing, amalgamating or extrapolating

During extrapolation process, Vesta used several bushfires to test their algorithm beyond trial limits. Some examples follow where comparisons were not valid:

Vesta quoted the Linton fire at 2 kph fire using an unpublished reference. The author can confirm this fire ran continuously through a low messmate forest with light shrubby understorey. Canopy was scorched on almost the entire fire area, confirming the flame was low. The original CFA report with progress map said the maximum spread rate was 1 kph. The Victorian Coroner's report said ROS was average 1 kph with patches up to 1.5 kph. Conclusion – inaccurate data

The Andrew fire (McCaw et al, 1992) described two ROS runs in the same weather conditions, but only the faster one was used in the Vesta extrapolation. The speeds were 1 kph and 1.8 kph. The omission of the lower rate is curious because it was one of Burrow's data points and was instrumental in generating Burrows' prediction model for tall WA forests. Conclusion – selective data usage, use both ROS.

Cheney et al (2012) added a few recent bushfires to the Projects Vesta (2007) list, including them on their updated verification chart. The Kilmore East fire of 2009 was quoted as 4.4 kph between 1pm and 2pm. The author conducted a detailed analysis of VBRC (2010) data and site inspection, finding that the vegetation was a mixed landscape of grass, plantation and low open forest. Most of the run was continuous fire front. The correct average is around 3 kph, but there were faster runs through grasslands. Thus the data is not comparable to a wind driven fire in tall forest. Conclusion – invalid data comparison

Summary to date: Vesta's performance against a few UFLCS criteria indicates deficiencies in key areas that affect the credibility of their model.

Application of first principles approach

Although Vesta did some excellent confirmatory research (eg, they confirmed much of what Burrows (1999) found a decade earlier in the same forest, especially that ROS is independent of fuel load, that there are two ROS mechanisms, and that top layer burns in wind), and made some new findings (eg, clarified a causal linear function between wind speed and ROS, clarified aspects of residence time, including its definition, its association with the tall flash flame and its duration in litter bed, quantified aspects of in-forest wind speed, short distance spotting, bark consumption and quantified an oscillating cycle of updraft / downdraft spread), they made some startling errors of judgement, as a quick run through the first principles process now indicates:

Define spread mechanism under investigation

The specific mechanism under investigation was not clarified, but it can be deduced that Vesta's compelling interest was in the wind spread mechanism. One of Vesta's aims specifies developing algorithms between ROS and wind speed and ROS and fuel bed variables. Another aim is to quantify changes in fire behaviour as fuel beds change with age (= time since fire). Another one is to develop a national fire behaviour prediction system. This suggests they are collecting data under the wind spread mechanism, but have not consciously realised that there are several other spread mechanisms that occur nationally to which the wind spread mechanism cannot be validly extrapolated. Their pre determined focus on applying the wind speed mechanism may have obscured their will to explore data for the existence of other mechanisms, as shown below.

Define theory to be tested

Theories to be tested were not identified, but it can be deduced their dominant theory is that fuel age or fuel bed factors are influential on ROS in wind driven fires, and their intention is to discover them.
The age related aim suggests an unarticulated theory that fire behaviour changes with age of fuel bed. They discussed the lack of evidence that fuel load influences ROS in wind driven fires, but did not specify it as a theory to be tested. They inadvertently excluded testing the theory that another spread mechanism was in operation.

Experimentation aims to quantify correlations between ROS and causal input variables that are relevant to the specified spread mechanism

Some 104 fires were lit and measured in a range of wind speeds, air dryness, terrain and forest fuel beds, ie, age classes and understorey structure. If experimentation is more effective when the least number of input variables are tested against the theory, the Vesta trials had a large number of variables. Experimentation includes input variables that have no known causal linkage to wind driven ROS, but Vesta does not include trials to isolate them and explore a causal link. There are so many input variables in the mix, some of which may interact and cause a lower ROS, some interactions might cause a higher ROS, but they cannot be determined because there were no trials that isolated variables and individually tested them for correlation with wind driven ROS.

