Proceedings of Bushfire CRC & AFAC 2012 Conference Research Forum
28 August, 2012
Perth Convention & Exhibition Centre

Edited by
R.P. Thornton & L.J. Wright

Published by:
Bushfire Cooperative Research Centre
Level 5 340 Albert Street
East Melbourne 3002 Australia

Citation: R. P. Thornton & L.J. Wright (Ed) 2013, 'Proceedings of Bushfire CRC & AFAC 2012 Conference Research Forum' 28 August 2012, Perth Australia, Bushfire CRC

Welcome from Editors

It is our pleasure to bring to you the compiled papers from the Research Forum of the AFAC and Bushfire CRC Annual Conference, held in the Perth Exhibition and Convention Centre on the 28th of August 2012.

These papers were anonymously referred. We would like to express our gratitude to all the referees who agreed to take on this task diligently. We would also like to extend our gratitude to all those involved in the organising, and conducting of the Research Forum.

The range of papers spans many different disciplines, and really reflects the breadth of the work being undertaken, The Research Forum focuses on the delivery of research findings for emergency management personnel who need to use this knowledge for their daily work.

Not all papers presented are included in these proceedings as some authors opted to not supply full papers. However these proceedings cover the broad spectrum of work shared during this important event.

The full presentations from the Research Forum and the posters from the Bushfire CRC are available on the Bushfire CRC website www.bushfirecrc.com.

Richard Thornton and Lyndsey Wright

June 2013

ISBN: 978-0-9806759-6-2

Disclaimer:

The content of the papers are entirely the views of the authors and do not necessarily reflect the views of the Bushfire CRC or AFAC, their Boards or partners.

Integrated economic assessment of management actions to reduce fire risk to Naseby, New Zealand

Fiona L. Gibson and David Pannell*
University of Western Australia
**corresponding author:* fiona.gibson@uwa.edu.au

Abstract

In the Otago region of New Zealand, Naseby is a small tourist town faced with an increasing risk of a severe fire event. Burning of tussock grasslands by pastoralists and recreational activity are just a few land management actions that pose significant risks to the town, surrounding communities, and biodiversity assets. We present a quantitative decision framework to provide an integrated assessment of the land management activities. The model was developed using existing literature and extensive consultation with stakeholders and fire researchers. We quantify trade-offs between economic, social and environmental outcomes from various fire risk mitigation strategies. We present results for a range of scenarios, exploring the tradeoffs between competing objectives for land management in Central Otago.

Introduction

There are many strategies that can be implemented to reduce the risk of fire damage to infrastructure and life. Given that funds available for fire management are limited, knowing which fire risk mitigation strategies provide the best value for money is a key question for policy makers. In light of recent catastrophic fire events in various part of Australia (Teague et al. 2009), the potential fire risks faced by communities in New Zealand has become increasing apparent to authorities. In this study we undertake an integrated assessment of several strategies aimed at reducing the frequency of fire events in the town of Naseby, in Otago, New Zealand. We identify which management practices intended to reduce the frequency of serious fires provides the highest expected benefits per dollar of investment.

Background

Research approach

The approach to the research was highly participatory, requiring input from stakeholders at all stages. The research question was developed in consultation with the funding agency (Bushfire Cooperative Research Centre), industry partner (National Rural Fire Authority) and stakeholders. A series of workshops were held in the region to define the problem, collect data and foster ownership of the project and outcomes with the industry partner and stakeholders. A follow-up workshop was held to present the preliminary model, discuss results and refine the data. Subsequent discussions with key stakeholders and fire researchers assisted with the finalisation of the model and results.

Study area description

The study area chosen by the industry partner and stakeholders is Naseby, a small town within the Otago region of New Zealand (see Figure 1). It is situated at the base of the Mount Ida Range, on the edge of Naseby forest, surrounded by pastoral, tussock and rock lands. It has a permanent resident population of approximately 100 people. However the population swells to over 3000 during the summer months as tourists come to enjoy the range of heritage and recreational activities on offer. Pastoral farming and forestry are important industries within the surrounding landscape (Central Otago District Council 2010).

