A Theoretical Framework for Wildfire Risk Assessment

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Abstract

A revision of the interaction between fire and risk management has been developed. The revision recognises that previous modelling methodologies have lacked a strong theoretical basis from which to develop. Without a strong base there is a limited ability to determine if the modelling procedure will achieve the desired management outcome or follow a tangent.

It is also recognised that the modelling demands required to meet the management needs for a fire risk assessment tool are such that a single model is not the answer. Rather the model is a process that defines the interaction of various elements of several models.

The new layout for fire risk assessment uses fire Likelihood and fire Consequence as the core elements within the design. The process requires an objective to be defined by the user so that the model will provide and answer that is relevant to the fire manager.

The core concepts of likelihood and consequence are developed using a series of models that interact with each other. Likelihood is developed using a wildfire spread prediction, an ignition probability and a human intervention model. Consequence is developed through a measure of economic loss based on the value and vulnerability of an asset to fire intensity. Environmental and social consequences while not widely understood or modeled in the context of wildfire are possible to assess also.

The proposed fire risk assessment process is a significant shift from the models previously developed in Australia and overseas. The theoretical base is a key component of fire risk assessment that has been missing to date. The theoretical base will allow for wide understanding of the modelling procedure and will open the way for parallel development of the models, both here and overseas. The theoretical base has identified missing elements of understanding and research that is required to better answer the questions fire managers are asking today. This will reinvigorate effort and research into this field and begin to show practical and effective solutions to risk assessment questions quickly.

Background

The Department of Sustainability and Environment (DSE) Victoria in conjunction with Melbourne University (through the Forest Science Centre) has continued to search for a means to utilise the capabilities of Risk Management to improve the management of wildfire across Victoria. It is firmly believed that an appropriate wildfire risk management technique can deliver significant benefits to the Victorian Government, the community and the environment.

The desire to undertake wildfire risk management is not new but has been in design and practice since the late 1960's. The early methods utilised a scaled index to qualify or quantify the risk (Countryman 1966 and New Zealand Forest Service, 1975 In Hawkes *et al.*

1997). Spatial modelling, using Geographic Information System (GIS) technology, began in the late 1970's but was not widely available to fire managers (Phillips and Nickey, 1978 In Hawkes *et al*. 1997). Wildfire risk modelling using spatial technology began in earnest in the early 1990's when the technology and data availability began to catch up with the concepts that had previously been constructed. However, limited application of this history of work has filtered into use by the fire manager.

The Forest Science Centre is determined to explore the basis behind wildfire risk management and mechanisms to deliver functioning tools to the fire manager that enhances their capabilities and exploits the use of current technology, data and human expertise.

This paper is a combination of two previous technical reports that describe a new procedural layout that will deliver wildfire risk management capabilities to the fire manager (DNRE 2002).

Historical Wildfire Threat Models

Some of the earliest wildfire threat modelling was carried out in Western Australia and was quickly followed by the United States, Canada, South Australia, New South Wales and Victoria (Hawkes *et. al.* 1997). The first developments of wildfire threat models followed on the heels of spatial technology availability. The earlier models were molded (in both design and function) to fit within the available technology, which is not an ideal point to begin to build a model for a management application.

Examples of this can be seen in the design and output from earlier models known as "Wildfire Threat Analysis" (Chatto 1998, Garvey 1995, Hawkes *et al.* 1997, Shields 1997, Sneeuwjagt 1998). The output of the model was the preparation of a map termed 'threat'. The output was generally delivered through a map overlay and ranking method. The map overlay method undervalues the complexity of the interactions that are occurring between the map inputs and the output, threat, and it also fails to answer management oriented questions such as costs, potential loss or resources required to manage a particular 'threat' output.

However, the earlier models in all their formats have assisted the push for increased spatial modelling technology, expanded thinking on the subject and an increase in managerial understanding of the applications of models.

Progressing from Threat Modelling

The Department of Natural Resources and Environment (NRE now DSE), undertook to review and refine spatial wildfire modelling in Victoria (Wilson 1998). A model was developed using a management oriented question. This was a significant shift from previous models that did not ask a specific question but rather attempted to provide an overarching output.