There is well accepted theory that wind speed and FMC of dead fine fuel are causally linked to wind driven ROS, but the low correlation rank of 0.47 for wind and almost zero for FMC was not commented on, yet it is a missed cue for further investigation.

Prior to analysis, Vesta adjusted ROS data to 7% FMC using a Burrow's FMC correlation (ie, $FMC^{-1.49}$) without any check testing. This was a significant omission in experimental method because the FMC correlation is critical to the credibility of the Vesta model. Their decision to forego FMC testing assumed they regarded the Burrows' algorithm as pertinent to their trials and technically accurate. They did not address the inconsistency between their own finding of almost zero correlation between FMC and ROS data and their application of the Burrows' correlation that doubles ROS for each 2% increase in FMC. The bushfire manager points out that in the tall flame piloted ignition mechanism, ROS may be independent of FMC changes in dry litter beds, and that in a wind spread mechanism fire, changes in FMC below say 7% seem to have a major influence on ROS. Thus, if the inconsistency had been addressed, the existence of two mechanisms may well have been identified.

Choice of the Burrows' function without testing was a significant error of judgement because a range of contemporary options was available. The exponential Burrows function derives from Burrows' own over-predicting model for WA forests. Why they did not adopt Burrows' lab correlation [exp (-0.11 x FMC)] is not known, particularly when it was used in other well researched fuel beds – in litter fuel for mallee fires since 1997 and in grass fuel since 1993 (Cruz et al, 2015). It generates a rise of 25% in ROS for each 2% rise in FMC between 7 and 3% FMC, compared to Burrows' power function which almost doubles ROS for each 2% rise. At the same time, there were at least three other higher response exponential functions for litter bed - exp (-0.227 x FMC), exp (-0.396 x FMC) and the local WA Red Book used exp (-0.6 x FMC) (Cruz et al, 2015).

In summary, because the FMC function is critical, and because there was considerable range of FMC possibilities at the time, and because their studies were based on a narrow range of FMC, ie, 5.6 – 9.6%, Vesta should have tested their obvious assumption that the Burrows' correlation holds true for lines of fire in drier fuel beds, particularly at 3% FMC. Not to test this assumption is scientifically unjustifiable.

The majority of Vesta's suite of correlations was between ROS data adjusted for FMC and data adjusted for age of fuel bed. Some examples follow:
- Fuel age was ranked at 0.48, but there is no known causal link between age per se and wind driven ROS, and they did not plan an investigation of one. The age related fuel bed variables were all adjusted for fuel age and they all have high correlation rankings with ROS. There was no comment or reference search or investigation to explain the causal influence of fuel structure on ROS.
- Fuel load and depth in litter bed and near surface had high ranking correlations with ROS and charts showed a slight but consistent linear trend, but Vesta dismissed them as insignificant in favour of other fuel bed variables.

Finally, Vesta reported "the best variables to build a model to predict fire spread" were surface fuel hazard score and multiplication of near surface fuel hazard score and near surface height. The other variables were the lower scoring wind speed and, despite a near zero correlation, fine fuel moisture. They developed this algorithm for their standardised data (7% FMC).

$$ROS = 30 + 3.102\,(U_{10} - 5)^{0.904} \times \exp(0.279\,FHS\ score + 0.611\,NS_{FHS}\ score + 0.13 NS_{height}).$$

Conclusion: Their validity of their method and conclusion depends on their unstated assumptions that Burrows' FMC algorithm is appropriate and that ROS is caused by the wind spread mechanism. If the FMC algorithm is incorrect or a significant portion of their data is caused by another mechanism, this assumption is invalid and the data will have to be revisited to derive an appropriate model. A later section describes other overlooked evidence that a second mechanism was clearly involved.

Verification

The Vesta algorithm tested well against their standardised data. The upper range was 1 kph. The correlation coefficient was high at 0.69.