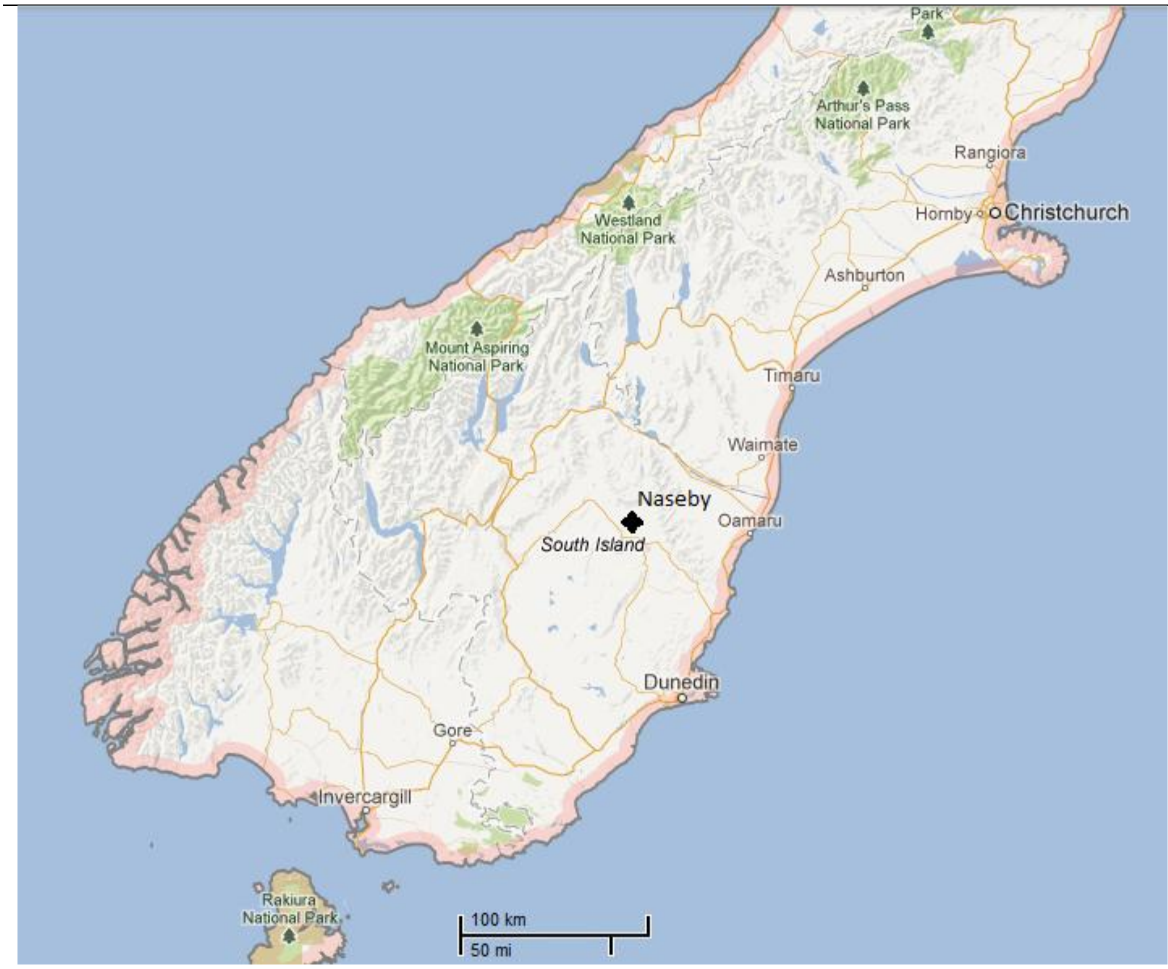

Figure 5 Study area location.

Fire risk and management surrounding Naseby

Fire risk varies considerably between different parts of New Zealand (Pearce and Clifford 2008). Climate change is predicted to increase fire danger in certain regions, including parts of Otago. This is primarily the result of predicted increases in temperature and decreases in rainfall, although higher wind speed and lower humidity is also predicted to contribute to higher future fire danger (Pearce et al. 2011).

Worsening fire conditions and limited capacity for fire suppression in some regions could result in more intense and damaging fires (Burrows 1999). Doherty et al. (2008) undertook an analysis of the reported fire incidents nationwide from the 1991/92 to 2006/07 and found that, within Otago, the number of wildfires has increased. The area of vegetation burnt in this region accounted for 41.5 percent of the total national area burnt.

