bushfire CRC

INTEGRATED ECONOMIC ASSESSMENT OF FIRE RISK MANAGEMENT STRATEGIES: CASE STUDIES IN CENTRAL OTAGO, NEW ZEALAND, AND MOUNT LOFTY REGION, SOUTH AUSTRALIA

FINAL REPORT FOR THE INTEGRATED ASSESSMENT OF PRESCRIBED BURNING PROJECT

Fiona L. Gibson and David J. Pannell

University of Western Australia

THE UNIVERSITY OF WESTERN AUSTRALIA

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Cover:
Left – Firefighters conducting a prescribed burn. Photo by CFA.
Right – A Volunteer firefighter controls a prescribed burn. Photo by Rebel Talbert, NSW Rural Fire Service.

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Executive summary

There are various options available to fire managers for strategically reducing losses from future fires. With limited funds, an increasing population to protect from fire, and an increasing tendency for people to live in fire-prone areas, fire managers face a significant resource allocation challenge. Knowing which fire-risk mitigation strategies provide the best value for money is potentially of great benefit. However the assessment of fire prevention strategies is complex, requiring integration of a large volume of information of various different types (technical, social, economic).

The aim of this study is to provide insights into the question of which fire-prevention strategies provide the best value for money? The approach taken in this analysis was inspired by INFFER (the Investment Framework for Environmental Resources) (Pannell et al., 2012), particularly by its application to the Gippsland Lakes (Roberts et al., 2012). The management problem addressed in that study was similarly complex as the fire management problem. It was addressed using a quantitative analysis that integrated information about risk, management, costs, and values, in a spatial context, with high levels of stakeholder consultation. A broadly similar approach is applied in this study. We present a quantitative decision framework to provide an integrated assessment of the benefits and costs of fire risk management strategies.

Case studies

The research was commission by the Bushfire Cooperative Research Centre (CRC) in 2011. The CRC put out a call to CRC end-users organisations for expressions of interest to participate in the research. Two end-users, the New Zealand National Rural Fire Authority (NRFA) and South Australia Department of Environment, Water and National Resources (DEWNR) proposed case studies. In New Zealand, the case study was centred in Central Otago region. In South Australia, the case study was the Mount Lofty Ranges region, on the eastern edge of Adelaide.

In both case study regions there is a mix of land uses: urban, peri-urban, agricultural and natural areas. However, the case studies differ in terms of the management problem and the management options to be assessed.

For the Mount Lofty Ranges, the management problem was selection of prescribed burning strategies to protect a range of asset types: life, houses, commercial property, infrastructure, commercial forest, and native forest. Three prescribed burning strategies were identified for analysis, ranging from burning 3 per cent to 11 per cent of the study region per year. The study evaluates the value for money provided by each of these strategies, and provides insights for the public land management agencies into the key factors driving the benefits and costs of prescribed burning.

For the Central Otago case study, the management problem was reducing fire risks to a town and adjoining commercial forest arising from planned burns undertaking by agricultural land managers to clear land and reduce weeds. Strategies to be evaluated included on-farm strategies (payments to reduce burning, regulation, training, logistical support) and off-farm strategies (regulation and education of town dwellers, reducing fuel load within the town, fire breaks, and prescribed burning of conservation land). The aim of the Central Otago analysis was to provide information to two distinct stakeholders groups regarding how their activities contribute to fire risk and which fire prevention strategies provide the best overall value for money.

Both case studies involved extensive consultation with stakeholders and relied on their input in formulating the decision problem, identifying the management options, providing data, providing judgements in cases where data were not available, and providing feedback on preliminary results. For Mount Lofty, consulted stakeholders included experts from various agencies and organisations responsible for management of fires, land, forests or water. For Central Otago, consulted stakeholders included agricultural producers, researchers, and experts from fire, land and forest management agencies.

Model description

The model integrates fire risk, fire spread, the damage caused by fires of different severities, asset values, weather conditions, impacts of fire-prevention options, and costs of those management options. It estimates the benefits and costs of various fire risk management strategies that aim to protect various assets, such as homes, pine plantations, biodiversity, life, industrial and commercial assets and infrastructure. The benefits are calculated as reduced damage to the assets and reduced suppression costs.

A baseline level of expected losses due to fire is estimated for a baseline scenario, which differs for the two case studies. The levels of losses depend on the magnitudes of, and interactions between, all of the factors listed above (fire risks to management costs). The calculations are repeated with a particular management strategy in place. The difference between the two results (with and without management) indicates expected net benefits of introducing the additional management regime, relative to the baseline.

The benefits are measured as *expected* benefits, meaning a weighted average, depending on the probabilities of different possible outcomes. This is important because the benefits and costs vary substantially from year to year depending on weather conditions and other factors. Results should be viewed as providing an indication of average benefits per year over a long run of years. This information, combined with the cost of the management strategy, is used to calculate a Benefit: Cost Ratio (BCR) for each strategy. The model allows the user to simulate many different strategies for fire risk management and observe the estimated BCRs for each.

Data collection

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 (expert working group). Parameter values for the model were determined through a literature review, existing databases and consultation with experts.

Key findings

The key findings across both case studies are as follows.

Various fire risk management strategies have potential to generate benefits, but they should be applied in a targeted way. This was particularly the case for prescribed burning in the Mount Lofty region study, where a general prescribed burning strategy across all sub-regions does not provide value for money but prescribed burning in targeted sub-regions does.

Some strategies have particularly high costs and these are unlikely to provide value for money unless they can generate exceptional levels of fire prevention. The high cost usually occurred because strategies required actions over a large area and therefore incurred costs over a large area.