The question asked was "What is the probability of first attack being successful?" given specific levels and conditions of detection, access, suppression resources, fuels, topography and weather. The question used was considered a central issue to fire management in Victoria and was coupled with prior research conducted by McCarthy and Tolhurst (1998).

Unlike the previous method of aggregating the spatial layers, the NRE model developed business rules to direct spatial layer interaction. The output from the model was a map(s) showing probabilities of first attack success. The input scenario could be varied to affect the output. Such adjustments include more or less resources, faster or slower travel times or changes to the fuel levels. This enabled flexibility for the model to influence decisions, such as the level of resource numbers required, based around the central question of the "probability of first attack success".

This model utilised "scenario analysis" similar in concept to that utilised by Bachmann and Allgower (1998) in their Framework for Wildfire Risk Analysis. Additionally, the model allowed for a sensitivity analysis to be conducted between inputs and outputs. Enabling the manager to quantify the efficiency of their effort to succeed in first attack. To determine the breadth of scenarios to be examined by a modelling process a user needs analysis was conducted.

User Needs Analysis / Analysis Characterisation

The user needs analysis was conducted using a semi-structured interview process with corporate fire managers, regional fire managers and international colleagues. Effort was made to draw out the underlying questions that must be answered by a wildfire risk model.

It was noted by one NRE manager, that the ability for the user to articulate what is required from a risk model had improved over time, allowing for a more refined analysis to be prepared. This author has noted similar improvements in managerial understanding of risk management, however further understanding is still required.

The interview replies are characterised through the following framework:
Scenario Type:

- Strategic through to Tactical
- Planning through to Operational

The output from each scenario is phrased in units of objective measures:

- Quantitative (e.g. - number of resources)
- Time (e.g. - travel time to a fire)
- Geographic (e.g. - location of depots)
- Dollars (e.g. - cost of suppression vs. prevention)
- Non dollar (e.g. - protection of a water catchment or of a community)

The unit of measure is phrased to provide an action for that unit of measure:

- Optimise
- Maximise
- Minimise
- Natural

Figure 1 below is a representation that encapsulates all fire risk related questions posed during interviews. This figure incorporates over 200 separately identified scenarios posed by fire managers.