Five years later, Cheney et al (2012) present a revised equation, which appears to predict 30 - 40% higher than Vesta (2007). The difference is not explained

$$R_A = 30 + 1.5308(U_{10} - 5)^{0.8576} FHS_s^{\ 0.9301} * (FHS_{ns} * H_{ns})^{0.6366} * B_1 .$$

Model development - extrapolation
They compared the model (with Burrows' FMC correlation included) to documented bushfires.

Their first comparison group was with bushfires up to 2.5 kph ROS. The spread mechanisms of each bushfire were not identified, which means that many spot fire spread mechanism fires were included in the mix.
The bushfire researcher reported "there was good agreement between predicted and observed rates of spread up to 2.5 kph".
The bushfire manager sees unconvincing agreement. For ROS < 1kph, half are outside the 25% bands and over predicted by up to 3 times. For ROS> 1 kph, the span is to large. Four local fires fall within 25% bands, but the other two locals are under predicted by half. One of the four was the 1.8 kph Andrew fire. The non-included Andrew fire of 1 kph would have fallen well outside the 25% bands, over predicted by 2. On balance, the scatter is too wide and there is nothing concrete to base a confidence level on. For example, if the researcher had targeted only wind spread mechanism fires, the trend line could be regarded as the expectation for a specific forest structure. If the prediction or the observation fell beyond expectation, the user could look for solid reasons to explain the difference, eg, shorter trees, open trees, more shrub cover.

Vesta then compared the model to bushfires with ROS between 2.5 kph and 20 kph. Again, these fires were not sorted for spread mechanism, although most were caused by spot fire spread mechanism.
The bushfire manager sees that only 2 of 10 data points fall within a band width of 25% of predicted ROS. Most of the remainder fall outside a 50% bandwidth. The highest observed bushfire ROS on this chart - 16 kph for Deans Marsh is a double error. Vesta's Table 8.3 reports it as 10 kph, and an authoritative reference describes it as a leap frog spot fire, and not a wind spread mechanism. Thus, there is no credible match between observed and prediction fires where ROS > 2.5 kph. Expectation is that design criteria for the model will exclude ROS > 2.5 kph.
The bushfire researcher concluded "examination of the full set of independent fires, … indicates that model predictions **match the general trend of observed spread rates** although many observations fall outside the ± 25% bounds" Vesta 2007 and Cheney et al (2012). They suggested the data scatter reflected unreliability of weather and fuel factors, rather than admit failure of the model. Then they triumphantly concluded - "the fire spread models developed here are designed for application in dry eucalypt forest with a litter and shrub understorey" Cheney et al (2012).

Summary to date: Vesta's performance against the first principles criteria indicates deficiencies in key areas that affect the credibility of their model. Non identification of mechanism and theory under investigation, combined with a large number of input variables led to ineffective data analysis and failure to identify two ROS mechanisms. Extrapolation process was flawed because it compares the model's algorithm which covers two mechanisms against ROS data that was caused by three mechanisms. This observation indicates the researchers believed that all spread mechanisms were the same, which may explain why they were unaware they could not extrapolate one mechanism's algorithm to other mechanisms.

Other findings from the due diligence review

Other concerns have come to light due to inadequate analysis or selective analysis or inability to consider other mechanisms.

Overlooking obvious evidence of other spread mechanisms

Video evidence

The videos of two sites were made available via Wotton et al (2012). They published two videos of fire spread with in-fire cameras, one of a fire in low light shrubby Dee Vee and the other in taller denser shrubby McCorkhill. All the diagnostic features of the tall flame piloted ignition spread mechanism are observed, particularly ROS = 20% of wind speed.