Fire use by landholders within and surrounding Naseby is regulated through the fire authorities, which are set up to deliver on the objectives and requirements of the *Forest and Rural Fires Act 1977* and follow the policy direction of the National Rural Fire Authority (NRFA). Fire use on private and public land within and surrounding Naseby is controlled by fire seasons and permits. Fire use by recreationalists within the commercial forest is prohibited.

Model description

Overview

The model integrates fire risk, fire prevention options, costs of those management options and the damage caused by fires of different severities in order to estimate the benefits and costs of various fire risk management strategies for Naseby and the adjacent commercial forest. We have measured the benefits only as reduced damage to the assets, not reduced suppression costs. A base-line level of expected losses due to fire is estimated on the assumption that there is no additional management in place. The level of these losses is determined by the probabilities of different weather conditions, the probability of fire escapes in each of those weather conditions and probability of fire spread over different parts of the landscape. Then the calculation is repeated with a particular management regime in place. The difference between these two results (with and without management) provides an estimate of expected benefits, and this, together with the cost of the management regime, is used to calculate a benefit cost ratio (BCR). The model allows the user to simulate many different strategies for fire risk management and observe the estimated BCRs.

The nature of the management problem and the technical and economic relationships within the model were determined through extensive consultation with scientists, fire regulators, local experts and land managers. Parameter values for the model were determined through a literature review, existing databases and consultation with fire experts and land managers. We now describe key aspects of the model.

Asset description

The assets being protected is the town of Naseby, its residents and the adjacent commercial and recreational forest. The combined value of these assets is estimated to be $252 million. This includes the improvement value of 306 buildings, $42 million (obtained from Central Otago District Council), the threat to the lives of the town's permanent residents, $2 million per life (value of a statistical life obtained from New Zealand Fire Service Commission 2007), and the commercial value of the plantation forest, $10 million (obtained from Ernslaw One forest manager). Values were not assigned to the agricultural and conservation land in the other management zones in the model, as the focus of the analysis is on protection of the town and the forest.

Management zones

The town and surrounding area are categorised into ten zones. The zones are defined in Table 1, Appendix.

Different management actions and different risks of fire escapes and fire spread were specified for each of the zones, as outlined below. Zones of different distances from the assets were included to represent the fact that more distant fires are less likely to spread to the town or forest. We choose a 20 kilometre boundary around the asset in consultation with local experts, who advised that a fire that started more than 20 kilometres away from the asset was unlikely to reach it given suppression efforts and natural/man-made fire breaks. The five kilometre boundary was also decided on in consultation with local experts. The zones were split into north and south sub-zones to represent the higher fire risk from the north due to prevailing wind directions.

Fire risk

The model calculates the expected number of fires from each zone that reach the asset within a year. This is determined by the number of fire escapes occurring per year in each management zone, and the proportion of escaped fires that spread to the asset. Each of these aspects depends on the weather conditions. The fire weather conditions are categorised in the New Zealand fire danger rating system as low, medium, high, very high and extreme. A value for the Fire Danger Class (FDC) for each region is generated each day using the data recorded by the nearest weather station.

Fire escapes

Fire escapes are defined as a lit fire that requires a fire crew to extinguish. The frequency of fire escapes per year in each management zone in each weather category was estimated using data gathered by the NRFA within the study area from January 1 1998 to June 30 2012. The data consists of reported incidents where a fire crew was called to control an escaped fire. In total there were 223 reported fire escape incidents, distributed across zones as follows: 24 in Zone 1; three in Zone 2; two in Zone 3n and one in Zone 3s; 27 in Zone 4n and 45 in Zone 4s; four in Zone 5n and zero in Zone 5s; 54 in Zone 6n and 63 in Zone 6s.

Fire spread

Fire spread is defined as fire occurring in either zone 1 or 2 as a result of a fire escape in any of the zones. For example, a fire may spread from zone 3a to zone 1 (the town). The model includes probabilities of fire spread (conditional on a fire escape) for each zone in each weather category. For example, in extreme FDC weather, we assume that any fire that escapes in zone 3s has a 0.01 probability of spreading to zone 1. The probability of spread to zone 1 for an escaped fire in zone 1 is 1.0. These probabilities were set by calibrating the model to produce fires of different severities at pre-determined frequencies (see the next section).