Benefits from reductions in fire spread from one zone to another were relatively low in both case studies. The majority of benefits were generated from strategies that were applied within or close to the valuable assets. Although information about fire spread was relatively weak, results were not sensitive to changes in the assumptions about spread within a plus/minus 50 per cent range.

On average, benefits from reducing asset losses are much larger than benefits from reducing suppression costs.

The most severe fires tend to cause the majority of losses, even after allowing for the fact that the most severe fires are rare events. This means that the majority of benefits from fire management occur in rare events. In between those rare events, strategies that offer good value for money on a long-term probabilistic basis may have costs in excess of benefits in most years.

The quantity and quality of available data was low for a number of key parameters. Some information was not collected, and some was not in an easily interpretable format.

In both case studies the model results were found to be sensitive to several variables about which uncertainty was high. These provide a potential focus for future data collection.

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Case study 1: Mount Lofty Ranges, South Australia

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1.1 Introduction

There are many strategies that can be implemented to reduce the risk of fire damage to life, property and the environment. One strategy that has received intense debate and scrutiny in the Australian community in recent years is prescribed burning. Prescribed burning is the planned application of fire under prescribed environmental conditions and within defined boundaries, to achieve a resource management objective. There are various benefits and costs from the application of prescribed burning. For example there may be reduced fire intensity and reduced suppression effort (Price and Bradstock 2012), loss or gain in biodiversity through different burning regimes (Burrows and McCaw 2013), a potential decrease in incident and extent of bushfires (Boer et al. 2009) and increased fire risk from uncontrolled prescribed burns.

Assessment of fire prevention strategies is complex, requiring integration of a large volume of information of various different types (technical, social and economic). Our model simultaneously represents existing bushfire fire risk, expected losses through asset damage, fire suppression costs, environmental damage from fires, the costs of conducting prescribed burning and the risk of escapes from prescribed burns, and evaluates the value for money, through benefit: cost ratios, of investments in prescribed burning intended to reduce fire risk to the community. We identify which prescribed burning regimes reduce fire risks at the highest expected benefits per dollar of investment.

1.2 Study area

SA Water (SAW), ForestrySA (FSA) and Department of Environmental, Water and Natural Resources (DEWNR) were identified by the Bushfire CRC as the industry end-users for this case study. The study area chosen by the end-users, in consultation with the project team, is shown in Figure 1. This area was chosen for several reasons:

- the three partner agencies, DEWNR, SAW and FSA, all manage significant parcels of land within the area;

- the area is designated as a Bushfire-Prone Area (under land-use planning) i.e. it has a high fire risk;
- the area contains a significant population centre and a range of land-uses; and
- the area has sufficient data to conduct the analysis.

Figure 1. Mount Lofty Ranges case study location.

Current fire risk management within the study area is predominately through prescribed burning. Prescribed burning is used in the study region for fuel hazard management for bushfire risk mitigation. Although prescribed burning can be used to achieve ecological and research objectives, these applications do not occur in the study area. Prescribed burning does not include back burning or burning out operations used to control bushfires (DENR 2011).

Fire risk management on public land is implemented through fire management (FM) zones. The three zones are:

- Asset Protection Zone (A)

- Bushfire Buffer Zone (B)
- Conservation Land-Management Zone (C)

The purpose of the A zone is to provide the highest level of protection to human life and highly valued built assets. Intensive fuel management strategies are implemented at distances of 40 to 100 meters in the reserve areas immediately adjacent to high-value assets (e.g. residential areas or individual residences, public utilities, visitor areas). The asset being protected may also fall within the A zone (e.g. a visitor centre). Strategically important areas for fire suppression, such as fire access tracks, may also form part of the A zone.

The B zone lies between 40 and 1000 meters away from the assets. In the urban interface a B zone may be used to complement an A zone. The B-zone may also be used to provide strategic fuel reduction, including firebreaks in or around a reserve

The C zone applies to all other areas, including native vegetation, natural and cultural heritage features, grazing areas, leases, salt lakes, plantations, revegetation sites.

In this study, various prescribed burning strategies were evaluated, involving different proportions of the three zones. These strategies are defined below.

1.3 Model description

1.3.1 Overview

The model integrates fire risk, fire spread, the damage caused by fires of different severities, asset values, weather conditions, impacts of fire-prevention options, and costs of those management options in order to estimate the benefits and costs of various fire risk management strategies that aim to protect various assets: homes, pine plantations, biodiversity, life, industrial and commercial assets and infrastructure (which includes water treatment plants, water pipes and work depots). The benefits are calculated as reduced damage to the assets and reduced suppression costs. A base-line level of expected losses due to fire is estimated on the assumption that the existing management and regulatory regime is maintained, but without the use of prescribed burning. The level of these losses depends on the magnitudes of, and interactions between, all of the factors listed above (fire risks to management costs). The calculations are repeated with a particular prescribed burning regime in place. The difference between the two results (with and without management through prescribed burning) indicates expected net benefits of introducing the additional management regime. The benefits are measured as *expected* benefits, meaning a weighted average, depending on the probabilities of different possible outcomes. This is important because the benefits and costs vary substantially from year to year depending on weather conditions and other factors. Results should be viewed as providing an indication of average benefits per year over a long run of years. This information, combined with the cost of the prescribed burning 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 for each. The basic structure of the model was adapted from an earlier study the researchers undertook in the Otago region of New Zealand.

As noted earlier, 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 (expert working group). Parameter values for the model were determined through a literature review, existing databases and consultation with an expert working group. We now describe key aspects of the model.

1.3.2 Asset description

The assets identified within the study area are human life, residential property contents and structures, commercial structures, industrial structures, state-government-owned facilities and infrastructure, pine plantations and biodiversity. Tourism, agricultural productivity and water quality values have not been accounted for. Advice from SAW is that historical fire events have not impacted significantly on the quality of drinking water within the region.