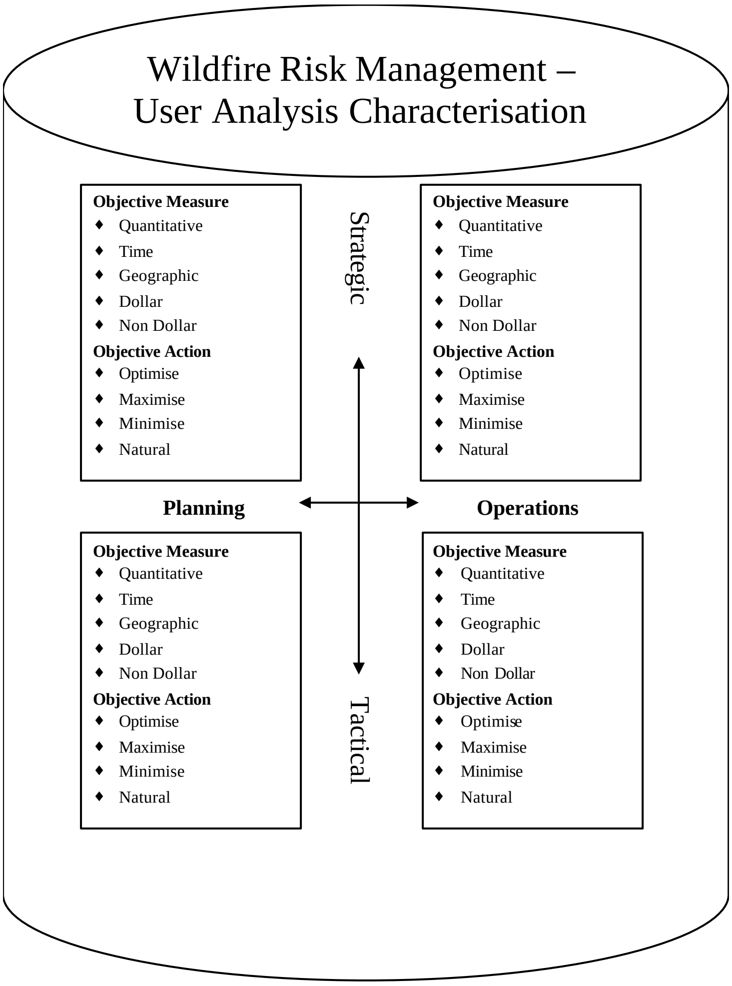

Figure 1. Characterisation of wildfire risk scenarios.

Concepts of Wildfire Risk Modelling

Risk is defined as the chance of something happening that will have an adverse impact upon objectives. It's measured in terms of consequence and likelihood. (Australian Standard, AS/NZS 4360. 1999).

The definition notes three separate components that combine to articulate risk:

- Likelihood (probability of an event)
- Consequence (impact of an event)
- Objective (to enable the consequence to be measured against)

Earlier attempts at modelling risk for fire management have missed one or more of these three components. For example, the earlier versions of "Wildfire Threat Models" did not develop an objective against which a measurable consequence could be assessed. Consequence was termed 'threat' in the earlier models and was a ranking, not a measure.

A model prepared by the Dept. of Natural Resources and Environment incorporated all three components to define risk - likelihood, consequence and objective. However, likelihood and consequence were a single inseparable component. The model is constrained to examine one objective only, the probability of success or not of first attack suppression efforts. Early modelling has not identified the three component aspects of risk within a model. This paper sets out a revised concept of the components of bushfire risk management in a simplified format.

A literature review provides few sources where likelihood and consequence are separately identified in the natural environment. The Australian Standard utilises a tabular method that combines likelihood and consequence to display it as a relative rank. Ranking in this form can confound the output by aggregating values and not providing a probability.

Metis Associates used the notions of likelihood and consequence to clarify a fire management problem. Figure 2. sets out the notions of likelihood and consequence as used by Metis Associates fire problem analysis. Consequence in this case was identified as the economic loss resulting from fire, implicitly the specific objective being to reduce the economic loss on commercial assets.

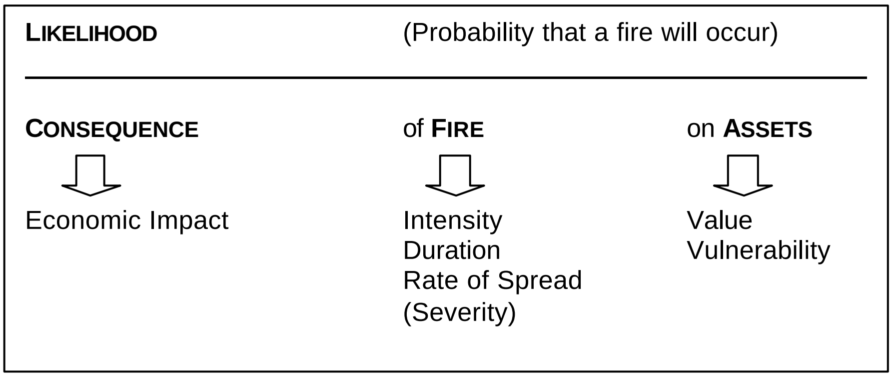

Figure 2. Relationship between Likelihood, Consequence and Impact in the context of fire risk. Taken from Metis Associates Generic Fire Management System.

Risk assessment in the context of environmental events such as wildfire is a relatively new process of understanding (Smith. 2001). However, figure 3 provides one of the earlier concepts of environmental risk assessment uncoupling several of the input elements.

A risk assessment is the first step designed to find out what the problems are. In practice, quantitative risk assessment has not been attempted for many environmental hazards but the following is a representation of how this may be conceptualised.

$$\textbf{Risk} = \frac{\textbf{Hazard (probability) x Loss (expected)}}{\textbf{Preparedness (loss mitigation)}}$$

Taken from Fournier d'Albe (1979) <u>In</u> Smith (2001). Environmental Hazards – Assessing Risk and Reducing Disaster

Figure 3. An alternative description of risk that reflects the impact of a potential hazard as mitigated by some timely response.