Fire severity

Fire severity denotes the level of loss of infrastructure, life or plantation value due to fire. Fire severity classifications are not currently stipulated in government policy and so the damage defined within each category was developed with participants at the stakeholder workshops. Whilst there are no historical records showing fire severities greater than medium severity, the workshop participants agreed that fires greater than medium severity are possible. A description of each severity category, the estimated number of fires in each severity category per century, and percentage of damage done to each asset are provided in Table 2, Appendix. As the asset is a combination of two zones (the commercial forest and Naseby town) a percentage of damage must be determined for each.

The frequencies of fires of different severities depend on weather conditions (Table 3, Appendix). For example, we assume that, of the fires that reach zones 1 or 2 on a day of high FDC weather, 74 per cent will be of low severity, and 2 per cent will be of very high severity. Along with the probabilities of fire spread, these frequencies were determined by calibrating the model to produce the fire frequencies specified in Table 2, Appendix.

Fire management strategies

The strategies tested in the model were based on strategies identified in the stakeholder workshop and in further discussions with local experts. The parameter values used were derived from consultation with experts in fire and land management. The strategies are as follows:

- Payments to landowners to compensate or reward them for not using burning for land management in the agricultural zones.
- Regulation prohibiting burning for land management within the agricultural zones.
- On-ground support (i.e. provision of fire-fighting resources) to landowners undertaking burns.
- Training programs for landowners undertaking land clearing burns. The program is implemented across Zones 3 and 4. We assign half the costs to Zone 3 and half to Zone 4.
- Regulation prohibiting fire use within Naseby town.
- Implement the Queenstown Red Zone Plan (Queenstown Lakes District Council 2011). The program aims to change people's behaviour through awareness and knowledge of fire risk issues within Naseby and is targeted at permanent residents or those who own property within the town. There are 306 listed buildings.
- Fire breaks, of varying widths, around the northern edge of the commercial forest, or around conservation land in Zones 5 and 6. In Zone 2 the fire breaks would be located on private land. In Zone 5 and 6 the fire breaks would be on conservation land.
- Prescribed burning of conservation land to reduce the risk of fire spreading across them.

The management strategies address fire risk in different ways; they reduce escapes and/or reduce spread. The management strategies in the town (Zones 1) and agricultural region (Zone 3 and 4) are designed to reduce fire escapes. As each management strategy is designed to target a specific cause of escaped fires (i.e., land clearing burns), the strategy can only reduce the proportion of fire escapes attributable to that cause. It is estimated that 80 percent of escaped fires in Zone 1 originate from human activity. Therefore each policy option that reduces escapes in Zone 1 through targeting human behaviour can only affect 80 per cent of escaped fires. Similarly, within the agricultural regions 40 per cent of escaped fires originate from land clearing burns (Doherty et al. 2008; *per comm*. 2012), and strategies that reduce escapes can only affect that proportion of the full set of fires.

In evaluating the cost-effectiveness of each management strategy, an estimate of the reduction in fire escapes is required. These parameter values, along with the strategy costs, stakeholder behaviour and fire spread, are available from the authors.

Economics

The expected loss in asset value (*EL*) for a particular asset for a given scenario is calculated by:

$$EL = \alpha\beta V \quad (1)$$

where *V* is the value of the asset, α is the expected number of fires per year that reach the asset, and β is the proportion of asset value that is lost per fire. This is calculated for each asset (Zone 1 and Zone 2) and each fire severity level, and weighted by the frequency of each severity level (Table 4, Appendix).

Examining Tables 2 and 4, fires of low severity have by far the highest frequency, but they result in low loss per fire, so that the total expected loss per year from low-severity fires is relatively low: $39,000 in Zone 1 and $7,400 in Zone 2. At the other end of the spectrum, extreme-severity fires have extremely low frequency, but extremely high losses, so much so that for Zone 1, they provide the highest expected loss.