Known Vesta data for McCorkhill fire:
FMC 6%, FDI (Fire Danger Index) 10.
Flame height is 10m,
Average ROS is at least 0.8 kph and wind is almost calm, say 5 kph.
ROS = 20% wind speed
Measurements from video suggest ROS at camera may be up to 1 m/sec,

Known Vesta data for Dee Vee fire:
FMC 6%, FDI 16.
Flame height is 2m,
ROS is at least 0.2kph and wind is 12 kph
ROS = 2% wind speed

The 20% ROS to wind speed ratio is the Vesta model's prediction line for 3% FMC. Thus, it would have under predicted this fire, because it was 6% FMC. Nevertheless, it allows deduction of the Vesta logic process. Vesta analysis apparently argued if ROS is 20% of wind speed at 5 kph it will maintain the same linear ratio to 60 kph for ROS of 12 kph.

Using that logic prevented them contemplating this line of thought - if high ROS occurs in virtually zero wind, it might mean this fire has a mechanism that is independent of wind speed. It might also mean that if a very tall flame has a higher spread rate than a short flame, it might mean that a multi layer fuel bed has a higher spread rate in low wind. The analyst would then have realised why the correlation between ROS and wind speed is lower and between ROS and fuel load is higher in a tall flame piloted ignition spread mechanism.

Correlation scores

The correlation scores are a clue to another spread mechanism. All the fuel hazard scores have higher correlation rank with ROS than wind speed. This should lead to a line of questions. Shouldn't higher density tall shrubs reduce wind speed and therefore reduce wind driven ROS? The answer is YES of there is a causal link between thicker, taller understorey and wind driven ROS. But there is no such link, which means a non wind mechanism is involved, one that requires a tall flame and works best in low wind – the tall flame piloted ignition mechanism. It can be argued that this omission of questioning occurred because of failure to follow first principles approach, and now undermines the credibility of the model.

Data omission during experimentation
The Vesta report openly admitted data omission. They dismissed “outlier” data without further investigation (p 67 and p 80) because they could not explain the high average ROS. The raw data points (at 9% FMC) were in-forest wind speed 3.6 kph and ROS 0.75 kph and in-forest wind speed 4.7 kph and ROS 1.25 kph. Standardised ROS (at 7% FMC) were 1.25 kph and 2 kph respectively. This is obvious evidence of the tall flame / pilot ignition mechanism.

The cautions of Finney et al (2013) are relevant. “As long as such anomalies remain unexplained, progress and confidence in fire modelling will be held back”.

Omission of investigations
Effect of spotting on ROS
A major Vesta aim was to develop a national fire prediction model. The existence of spot fire mechanism fires is well known. McArthur Meter system incorporates the impact of short distance spotting into ROS (McArthur, 1967) and also predicts an average distance for medium to long spotting, (spotting distance in km averages 3X ROS in kph). But it does not predict a spread rate for the spot fire driven fire. Vesta set up trials to quantify distance and distribution of short distance spot fire. A trial that sought to assess impact of spot fire parameters on ROS would have been useful for the bank of fire behaviour knowledge.

Effect of fuel loading of ROS
The Vesta study quantified bark consumption, but did not relate it to impact on ROS. It also measured a large number of fuel bed structure features with quantitative and qualitative variables. Their correlations with ROS were consistently high, higher than wind speed and FMC. It can be argued that the correlations would be reversed in a wind spread mechanism fire. It can be argued in hindsight that it means most Vesta fires were the high flame piloted ignition mechanism. But some fires were wind driven, and the impact of shrub structure on ROS lays hidden within the data base, recoverable only with appropriate data stratification.

DISCUSSION

The due diligence review has revealed that Vesta collected a mass of evidence from fire trials on the assumption that the spread mechanism was wind driven, and developed a model for wind driven fires. But Vesta missed considerable evidence that another spread mechanism was in operation and dismissed findings of high ROS at low wind speeds because they could not explain them. The bushfire manager estimates that more than half the fires were caused by the tall flame piloted ignition spread mechanism. The key identifying feature of this mechanism is tall flame, low wind speed and considerable spotting landing near the base of the advancing flame.