1.3.3 Management sub-regions and strategies

The study area is categorised into 10 management sub-regions. The sub-regions are illustrated in Figure 2 and defined in Table 1. Description of management sub-regions and number of hectares (ha) within each sub-region.

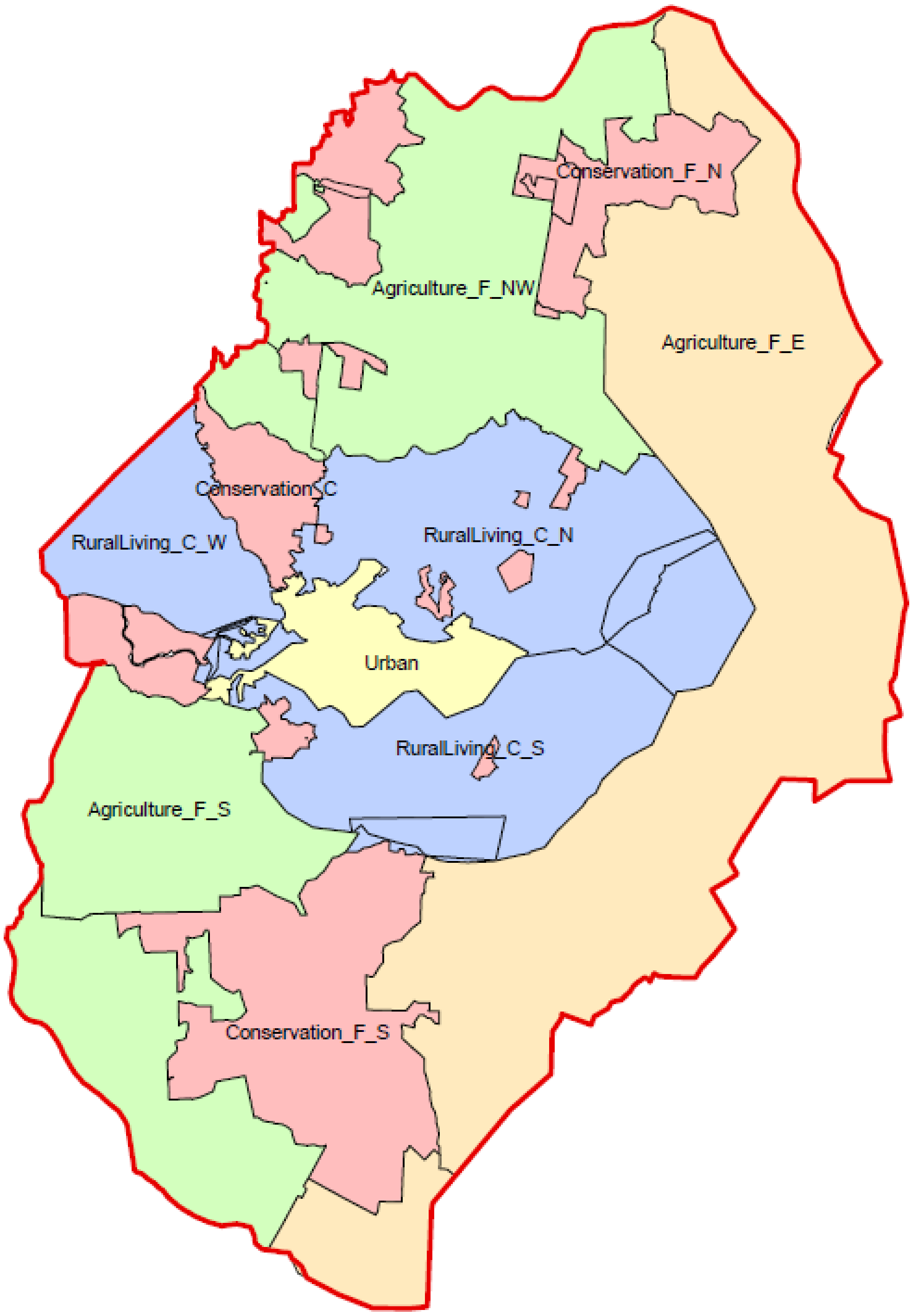

Figure 2. Management sub-regions within the Mount Lofty Ranges study area.[1]

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[1] Rural_Living_C_N = Rural Living North; Rural_Living_C_S = Rural Living South; Rural_Living_C_W = Rural living West = Conservation_C = Conservation Central; Conservation_F_N = Conservation North; Conservation_F_S = Conservation South; Agriculture_F_S = Agriculture South; Agriculture_F_E = Agriculture East; Agriculture_F_NW = Agriculture North-West.

All sub-regions, except the conservation sub-regions, have residential properties. The urban sub-region has concentrated residential development, whereas the rural living sub-region has residential properties scattered through hills and forest. The assets within the conservation sub-region are tourism infrastructure, such as a visitor centre and a wildlife park, state-government offices and service infrastructure, such as treatment plants, depots, pipeline and workshops. There are scattered properties and more-concentrated settlements through the agricultural sub-regions. Different levels of asset values, risks of fire incidents and fire spread were specified for each of the sub-regions (see below).

Table 1. Description of management sub-regions and number of hectares (ha) within each sub-region.