The benefit of a management practice is defined as the reduction in the expected loss in asset value per year as a result of the management practice. Expected loss is calculated with the management practice in place and subtracted from expected loss for the base-case management scenario, with no new management strategy. The decision metric evaluating the efficiency of each management strategy in reducing fire risk is a benefits cost ratio. The benefit-cost ratio (*BCR*) for strategy *X* is calculated as:

$$BCR_X = \frac{(EL_X - EL_0) \times P_X}{C_X} \quad (2)$$

where EL_0 is the expected loss under the base-case, P_X is the probability that strategy *X* will be successful, and C_X is the cost of strategy *X*. The decision rule when using a BCR is to accept a strategy only if its BCR is greater than 1, and in deciding between alternative policies, select the one with the highest BCR.

Dealing with uncertainty

Uncertainty about model parameters is addressed in a variety of ways. A subjective probability of failure for each strategy was estimated and included in calculation of expected benefits. Feedback on the model parameters and model results was elicited to stakeholders in documents and workshops. Break-even analysis is used to provide a guide to the robustness of the results. Break-even analysis is a form of sensitivity analysis that is useful to test whether a conclusion from the model is likely to change as a result of changes in parameter values within the range of uncertainty (Pannell, 1997).

Data collection

The parameter values were determined from the literature, from existing databases and thorough consultation with fire experts and land managers. The statistics on fire escape causes from the Otago region came from Doherty et al. (2008) and expert opinion. Data on fire escapes was provided by the NRFA. The data spanned from January 1 1998 to June 30 2012. Three stakeholder workshops were held in Alexandra, Otago, to assist in defining the decision problem, the management strategies and collecting information from local experts, including feedback on assumptions and preliminary results.

The effectiveness of each fire break strategy in reducing fire spread was estimated using the Australian grassland fire break breaching model (Wilson 1988) and expert judgement (Pearce pers comm. 2012). The effectiveness of a fire break in holding a fire is dependent on the width of the fire break, fire intensity and the presence of trees within 20 m of the upwind side of the break. Trees can provide a source of embers that can breach the break through spotting (Wilson 1988). The probability of a defined fire break width (6, 10 or 15 metres) holding a fire within Zone 2, 5 and 6 is given for each FDC under the following assumptions: the upper fire intensity value for each class and 10,000 kilowatts per metre for the extreme FDC (flame lengths of approximately 5.5 metres). As it was impossible to accurately determine whether trees were present or absent at each point along the zone boundaries, the probability of holding values were given as the midpoint between the tree absent and tree present estimate.

Results and discussion

The benefit, project risk, cost and BCR for each management strategy are provided in Table 5, Appendix, for standard parameter values. For agricultural and conservation management strategies each was initially tested jointly in both the within 5 kilometre and beyond 5 kilometre zones. If the strategy had a BCR greater than 1, the BCRs within each zone and each sub-zone were explored. Only eight of 22 strategies examined have BCRs greater than 1.

The highest BCR is for the community education program in Zone 1 (17.57). Regulating against fire ignitions within Zone 1 is moderately cost-effective (3.54); however implementing a council rubbish collection program is not (0.45). Within Zone 2, the 6, 10 and 15 metre fire breaks are all highly cost-effective (4.35, 6.17 and 7.58 respectively). Moderately high BCRs are also reported for landowner training within Zone 3 and 4 (2.33), and landowner training within zone 4 (2.92).

The remaining BCRs are less than 1, and range from .00 to .87. Payments, regulation and on-ground support strategies within Zone 3 and 4 are very poor value for money. Part of the reason for this is that, given the data and assumptions of the model, few fires would reach the assets from these zones. For example, 1 fire in 89 years would reach Zone 1 from Zone 4. Therefore, the benefits from reducing escapes within these zones is low, while the estimated costs of payments or regulatory compliance are high.

Fire break around conservation land (Zone 5 and Zone 6) result in benefits that are smaller than costs, except for the 15 metre break in Zone 5, for which benefits approximately equal costs.

The majority of the moderate to high BCRs are for management strategies within the asset zones, 1 and 2. Similarly, BCRs tend to be higher for management within the adjacent zones (3 and 5) rather than in the more distant zones (4 and 6), although not in every case.