It can be concluded that by applying the wind speed algorithm to ROS data that is independent of wind, Vesta has produced an invalid model that systemically over predicts ROS at an unverifiable rate. Furthermore, use of Burrow’s high ratio FMC

coefficient when the correlation rank of FMC to ROS was almost zero will also cause the Vesta model to systemically over predict at an unverifiable rate.
The over prediction of ROS flows on to prediction of flame height, which Vesta has tied to ROS as follows
Flame height = 0.0193 x ROS^0.723 x exp (0.64 x Ef) Ef is height of elevated layer.

Apart from the scientific error of using a dependent variable (ROS) in the equation, there is no fire behaviour theory that provides an unconditional causal link between ROS and flame height. ROS may have been used as a proxy for the independent variable wind speed, but even so, because most Vesta fires were probably due to a non wind spread mechanism, wind will have a low correlation, meaning that ROS is probably a proxy for fuel bed variables like height and loading that tend to increase flame height, and in the tall flame piloted ignition mechanism, taller flame may mean higher ROS.

As the flame height equation stands now, if ROS is 1.2 kph and Ef is 2m tall, flame height calculates to 12m. But if ROS is 12 kph in the same fuel bed, flame height becomes 62m, which is not only excessive, but it cannot be corroborated by known fire behaviour theory. Perhaps a review of Vesta data stratified for wind and non wind spread mechanism will quantify the correlation between fuel load and height (as direct causal input variables) and flame height.

The public berating of the McArthur Meter model and replacement with the Project Vesta (Cruz et al, 2015) may be premature and the bushfire manager urges it to be suspended until the Vesta data is reanalysed according the first principle approach. The suspension will also allow time to assess other unintended downstream consequences. Two are now discussed:

Public confidence in bushfire warning system: The McArthur Meter is a major tool in the public warning system for bushfire behaviour danger. For the researchers to replace the Meter's prediction system, which is joined at the hip with the Meter may send the wrong message and lead to a loss of confidence in the Meter. This could lead to another set of unintended consequences. For the authorities to accept the seriously flawed Project Vesta model in the place of the McArthur prediction system on the recommendation of senior researchers could lead to a serious loss of public confidence in the judgement of fire authorities and the capability of researchers.

Planning laws for new house construction: The McArthur Meter prediction system is embedded within planning laws in Victoria and other states via AS3959. The Australian Standard uses the old version where fuel load of litter, and elevated fuel beds and even canopy loading is added together to achieve the higher ROS and this ROS is used to predict an embellished flame height from which a radiation loading onto the proposed new house site is calculated for the purpose of determining the level of fire resistance for the new house. As scientifically incorrect as this trail of equations and argument is, it is incorporated into current planning laws. To change from the McArthur prediction system to the project Vesta model will not be without difficulty and will be subject to intense scrutiny.

Review the McArthur Model verdict The bushfire manager urges a reassessment of the McArthur Meter prediction system before it is further unfairly condemned. It has a very worthwhile role when assessed against the first principles approach. The starting point is that it needs to be seen as a wind spread mechanism, and as such the relevant fire behaviour theory is that ROS is proportional to wind speed and inversely proportional to FMC. Its work place is the "McArthur forest", ie, tall trees and predominantly litter fuel bed. After examining Burrows (1999) and McArthur's reports, it became clear to the bushfire manager that fuel load was a bogus variable in wind driven fires and that McArthur's ROS predictions were invalidly inflated to account for a different mechanism – the short distance spotting booster effect. An acceptable work-around has been to use his Meter at 10 t/ha loading as an indicator of worst case wind driven ROS, ie, up to about 1.2 kph, or ROS = 8% of fuel bed wind speed, or 2% of open wind speed.

The bushfire manager can then use the Meter as a guideline for identifying the mechanism of a fire under observation and thereby explaining the divergence, eg, if the ratio of ROS to open wind is substantially higher than 2%, it means a different fuel type or spread mechanism is involved.
Thus, if ratio is 3 – 5%, the mechanism may be wind driven if wind speed was also high and fuel type may be shorter forest or open forest.
If ratio is 5 – 20% and wind speed is low, the mechanism may be tall flame piloted ignition spread, provided fuel bed allows tall flames to occur.
If ratio is 5 – 20% and wind speed is high, the mechanism may be spot fire spread, provided vegetation and terrain allows medium to long distance spotting.