Sub-region	Description	Total	A zone	B zone	C zone
Urban	Dense residential	2059	1	0	1
Rural Living North	Less dense residential adjacent to the north side of Urban sub-region	6538	6	17	293
Rural Living South	Less dense residential adjacent to the south side of Urban sub-region	4740	1	3	48
Rural Living West	Less dense residential adjacent to the west side of Urban sub-region	2701	9	104	69
Conservation Central	Conservation land adjacent to Urban sub-region	2510	134	489	1814
Conservation North	Conservation land not adjacent to but on the north side of Urban sub-region	330	61	508	2659
Conservation South	Conservation land not adjacent to but on the south side of Urban sub-region	5244	2	46	4817
Agriculture South	Agricultural land no adjacent to but on the south side of Urban sub-region	8381	1	1	1686
Agriculture North-West	Agricultural land no adjacent to but on the north-west side of Urban sub-region	8472	7	53	562
Agriculture East	Agricultural land no adjacent to but on the east side of Urban sub-region	19042	0	1	153

The management actions tested in this model are different applications of prescribed burning. Three regimes were chosen by the expert working group and these are:

1. Prescribed burn 100 percent of the A zone and 10 percent of the B zone (100A/10B/0C) each year;
2. Prescribed burn 100 percent of the A zone, 10 percent of the B zone and 5 percent of the C zone (100A/10B/5C) each year; and
3. Prescribed burn 100 percent of the A zone, 10 percent of the B zone and 10 percent of the C zone (100A/10B/10C) each year.

As the A, B and C fire management zones are applied across the study area, prescribed burning occurs in all management sub-regions described in Table 1. Management strategy (2) was identified by the working group as most closely resembling the prescribed burning regime that is currently in place for the study area. The estimated hectares in each fire management zone, within each sub-region are given in Table 1.

1.3.4 Fire risk

Fires may start in any sub-region (Table 1). The probability of a fire incident depends on the weather conditions. Fire weather conditions are categorised in the South Australia fire danger rating system (the Forest Fire Danger Index or FFDI) as Low-Moderate, High, Very high, Severe, Extreme and Catastrophic. A value for the FFDI for each region is generated each day by Bureau of Meteorology using data recorded by the nearest weather station. The probability of a fire incident per day is specified, based on historical numbers of fires in each sub-region. Then, based on the historically observed frequencies of different FFDI days across the year, the expected number of fire incidents per year is calculated for each sub-region, broken down by weather conditions.

The next stage is accounting for fire spread. A fire that starts in any sub-region can potentially spread to any other sub-region in the model. The number of fires occurring in a sub-region during a year is the sum of the number of fire incidents that commence in that sub-region and the number of fires that spread into that sub-region from another sub-region. The probabilities of fire spread from each sub-region to each other sub-region are specified, depending on weather conditions, as the distance between sub-regions and the prevailing wind direction. Combining these probabilities with the number of fire incidents commencing in each sub-region (calculated as described above) allows calculation of the absolute number of fires spreading from each sub-region to each other sub-region, per year, on average.

1.3.5 Fire consequence

Fire consequence denotes the level of loss of infrastructure, life, biodiversity, property (residential, commercial and industrial) and pine plantation value due to fire. There are five fire consequence (damage) classifications used for life, residential property and biodiversity in the DENR Risk Manual: insignificant, minor, moderate, major and critical (see Table 2 for a description fire consequence in relation to life and property). In the absence of damage classifications for industrial and commercial property, infrastructure and pine plantation loss, we apply those specified in Table 2.

For each asset type and fire consequence category, a percentage of assets lost is defined, with the exception of ‘life’. Life lost per fire consequence category is specified in terms of expected number of lives lost for each fire consequence level.

1.3.6 Economics

The expected loss in asset value (*EL*) per year for a particular sub-region for a given scenario is calculated by:

$$EL = \alpha\beta V \tag{1}$$

where α is the expected number of fires per year that affect the assets of that sub-region, β is the proportion of asset value that is lost per fire, and V is the value of the assets in the sub-region. This is calculated for each sub-region and each fire consequence category, and weighted by the frequency of each consequence category.

The suppression effort (*SE*) is calculated by sub-region as:

$$SE = \alpha S \tag{1}$$

where S is the cost of suppression effort per fire. For each sub-region, suppression cost is weighted by the frequency of fires for each consequence category. Suppression cost per fire consequence is assumed to be uniform across each sub-region.

Table 2. Fire consequence categories and description for life and property.

Fire consequence[1]	Description [1]
Insignificant	No fatalities or injuries. Small number or no people are displaced and only for short duration. Little or no personal support required (support not monetary or material). Inconsequential or no damage. Little or no disruption to community. Little or no financial loss.
Minor	Small number of injuries but no fatalities. First aid treatment required. Some displacement of people (less than 24 hours). Some personal support required. Some damage. Some disruption (less than 24 hours). Some financial loss.
Moderate	Medical treatment required but no fatalities. Some hospitalisation. Localised displacement of people who return within 24 hours. Personal support satisfied through local arrangements. Localised damage that is rectified by routine arrangements. Normal community functioning with some inconvenience. Significant financial loss.
Major	Extensive injuries, significant hospitalisation, large number displaced (more than 24 hours duration). Possible fatalities. External resources required for personal support. Significant damage that requires external resources. Community only partially functioning, some services unavailable. Significant financial loss – some financial assistance required.
Critical	Large number of severe injuries. Extended and large numbers requiring hospitalisation. General widespread displacement for extended duration. Extensive number of fatalities. Extensive personal support. Extensive damage. Community unable to function without significant support.

[1] Source: DENR (2011) Fire policy and Procedure Manual: Section 3.

[2] Source: percentages derived by the researchers from the fire impacts (dollars lost and hectares burnt) recorded in the Country Fire Service fire incident database and results published by

[3] Source: frequency of Insignificant and Minor fires determined using the Country Fire Service fire incident database . Moderate, Major and Critical fires determined using DEWNR historical records and expert opinion.