Break-even analysis

Break-even analysis is applied here to the parameters judged to have the greatest uncertainty: management strategy effectiveness in reducing fire escapes and fire spread. The conclusion tested is whether each strategy has a BCR greater than 1. We report parameter values and percentage changes in parameter values that would result in BCRs of 1 (Table 6, Appendix).

Overall, the break-even analysis shows that the conclusion that minimising fire risk close to assets delivers the best value for money is a robust finding.

Conclusion

The model provides a number of insights into the relative cost-effectiveness of alternative strategies to reduce the fire risk for Naseby and the commercial forest. The most efficient policies to reduce fire risk are those that would be implemented within the asset zones, rather than on land some distance from the assets. The analysis suggests that the further away from an asset a fire risk reduction policy is implemented, the less efficient it will be in reducing fire risk. Particular strategies identified as offering high value for money include the community education program with Naseby residents and a fire break around the northern edge of the commercial forest. By contrast, strategies for which the expected benefits are greatly outweighed by the costs include payments or regulation to eliminate landowner burning practices, on-ground support to landowners and prescribed burning of public land. These findings are reasonably robust to uncertainty in key parameter values.

References

Alexander ME (2000) Fire behaviour as a factor in forest and rural fire suppression. Forest Research, Rotorua, in association with the National Rural Fire Authority, Wellington. Forest Research Bulletin No. 197, Forest and Rural Fire Scientific and Technical Series, Report No. 5.

Burrows N (1999) Fire ecology and management information transfer from Western Australia to New Zealand. Science and Research Internal Report No.166. (Department of Conservation, New Zealand)

Byram GM (1959) Combustion of forest fuels. In 'Forest fire: control and use'. (Eds KP Davis). pp 90-123. (McGraw-Hill: New York)

Central Otago District Council (2010) Naseby Community Plan. (Central Otago: New Zealand)

Pannell DJ (1997) Sensitivity analysis of normative economic models: Theoretical framework and practical strategies. *Agricultural Economics* **16**, 139-152.

Pearce HG, Kerr J, Clark A, Mullan B, Ackerley D, Carey-Smith T, Yang E (2011) Improved estimates of the effect of climate change on NZ fire danger. Scion, Christchurch, and NIWA, Wellington. Report No. 18087.

Pearce HG and Clifford V (2008) Fire weather and climate of New Zealand. *New Zealand Journal of Forestry* **53**, 13–18.

Queenstown Lakes District Council (2011) Queenstown Lakes District Council Rural Fire Plan. (Queenstown: New Zealand)

Teague B, McLeod R, Pascoe S (2009) Victorian Bushfires Royal Commission. Parliament of Victoria. Final Report. (Melbourne: Victoria).

Wilson AAG (1988) Width of firebreak that is necessary to stop grass fires: some field experiments. *Canadian Journal of Forest Research* **18**, 682-687.

Appendix

Zone	Definition	Current area (ha)
1	The town site of Naseby	62
2	The commercial forest adjoining Naseby	2100
3n	Agricultural land within 5 km to the north of Zone 1/ 2	2127
3s	Agricultural land within 5 km to the south of Zone 1/ 2	3184
4n	Agricultural land between 5 and 20km to the north of Zone 1/ 2	39074
4s	Agricultural land between 5 and 20 km to the south of Zone 1/ 2	55135
5n	Public land within 5 km to the north of Zone 1/ 2	114
5s	Public land within 5 km to the south of Zone 1/ 2	62
6n	Public land between 5 and 20 km to the north of Zone 1/ 2	33136
6s	Public land between 5 and 20 km to the south of Zone 1/ 2	1915

Table 3. Description of management zones and number of hectares (ha) within each zone.

Severity	Description	Estimated fires per century (per year) in Zone 1/ 2	Percentage of asset damaged	
			Zone 1	Zone 2
Low	20 percent of a single property or 10 ha forest	140 (1.4)	.0.01	.48
Medium	One property or 50 ha of forest	20 (0.2)	.06	2.38
High	Five properties or 350 ha forest	4 (0.04)	.28	16.67
Very high	30 properties and two lives or 1050 ha forest	2 (0.02)	3.00	50.00
Extreme	320 properties and 30 lives or 1800 ha forest	1 (0.01)	40.66	85.71

Table 4 Fire severity category, severity description, frequency of fires per century and per year and percentage of asset damaged.