Bachmann and Allgower (1998) prepared another conceptual framework for wildfire risk assessment. Their work describes a series of inputs including ignition, fuel, weather conditions and the impacts of fire on natural and human assets, and uses a mathematical matrix methodology to combine the inputs. The methodology is only practical for assets that can be given a quantified or monetary value. The framework is limited to providing a risk number, or series of numbers, as the output. This framework is similar to the previous wildfire threat models in that it gives an output that the manager must then use to filter through various risk mitigation options for them to estimate their best course of action.

A revised layout for wildfire risk assessment is proposed in Figure 4. This layout follows closely with the concept developed by Metis Associates and Fournier d'Albe in Smith (2001) and is capable of analysing scenarios characterised from the user needs analysis.

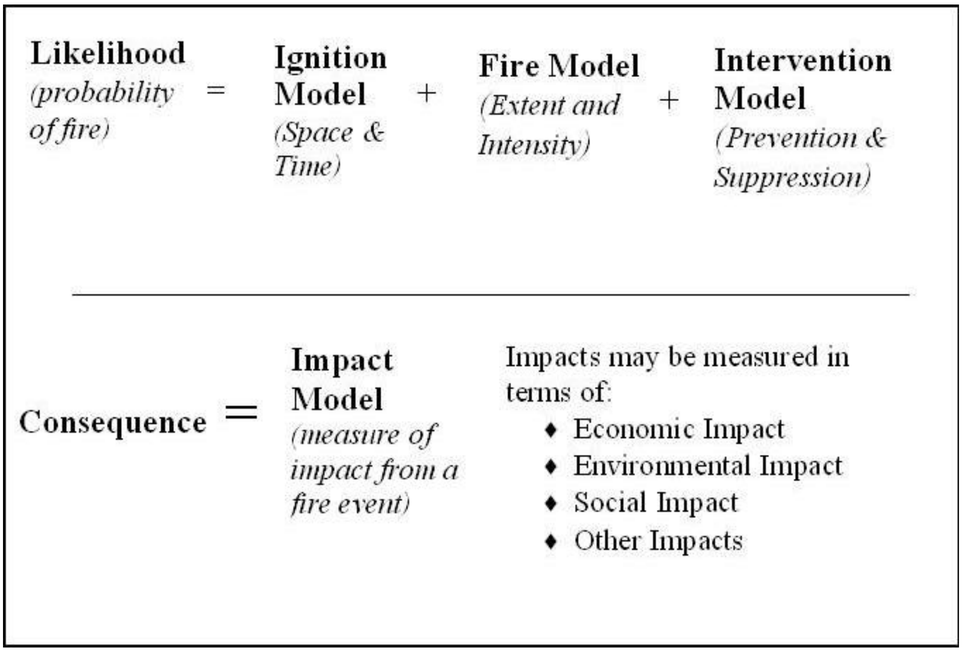

Figure 4. The conceptual layout for Wildfire Risk Management proposed here.

The revised layout is designed to be capable of display in a landscape format and would utilise modelling techniques in both spatial and non-spatial arrays. The revised layout is also aimed at more closely representing the effects that a fire manager can have upon the extent of wildfire across the landscape.

It is envisaged that the Ignition Model will provide the time and location of ignition across the landscape. The Fire Spread Model will provide the extent and intensity of fire events across the landscape and the Intervention Model will provide the effects that human intervention measures, both suppression and prevention efforts, have on the extent and distribution of fires across the landscape. The Impact Model will provide the measure against which an objective can be assessed - economic, environmental and social.

The revised layout builds upon the theoretical elements from risk management principles and provides a footing upon which the modelling procedure can begin in relation to wildfire risk management.