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, which is defined as no prescribed burning. The decision metric evaluating the efficiency of each management strategy in reducing fire risk is a benefit: cost ratio. The benefit-cost ratio (*BCR*) for strategy *X* is calculated as:

$$BCR = \frac{\sum_{R,W}[(SE_{W,R} - \overline{SE}_{W,R}) + (EL_{W,R} - \overline{EL}_{W,R})]}{\sum_{R} C_R} \quad (2)$$

where $SE_{W,R}$ is the cost of suppression effort in weather condition *W* in sub-region *R* for the management strategy being evaluated, $\overline{SE}_{W,R}$ is the cost of suppression effort for the base case, $EL_{W,R}$ is the expected loss of asset value in weather condition *W* in sub-region *R* under the management strategy, $\overline{EL}_{W,R}$ is the expected loss of asset value under the base-case, and C_R is the cost of the management strategy in sub-region *R*. 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 policy with the highest BCR.

1.3.7 Dealing with uncertainty

Uncertainty about model parameters is addressed in a variety of ways. Feedback on the model parameters and model results was elicited from stakeholders in documents and workshops. Sensitivity analysis is used to provide a guide to the robustness of the results (Pannell, 1997).

1.4 Data collection

A variety of data sources were employed: existing research literature, official databases, existing models, and expert opinion. There were a number of information limitations in the available literature and databases. For example, data was missing or known to be inaccurate; or data was aggregated spatially, or across weather conditions, or across fire severity levels, rather than being available at a disaggregated level. In these cases we relied on the expertise of fire experts and land managers, elicited at two workshops or in discussions subsequent to the workshops.

Workshops were held in Adelaide on September 24 2013, 14 November 2012 and 28 March 2012 with participants from the various participating organisations. Participants included representatives of SAW, FSA and DEWNR. Participants played a variety of roles: defining the research problem, specifying the study region, specifying the management regimes to be evaluated, suggesting sources for data, providing data, providing expert opinions for parameters, providing feedback on the quality of data and parameters used, providing feedback on the model structure, and providing feedback on preliminary results.

The following subsections present key data and assumptions used in the analysis.

1.4.1 Asset value

The estimated value of each asset, within each management sub-region is provided in Table 3. The population and residential, commercial and industrial values were sourced from the National Exposure Information System (NEXIS) up-to-date aggregated exposure data based upon building-level detail for all residential, commercial and industrial building in Australia (GeoScience Australia 2013). Contents and structural values are combined to produce residential assets. Only structural values were available for commercial and industrial assets.

GeoScience Australia provides the following descriptions of each data source:

- The population estimate methodology takes into account, the average population per occupied private dwelling structure type for each Statistical Area, the proportion of unoccupied dwellings in the total dwelling stock by structure type, the ratio between the 2011 Estimated Resident Population and the Census population counts and the number of NEXIS derived residential dwellings.
- Replacement cost is the cost to rebuild the existing structure (size and construction material) at current building standards at the current costs.
- Contents value is calculated as a proportion of the replacement cost, adjusted depending on the gross income classification.

The average value per hectare of pine plantation, \$9,083, was provided by FSA. The value covers the loss due to fire, and cost to clear the trees and re-establishment of trees. Cost varies slightly between tree age classes: 1 to 14 years is \$9,250 per hectare, 15 to 29 years is \$10,000 per hectare and greater than 30 years is \$8,000 per hectare. Given the small variation in value range, we used the average across the three age classes.

The Office of Best Practice Regulation recommends a value of $3.5 million per life, which is based on international and Australian research. Due to challenges involved in deriving the Value of a Statistical Life estimates, sensitivity analysis is a recommended (Department of Finance and Deregulation 2008).

The value of the SAW pipeline is estimated at $150 million (300 kilometres x $500 per metre) and the value of the infrastructure (e.g., treatment stations, pumping stations, depot and workshops) is estimated at $185 million. The pipeline is spread throughout the study area, so the values are evenly distributed across all sub-regions. The treatment assets are approximately distributed amongst the sub-regions as follows: 60 percent conservation sub-regions, 30 percent rural living sub-regions, 10 percent agricultural sub-regions and 10 percent urban sub-regions.

Environmental values are relevant in two parts of the analysis: (a) they may be affected by bushfires, so reductions in bushfire risks affect environmental values; and (b) prescribed burning itself may affect environmental values through escaped fires. These impacts are further broken down into two components: the effects of fire on the environment, and the community’s valuation of those effects. All of these aspects are included in the analysis.

Consider the community’s valuation of the environment, including use (recreation) and non-use values (existence value of native plants). Data on these values in dollar terms is not readily available for the case study region. Our approach is to extrapolate a value (termed “benefits transfer”) for native vegetation obtained from another study in South Australia. Hatton MacDonald and Morrison (2010) estimate implicit prices for changes in the area of good quality scrubland and grassy woodland in the Upper South East of South Australia using individual responses to a choice experiment survey. (See Morrison (2009) for a comprehensive description of choice experiments.) When aggregated across the SA population, assuming that 58 per cent of households in South Australia had the same preferences as the average of the sample in this study, the dollar per hectare value of scrubland is $810 and grassy woodland $1192.

Table 3. Value of assets within each management sub-region.

Sub-region	Pines	Biodiversity	Life	Residential	Industrial/ commercial	Infrastructure
Urban	$75,000	$140,000	$17,000,000,000	$1,003,000,000	N/A	N/A
Rural Living North	$370,000	$1,200,000	$9,000,000,000	$580,000,000	$1,100,000,000	$33,000,000
Rural Living South	$250,000	$870,000	$13,000,000,000	$880,000,000	N/A	$33,000,000
Rural Living West	$4,000	$800,000	$6,500,000,000	$499,000,000	N/A	$33,000,000
Conservation Central	$26,000	$2,500,000	$8,300,000,000	$11,000,000	N/A	$67,000,000
Conservation North	$1,500,000	$2,700,000	$5,500,000,000	$2,100,000	N/A	$67,000,000
Conservation South	$5,900,000	$3,200,000	$1,800,000,000	$1,200,000	N/A	$67,000,000
Agriculture South	$470,000	$1,000,000	$14,000,000,000	$1,090,000,000	N/A	$11,000,000
Agriculture North-West	$310,000	$1,600,000	$16,000,000,000	$1,060,000,000	$496,000,000	$11,000,000
Agriculture East	$1,100,000	$890,000	$21,000,000,000	$1,240,000,000	$185,000,000	$11,000,000

Not available (N/A). Assumed to be zero.