When the fuel load variable is removed from the McArthur Meter prediction system, the criticisms become straw men when assessed against the first principles approach. Project Vesta (2007) criticisms were listed as:
1 Under predicting ROS in allegedly high intensity fires - their examples were the trial fires of Aquarius and Burrows
Response: Even though the bushfire manager would classify these as moderate intensity fires, some or most of these fires were non wind spread mechanism fires, meaning higher ROS with lower winds. As such, they cannot be compared to the wind spread mechanism McArthur Meter model.
2 Under predicting ROS in severe bushfires (their only example was the Deans Marsh 10 kph fire
Response: Invalid comparison because this was a spot fire driven, whereas McArthur's Meter predicts wind driven fires.
3 McArthur's technique had experimental errors
Response: Unverifiable. McArthur's data and analysis have never been available for inspection
4 McArthur's practice of extrapolating low intensity fires to severe bushfires
Response: Invalid criticism. McArthur's prediction peaks at ROS of 3 kph, and based on analysis of his reports on severe bushfires, his extrapolations involved wind driven mechanism bushfires but were confounded by his addiction to the fuel load variable. On the other hand, Vesta and Burrows extrapolated their algorithm (for combination of two spread mechanisms) for low and moderate intensity fires to severe bushfires that ROS of 12+ kph that were typically spot fire spread mechanisms.

Cruz et al (2015) add two more criticisms:
5 "Model known to under predict the spread of wildfires by a factor of 2–3"

Response: Comparison is invalid unless fire spread mechanisms have been identified in data populations.

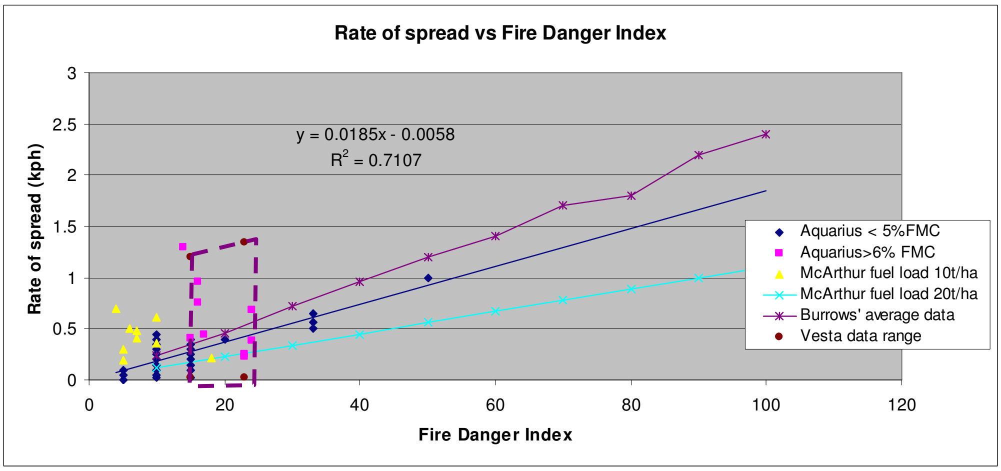
6 "Model use requires a number of subjective adjustment factors that lack a scientific basis"

Response: Misuse of the McArthur Meter by individuals who extend it past its design criteria is the fault of the individual, not the Meter, and is not a valid argument to discredit its value.

Presumably, this refers to their observation that "To counter the known under-prediction bias in the Mk 5 FFDM, some authors have suggested the use of total fuel load, defined as the sum of fine surface, elevated and bark fuels (e.g. McCarthy et al. 1998), as an input instead of only the surface (i.e. litter) and near-surface fuels … This increase in the fuel load input led to a proportional increase in the predicted rate of fire spread". This reference concerns the Overall Fuel Hazard Guide produced by government departments and highlights that the practice of bulking up fuel load is an unscientific misuse of the McArthur Meter model, taking it well beyond its design criteria. Fig 5 in Tolhurst and Chatto (1999) shows how progressive inclusion of total fuel load including canopy raised McArthur model prediction to observed ROS.