Estimating Likelihood and Consequence

The likelihood of an event is a measure of the probability that an event will occur. For fire management it is the probability that a fire will occur across any particular area of the landscape. There are two ways that the probability of a wildfire event can be estimated - direct and indirect. The first uses historical events that have been directly measured. The second uses an indirect method of modelling the event into the future to attempt to estimate a probability of future occurrence. An amalgamation of the two can also be utilised to cross check and balance the outcomes of both estimates.

Historical occurrence probability
The history of fire events can be used to estimate a probability of that the same event will occur again. The area burnt and location of the area is required to enable a probability to be estimated.

This method is best done using a spatial display tool such as a Geographic Information System to represent the spatial and temporal nature of fire across a landscape and over time. If spatial data is not available a land unit, of not too large an area, could be used in a similar manner. The output from this exercise is a probability, in either a map format or land unit table, providing each land areas likelihood of being impacted by fire based on historical occurrence. Caution must be exercised to correctly define the timeframe for which the output probability estimate is valid.

Projected modelling probability
Ignition, Spread and Intervention modelling is an indirect estimation method that simulates fire across the landscape and the effect of human intervention. A fire model would incorporate a range of climatic variables, fuel and terrain and ignition locations that can occur over time and across the landscape. An intervention model incorporates elements such as first attack success (combining travel times, fuel type and quantity etc), prescribed burning activities in the district, road maintenance or construction, or the introduction of more or less resources to a fire district. The development of an intervention type model has already begun through NRE's modelling of first attack success. The concepts and mechanisms to assess various human interventions can be further developed from this point.

This modelling methodology is used in the insurance industry to predict the probability of catastrophic events such as a cyclone or flood affecting areas of the landscape that they are insuring against possible loss.

Simulations of fire are run multiple times across the landscape for a long period, say 100 years, to estimate the probability of a fire effecting any one point in the landscape. There are already several landscape scale fire spread models which could be considered for this work. The product of the simulation is a landscape scale output indicating the probability of a fire occurring in any one location for a fire season, or the time period set in the model.

Consequence
The consequence of an event is a measure of the impact of an event upon specified objectives. Most consequences examine the negative impacts of an event, however fires can have positive impacts. Objectives can be stated for impacts such as economic, social or environmental impacts. The most sophisticated articulation of a consequence is possible if a measure for the objective is available and the measure can be quantified and represented in the risk assessment procedure.

At present fire managers have a measure of economic impact since there is a mature understanding of economic measures, i.e. dollars. However our understanding of measures that can be used for social or environmental objectives is limited.

The limitation of not having well-established measures for environmental or social objectives does not negate their use in risk management or risk assessment procedures. This limitation forces us to recognise that we do not have a substantial enough understanding of this field and we should establish means and mechanisms to better understand, articulate and measure against these objectives. The current limitation of measures should, in part, frame future research.

Estimating Economic Consequence

Fire has an economic impact on various assets, or assets types. At present, economic impact on an asset can be quantified and displayed as a relation between fire severity and vulnerability of the asset to fire, see figure 5. In general, the greater a fires severity, the greater the economic impact on an asset, however this must be tempered with the vulnerability of that asset to a fire. For example, a freeway has a commercial value but it is not directly vulnerable to economic loss resulting from a fire, whereas a pine plantation is certainly vulnerable to economic loss resulting from a fire.