The expert working group noted that the conservation value of the study area region is such that it is regarded as a biodiversity hotspot. The Upper South East is not considered to be a biodiversity hotspot. To the best of our knowledge there are no studies within Australia that have estimated a value per hectare for native vegetation within a biodiversity hotspot. Thus, we will use the extrapolated values as a starting point and use sensitivity analysis to explore the implications of alternate values for biodiversity within the study area.

The other aspect is the impact of fire on the environment. This is uncertain and somewhat controversial. Our base-line assumption is that critical fires do cause significant losses of biodiversity values, and that major fires cause modest losses. However, given the uncertainty about this relationship, we apply sensitivity analysis to these parameters.

1.4.2 Fire risk

The frequency of reported fire incidents per year in each management sub-region in each weather category was estimated using data collected by the Country Fire Service (CFS) from January 1 1997 to 11 February 2013. The data consists of reported incidents where a fire crew was dispatched to an escaped fire. In total there were 2722 reported fire escape incidents over the time period, within the relevant fire brigade regions. As the management sub-regions are determined by predominant land use, not fire brigade, the number of reported fire incidents per sub-region are approximated using the proportion of each fire brigade within each management sub-region. In addition, the reported fire incidents caused by prescribed burning were removed from the data so the model reflects fire risk with no prescribed burning regime in place. The number is approximately 1 reported incident per year since the start of the burning program in 2003, which equals approximately 10.7 fires removed proportionally across the management sub-regions.

Each of these aspects depends on the weather conditions. The frequency of each FFDI per year is reported in Table 4. Due to the time required to manually assign reported fire incidents to an FFDI category, the distribution of reported fire incidents across FFDI categories is determined by using a sub set of the incident data: for the year 2005. The distribution of reported fire incidents across FFDIs and predicted absolute number of reported fire incidents per year is provided in Table 4.

Table 4. Frequency of FFDIs, reported fire incident by FFDI and absolute number of fires per year by FFDI and sub-region.

Sub-region	LM	H	VH	S	E	C	Total
Frequency of FFDI per year							
All sub-regions	66.2	18.0	10.1	4.7	0.8	0.2	100
Frequency of reported fire incidents by FFDI							
All sub-regions	0.28	0.33	0.29	0.1	0.004	0.0004	1
Number of reported fire incidents per year by FFDI and sub-region							
Urban living	5.50	6.48	5.69	1.89	0.07	0.01	19.64
Rural Living North	6.26	7.37	6.48	2.14	0.08	0.01	22.34
Rural Living South	4.50	5.31	4.66	1.54	0.06	0.01	16.08
Rural Living West	4.74	5.58	4.90	1.62	0.06	0.01	16.91
Conservation Central	3.06	3.60	3.17	1.05	0.04	0.0044	10.92
Conservation North	2.39	2.82	2.48	0.82	0.03	0.00	8.54
Conservation South	1.85	2.18	1.91	0.63	0.02	0.00	6.60
Agriculture South	3.87	4.56	4.01	1.33	0.05	0.01	13.82
Agriculture North-West	7.38	8.70	7.65	2.53	0.09	0.01	26.37
Agriculture East	9.12	10.75	9.45	3.13	0.12	0.01	32.59

Note: due to a lack of data, the frequency of FFDIs and reported fire incidents by FFDI were assumed to be uniform across sub-regions.

1.4.3 Fire consequence

It was difficult for the expert working group to categorise damaging historical fires using the data. Although the CFS database enables fire managers to record factors that indicate fire consequence - area burnt, economic loss, impact to life and property - for each reported fire incident, there was general inconsistency in reporting of these factors. For example, the CFS data used to estimate fire severity frequencies has an option for recording economic losses and area burnt. However from the 3,742 recorded incidents, 2,018 (53.9 percent) did not report the area burnt and 2,045 (54.6 percent) did not report the economics losses from the incident.

Frequencies for the insignificant, minor and moderate fire consequence were able to be estimated from historical data for life and property damage. They are uniform across management sub-regions and are 1783, 135 and 12 insignificant, minor and moderate fires respectively per century. It was difficult to tell whether there were any ‘major’ and ‘critical’ fires during the 1997 to 2013 period. By reviewing historical data provided by DEWNR and speaking with stakeholders we determined the probability of ‘major’ fires to be 2 in 100 years and a ‘critical’ fire to be 1 in 100 years. We relied on expert opinion to define these probabilities for major and critical fires. Historical impact of fire on biodiversity values was not recorded.

The proportional loss of asset value with each fire consequence category is provided in Table 5.

Another challenging area was the estimation of the relationship between fire weather conditions and fire consequence. The model design is based on recognition that there is not a one-to-one correspondence between weather conditions and fire consequence. Within a set of fires occurring at a given FFDI, losses may vary significantly, depending, for example, on weather changes, fuel loads, the location and timing of the fire and the success of suppression efforts. Therefore, there is a probability distribution of fire consequence levels for each FFDI. In consultation with experts, we made the following assumptions: all reported fire incidents on Low-Moderate and High FFDI conditions are insignificant; the proportion of fires that are of insignificant consequence decreases with more severe FFDI; the proportion of fires that are more damaging increases with more adverse FFDI conditions.