With Vesta (2007) and Cruz et al (2015) confirming the insignificance of fuel load on ROS in strong winds, the McArthur Meter model must now be adjusted to remove fuel load an input. That will terminate fuel load bulking practices and the Meter model can revert to match the original research upon which it was based.

In conclusion, when seen in perspective, apart from the fuel load variable, the criticisms are unfounded. Note on the chart that Burrows average range of field data sat between McArthur's fuel loads of 10 and 20 t / ha, and it included the 1 kph run of the Andrew fire, which was a wind driven fire. Note also that the Aquarius (Budd et al, 1997) and Vesta fires were at the lower end of the FDI scale, and note in particular their much higher ROS. When these fires are identified as a different spread mechanism, they exonerate the wind spread mechanism McArthur model from criticism and enable its continued use as a guide for wind driven forest fires.



Note: The uneven McArthur line is taken from the Meter table

CONCLUSION

To advance the future development of fire behaviour in Australia, the bushfire manager and the bushfire researcher must now review both the McArthur Meter model and the Project Vesta model. Both have systemic flaws that the first principles approach has identified. To condemn both as worthless is not necessary because they both be salvaged. The key to future development is to clarify the mechanism and the operating theory for each model and the design specifications. The McArthur model remains useful as a predictor for wind spread mechanism fires in the “McArthur forest”. The Project Vesta model is currently of no practical use to the bushfire manager but its data is stratified into wind spread and tall flame pilot ignition spread mechanisms and appropriate logarithms are redeveloped, it will become a useful predictor for both mechanisms in tall forests with variable shrub layer. A predictor for spot fire spread mechanism remains unaddressed by the bushfire researcher at this stage.

APPENDIX

Spread mechanisms

This is the bushfire manager’s understanding of ROS mechanisms and the rules of engagement relevant to the Project Vesta review. (Summary known flame spread and flame height mechanisms are available from the author.) There are two groups - flame spread mechanisms and spot fire spread mechanisms.
Flame spread mechanisms are in two categories, fuel bed related and non fuel bed related.
(1) Flame spread mechanisms refer to a continuous spreading mother flame front. Common examples include:

Flame spread mechanism	**Heat transfer mechanism**	**Ignition mechanism**
Radiation spread mechanism	Radiation	Auto ignition
Tall flame – piloted ignition	Radiation and mass transport of firebrand	Hot ignition by fire brand
Wind driven	Convection	Flame contact
Slope driven	Convection and radiation	Flame contact

(2) Non fuel bed related spread mechanisms include flame merging and trench effect flame attachment.

Spot fire spread mechanisms refer to ignitions of fuel bed at a distance from the mother flame front. Sub categories are based on spotting distance, intensity of spotting and number of spotting generations. Common examples include:

Spot fire spread mechanism	**Heat transfer mechanism**	**Ignition mechanism**
One off spotting - short medium or long distance	One generation of mass transport of firebrands	One off cold ignition by firebrand
Leap frog spotting	Multiple generation of mass transport of firebrands	Successive cold ignitions by each generation of firebrands

Rules of engagement

- ROS in a fuel bed is the outcome of a specific fire spread mechanism that is a unique combination of heat transfer method, ignition method, fuel bed factors and environmental factors that can collectively be expressed as an algorithm of influential input variables.
- The ROS model and algorithm apply to one mechanism only, which must be clearly defined.

- Extrapolation of a model to include ROS data known to be caused by another mechanism is invalid.
- It is invalid to develop a model or algorithm from ROS data caused by different mechanisms.
- Assembly of ROS data derived from different mechanisms is acceptable for comparison only.

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