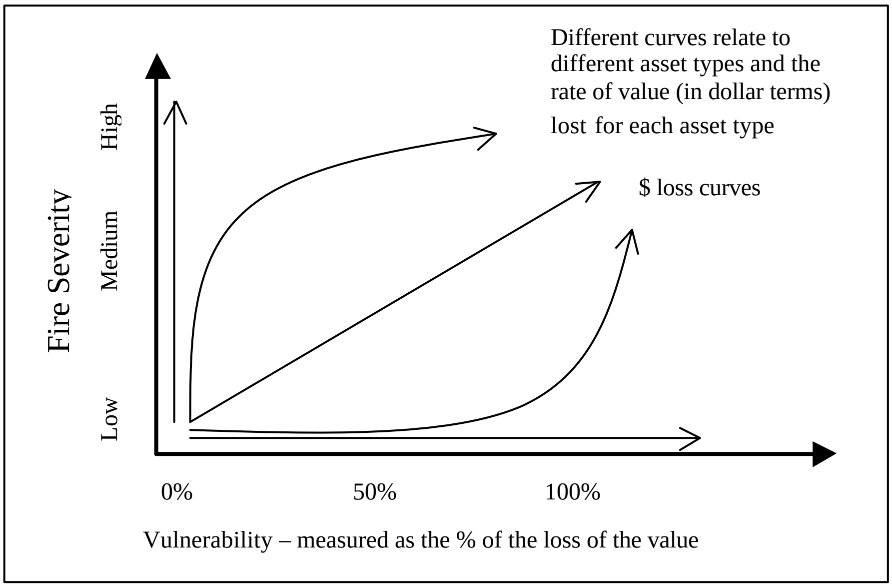

Figure 5. A representation of the economic impact of fire on different assets.

The impact of fire severity upon commercial values is not a measure that has previously been widely estimated for particular asset types relating to wildfire management. This is a field of information gathering that requires further effort to determine the relationships between fire severity and economic impact.

Fire severity can be measured or estimated and the commercial value of an asset can be measured or estimated. If these two inputs are prepared and the loss relationships derived then potential economic impacts can be estimated. This work should be extended to cover all asset types.

Estimating Environmental Consequence

A single measure of environmental impact, similar to dollars used for economic impact, is not available. However some measures for individual components of the environment are possible such as:

- Soil erosion resulting from fire
- Stream turbidity resulting from fire
- Specific flora loss resulting from fire
- Specific changes to fauna habitat resulting from fire

One possible measure that could be used, suggested by fire ecologist, Ross Bradstock (Pers. Comm) is described as the “probability of landscape scale extinction”. A representation of how this may be viewed in relation to an impact model is provided in figure 6.

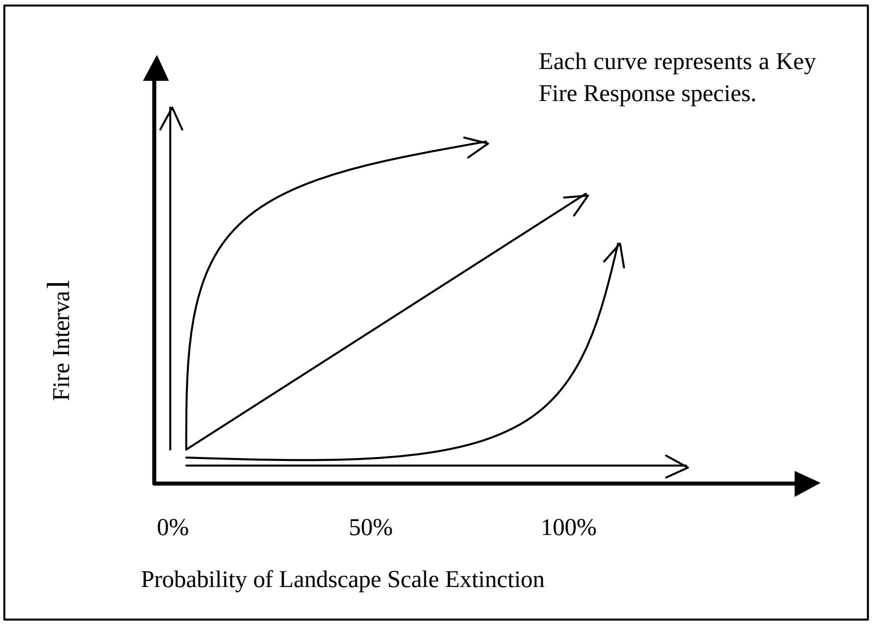

Figure 6.
A theoretical representation of the probability of landscape extinction for different plant species in response to different inter-fire intervals

A single environmental impact measure, such as dollars used for economic impact, is not available. Each aspect of environmental impact has temporal and spatial variation and its own measure, or set of measures and no common measure is yet available. The Montreal sustainability criteria are too numerous to use for this purpose and if a 'common' impact measure is to be developed, significant research will be required to set this out and gain wide support. This is an area where significant research development can occur.