Table 6 shows, for the base-case with no prescribed burning, the estimated probability distributions of fires of different severities, for given fire weather conditions. The same distributions are assumed for all sub-regions. With prescribed burning, the probabilities move slightly towards less severe fires, by an amount that reflects the extent of prescribed burning in each sub-region (see Table 8).

Table 5. Proportional loss of asset value (residential, commercial, industrial, infrastructure, pine plantation and biodiversity) and absolute number of lives lost with each fire consequence category.

Sub-region	Fire consequence category				
	Insignificant	Minor	Moderate	Major	Critical
			Proportion of asset values lost		
Urban	0	0.01	0.05	5	30
Rural living sub-regions	0	0.03	0.1	10	40
Conservation sub-regions	0	0.03	0.1	15	60
Agriculture sub-regions	0	0.01	0.05	5	20
			Absolute number of lives lost		
Urban	0	0	0	0.3	14.9
Rural Living North	0	0	0	0.17	8.29
Rural Living South	0	0	0	0.23	11.27
Rural Living West	0	0	0	0.12	5.77
Conservation Central	0	0	0	0.15	7.39
Conservation North	0	0	0	0.1	4.88
Conservation South	0	0	0	0.03	1.67
Agriculture South	0	0	0	0.26	12.97
Agriculture North West	0	0	0	0.28	13.98
Agriculture East	0	0	0	0.38	18.88

Table 6. Baseline relative frequencies of fire consequence for each FFDI in Conservation North.

Fire consequence	FFDI					
	LM	H	VH	S	E	C
Insignificant	1	1	0.82	0.76	0.68	0.50
Minor	0	0	0.17	0.20	0.20	0.18
Moderate	0	0	0.010	0.032	0.025	0.10
Major	0	0	0	0.010	0.015	0.12
Critical	0	0	0	0.0022	0.08	0.10

1.4.4 Prescribed burning impact on fire risk

We attempted to obtain information from the fire behaviour model PHOENIX RapidFire (Tolhust et al. 2008) to provide parameters regarding the effectiveness of each prescribed burning strategy at reducing fire spread. However, due to the timeframe, we were unable to get robust results from Phoenix for all strategies under all weather conditions. Therefore we elicited this information from the expert working group.

There are four different effects of prescribed burning on fire risk: a reduction in reported fire incidents in subsequent years, an increase in reported incidents caused by escaped prescribed burns, a reduction in fire spread between sub-regions and a reduction in average fire severity. The values used for the first three of these effects are given in Table 7 for one of the 10 sub-regions – Conservation North.

There are equivalent tables for each sub-region. Different sub-regions have different areas of prescribed burning depending on the areas of A, B and C zones that they contain. In adjusting these parameter values between different sub-regions, Conservation North is used as the benchmark and parameters are adjusted in proportion to the average area of prescribed burning per year. The same occurs for the absolute numbers of reported incidents from prescribed burning.

Across all sub-regions the total number of reported fire incidents caused by prescribed burning equals 1 per year for strategy 100A/10B/10C[2], 0.5 for strategy 100A/10B/05C and 0.2 for strategy 100A/10B/0C. These numbers were estimated by the expert working group.

Table 7. The impact of prescribed burning (PB) strategies on fire risk in Conservation North sub-region.

Strategy description	FFDI					
	LM	H	VH	S	E	C
Proportional reductions in reported fire incidents						
100A/10B/0C	0.02	0.07	0.06	0.035	0.025	0.015
100A/10B/05C	0.05	0.15	0.13	0.08	0.06	0.04
100A/10B/10C	0.09	0.27	0.24	0.24	0.11	0.07
Proportional reductions in spread to neighbouring sub-regions						
100A/10B/0C	.02	.07	.06	.035	.025	.015
100A/10B/05C	.05	.15	.13	.08	.06	.04
100A/10B/10C	.09	.27	.24	.24	.11	.07
Proportion reductions in spread to sub-regions that are two sub-regions away						
100A/10B/0C	.005	.018	.015	.009	.006	.004
100A/10B/05C	.013	.038	.033	.020	.015	.010
100A/10B/10C	.023	.068	.060	.060	.028	.018
Absolute number of reported fire incidents caused by escaped prescribed burns						
100A/10B/0C	0	0.008	0.03	0.03	0.001	0
100A/10B/05C	0	0.02	0.07	0.07	0.003	0
100A/10B/10C	0	0.04	0.13	0.15	0.01	0

An important consequence of prescribed burning is that it may reduce the severity of fires burning on recently burnt ground. As well as reducing the likely losses resulting from fires, this results in lower suppression costs. Table 8 shows the relative frequencies for the Conservation North sub-region under the 100A/10B/05C prescribed burning regime. The differences in probabilities between Table 6 and Table 8 are not large, but they are sufficient

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[2] This nomenclature means that the strategy involves burning 100 percent of the A zone, 10 percent of the B zone and 10 percent of the C zone.

to generate significant benefits. The assumed reductions in fire severity are less for less intensive prescribed burning regimes. They are also different in different sub-regions. We use Conservation North as a benchmark, and scale the effect of prescribed burning on fire severity in proportion to the average area of prescribed burning per year in each sub-region.

Table 8. Relative frequencies of fire consequence for each FFDI in Conservation North for the 100A/10B/05C strategy.