	Fire Danger Class				
Fire severity level	Low	Medium	High	Very high	Extreme
Low	1	0.89	0.74	0.56	0.38
Medium	0	0.09	0.2	0.3	0.4
High	0	0.02	0.04	0.08	0.1
Very high	0	0	0.02	0.04	0.08
Extreme	0	0	0	0.02	0.04
Total	1	1	1	1	1

Table 5. Relative frequencies of fire severities in each Fire Danger Class rating.

	Expected loss ($/year)	
Fire severity	Zone 1	Zone 2
Low	$39,000	$7,400
Medium	$29,000	$18,000
High	$33,000	$30,000
Very high	$192,000	$61,000
Extreme	$948,000	$40,000
Total	$1,240,000	$156,000

Table 6. Expected loss in asset value per year given the probability of each fire severity occurrence.

Management strategies	Benefit	Probability of success	Cost	BCR
Zone 1				
Regulation	$791,000	0.90	$201,000	3.54
Community education	$439,000	0.80	$20,000	17.57
Rubbish removal	$95,000	0.95	$184,000	0.45
Zone 2				
6 metre fire break	$52,000	0.90	$11,000	4.10
10 metre fire break	$77,000	0.90	$12,000	5.61
15 metre fire break	$101,000	0.90	$14,000	6.66
Zone 3 and 4				
Payments	$17,000	0.81	$4,220,000	0.00
Regulation	$17,000	0.64	$4,580,000	0.00
On-ground support	$14,000	0.90	$398,000	0.03
Landowner training	$15,000	0.90	$6,000	2.33
- zone 3	$1,000	0.95	$1,300	0.80
- zone 4	$14,000	0.95	$4,550	2.92
Zone 5 and 6				
6 metre fire break	$58,000	0.36	$64,000	0.32
- zone 5	$19,000	0.6	$16,900	0.67
- zone 6	$40,000	0.6	$47,100	0.50
10 metre fire break	$84,000	0.36	$97,600	0.31
- zone 5	$28,000	0.6	$19,100	0.87
- zone 6	$59,000	0.6	$78,500	0.45
15 metre fire break	$109,000	0.36	$96,800	0.40

- zone 5	$36,000	0.6	$20,300	1.06
- zone 6	$76,000	0.6	$76,500	0.59
Prescribed burning	$2,000	0.25	$3,093,000	0.00

Table 7 Benefit cost ratios for each management strategy.

Management strategies	Original value(s)	Break-even value(s)	% change
Zone 1			
Regulation	.90	.26	-71
Community education	.50	.03	-94
Rubbish removal	.10	.22	+120
Zone 2			
6 metre fire break	.85,.83,.76,.76,.4	.21,.21,.2,.17,.1	-75
10 metre fire break	.96,.95,.92,.87,.62	.19,.19,.18,.17,.12	-80
15 metre fire break	.99,.99,.99,.97,.84	.15,.15,.15,.15,.13	-85
Zone 3 and 4			
Payments	.90	N[a]	N
Regulation	.90	N	N
On-ground support	.75	N	N
Landowner training	.75	N	N
- zone 3	.80	N	N
- zone 4	.80	.28	-65
Zone 5 and 6			
6 metre fire break			
- zone 5	.85,.83,.76,.76,.4	N	N
- zone 6	.85,.83,.76,.76,.4	N	N
10 metre fire break			
- zone 5	.96,.95,.92,.87,.62	N	N
- zone 6	.96,.95,.92,.87,.62	N	N
15 metre fire break			

- zone 5	.99,.99,.99,.97,.84	.89,.89,.89,.87,.76	-10
- zone 6	.99,.99,.99,.97,.84	N	N
Prescribed burning			
- zone 5	0.4,.2,.1,.1,.0	N	N
- zone 6	0.4,.2,.1,.1,.0	N	N

Table 8. Break-even values (and percentage changes) for uncertain parameters to generate BCRs of 1. For Zones 1, 3 and 4 the parameters tested are the proportional reductions in fire escapes due to the management scenario. For Zones 5 and 6 the parameters tested are the proportional reductions in fire spread to Zone 1.

[a] N means that there is no value within the range zero to 1.0 (the feasible range for these parameters) that results in a BCR of 1.0.