Estimating Social Consequence

The capacity to measure social impacts of a fire is even less well known than environmental impact. This is not a reason to discount it but rather is a field of interest that requires wider attention and research to begin to develop measures that are relevant and the wider community can understand.

Social impacts such as loss of life or decline in health, such as a measure of the increase in respiratory cases at a hospital, are measurable and can be used as objectives. These measures themselves are not highly developed or widely accepted for forest fires. More complex notions or measures of a communities' resilience to a fire event are not easily assessed either. Some work in this field has occurred through organisations such as GeoScience Australia, through their "cities" multi-hazard project, however, this is an area where significant research development can occur.

Conclusion

Risk Management and the application of risk assessment procedures in fire management has been sitting on unstable foundations. The unstable foundation has confounded the development of risk assessment techniques. The conceptual layout of the risk assessment process detailed in this report provides a sound starting point from which to progress the use of fire risk assessment.

The outcomes from a risk assessment procedure are practically oriented toward the requirements of the fire manager and are possible to be tested within our existing technology capabilities.

The risk assessment modelling process may introduce new outcomes that have previously not been achievable so that they will guide in part research agendas, such as improved environment and social measures. The modelling process may also provide an improved ability to conduct sensitivity analyses between competing research fields or management choices, such that those areas that will yield the greatest desirable impact can be prioritised.

This paper has revised the conceptual layout for fire risk assessment and fire risk assessment can now begin to be progressed on a more solid foundation that is based on existing risk management theory. The risk assessment process has practical outcomes that can be used by the fire manager and the technical environment in which this process would be developed is currently possible.

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References

Australian Standard on Risk Management (1999). AS/NZS 4360.

Bachmann A. & Allgower B. (1998). Framework for wildfire risk analysis. Proc. 14th Conference on Fire and Forest Meteorology, Nov. 1998.

Bradstock R. (2001). Personal Communication. NSW National Parks and Wildlife Service.

Chatto K. (1998). Development of a Wildfire Threat Analysis Model for South Eastern Australia. Proc. 14th Conference on Fire and Forest Meteorology, Nov. 1998.

Countryman, C.M. (1966). Rating fire danger by the multiple base index system. J. of For. Aug.: 521-536.

DNRE (2002). The Development of a Bushfire Risk Framework for Victoria. Dep. of Nat. Res. & Env., Victoria. Research Report No. 59. In conjunction with the Forest Science Centre and Metis Associates.

Fournier d'Albe, E.M. (1979). Objectives of volcanic monitoring and prediction. Journal of the Geological society of London, vol 136, pg. 321-326.

Garvey M. (1995). The use of geographic information systems to analyse wildfire threat. Fire Management Quarterly, March 1995. Country Fire Authority, Victoria.

Hawkes B., Beck J. and Sahle W. (1997). A wildfire threat rating system for the McGregor Model Forest. Proc. 13th Fire and Meteorology conference, Lorne, Australia, Oct 1996.

McCarthy G.J. & Tolhurst K.G. (1998). Effectiveness of firefighing first attack operations by the Department of Natural Resources and Environment from 1991/92 – 1994/95. Research report No. 45, Dept. of Natural Resources and Environment, Victoria.

New Zealand Forest Service (1975). Forest fire risk grading. New Zealand Forest Service, Wellington 2nd Ed. 24p.

Phillips C. and Nickey B. (1978). The concept of 'spatial risk' and its application for fire prevention. Fire Management Notes 39(4) 7,8 & 19.

Shields B (1997). Wildfire threat analysis – A discussion paper. Unpublished report to State Forests of NSW, Australia.

Smith K. (2001). Environmental Hazards: Assessing Risk and Reducing Disaster. Published by Routledge, London.

Sneeuwjagt R. (1998). Application of wildfire threat analysis in south western forests if Western Australia. Proc. 14th Conference on Fire and Forest Meteorology, Nov. 1998.

Wilson A. (1998). Fire Planning Support Tool. Unpublished report to Dept. of Natural Resources and Environment, Victoria.