Fire consequence	FFDI					
	LM	H	VH	S	E	C
Insignificant	1	1	0.84	0.78	0.70	0.52
Minor	0	0	0.15	0.18	0.18	0.17
Moderate	0	0	0.0090	0.030	0.024	0.10
Major	0	0	0	0.0092	0.022	0.12
Critical	0	0	0	0.0020	0.072	0.090

1.4.5 Prescribed burning costs

Prescribed burning incurs a number of costs. At the start of the financial year a burn program is prepared for each region. Individual burn plans are also prepared, covering environmental assessment, risk assessment, notification of effected parties and post-burn assessment. Prior to implementing the prescribed burn, fuel and site monitoring is required. Personnel and vehicles are required to implement the burn. The post-burn activities include vegetation monitoring and managing weeds that may encroach into the burnt area.

The breakdown of prescribed burn costs for the study area is provided in Table 9. Using the DEWNR data, $416 per hectare is spent on administering the prescribed burning program, $235 on monitoring and post burn weed management and $1127 on the implementation of the burn. The total cost per hectare for DEWNR to undertake prescribed burning within the study area is $1,778. The cost per hectare for FSA and SAW is $239 and $778 respectively. The difference is due to DEWNR absorbing some fixed costs, such as training, therefore only charging for implementing the prescribed burn (pers. comm. Ian Tanner 2013).

According to the expert working group, prescribed burning in the study area is not carried out for ecological improvement. Therefore the ecological impact is included as a cost. To the best of our knowledge there are no studies within the study area that quantify the ecological impact from prescribed burning, therefore we assigned it $0 cost. However, we will use sensitivity analysis to explore the implications from assigning an ecological cost from the prescribed burning regimes.

1.4.6 Fire suppression costs

The cost of fire suppression for each fire consequence in the study area was estimated using information provided by the expert working group (Table 10). Moderate, Major and Critical fires required on-ground and incident management support 24 hours per day, whereas less severe fires do not. This is factored into the calculations of effort and cost (Table 10). The values are provided in Table 10 and apply uniformly to all management sub-regions.

Reported fire incidents in FFDI conditions above 50 (severe, extreme and catastrophic) were considered uncontrollable. Suppression effort is required to protect specific assets, but its effectiveness in extinguishing fires quickly diminishes as fires reach higher severity levels.

1.5 Results and discussion

To illustrate aspects of how the model works and the results it produces, Table 11shows a selection of results for one of the sub-regions – Conservation North. The columns give results for the baseline strategy with no prescribed burning (labelled “No PB”) and for the three prescribed burning strategies, with burning of 100 percent of the A zone, 10 percent of the B zone and 0, 5 or 10 percent of the C zone. These three strategies involve burning 112 ha (3 percent of the area of the sub-region), 245 ha (7 percent) or 378 ha (11 percent) per year, respectively. Results are shown for scenarios where these burning strategies are applied in Conservation North only, with no prescribed burning in the other sub-regions. Results would be different if, for example, they were applied across the whole region.

Table 9. Cost of prescribed burning program per year for the study area, attributed to DEWNR unless otherwise specified.

Activity	$ per year
Weed management and post burn monitoring	
Salaries	$221,000
Contracted burns	$38,900
Consumables and related equipment	$10,000
Burn planning	
Operational mapping	$7,300
Environmental assessment	$138,100
Operations plans	$14,300
Burn implementation	
Pre-burn and post-burn attendance	$500,000
Burn attendance	$497,600
Equipment	$300,000
Total	**$1,727,200**
FSA burn program (260 hectares)	
Burn planning	$19,200
Weed management	$19,500
Burn implementation	$23,500
Total	**$62,200**
SAW burn program ($210 hectares)	
Pre-burn attendance	$12,200
Burn attendance	$52,800
Burn planning	$84,500
Contracted burns	$13,800
Total	**$163,300**

Table 10. Fire suppression effort and cost per activity and fire consequence.

Fire consequence	No. of suppression days	On-ground FTE	No. of vehicles used	Incident management FTE	No. of aircraft used	No. rotaries used	No. air crane used	Prop’n FTE needing food/ accommodation	TOTAL $
Insignificant	0.1	4	1	0	0	0	0	0	$ 200
Minor	1	40	10	4	0	0	0	0	$22,000
Moderate	3	500	50	100	2	0	0	0.3	$910,000
Major	4	700	70	150	4	2	1	0.5	$2,400,000
Critical	7	1000	100	200	6	2	1	0.75	$5,900,000

Consider the average number of fires per year of different severities. Firstly, note that less severe fires are much more frequent than more severe fires, ranging from eight Insignificant fires per year down to 0.062 Critical fires per year (one in 160 years) in this sub-region. Secondly, the benefits of prescribed burning in terms of reduced fire incidents in subsequent years outweighs the risk of escaped prescribed burns. This is reflected in the falling frequencies of fires of each severity level as prescribed burning is applied more extensively. For example, the number of Moderate fires declines from 0.056 to 0.046 per year (from one in 18 years to one in 22 years) as we move from no prescribed burning to the most intensive burning strategy. The declining number of fires is reflected in a decline in the suppression costs (from $129,000 per year in total to $111,000). These expected suppression costs allow for the frequencies of different fire severities and the different suppression costs for fires of different severities.

The total expected asset loss also declines with the more extensive prescribed burning strategies. The model calculates losses separately for residential properties, biodiversity, life, pine forest, infrastructure and industrial properties, as shown in the table. In this sub-region, the greatest average losses are in infrastructure. In other sub-regions, the values of these asset categories vary widely, and this is reflected in the expected losses.

The calculated benefits of prescribed burning are shown at the bottom of the table. These are calculated from the preceding results as differences between the baseline and prescribed burning strategies. Of the two types of benefits measured, the reduction in asset losses is substantially greater than the saving in suppression costs. On the other hand, in percentage terms, the benefits of the most intensive prescribed burning strategy amount to around 1 percent of the total losses, and 14 percent of the suppression costs.

Table 12 shows a breakdown of the costs and benefits of prescribed burning into various components. Results are shown for two sub-regions, based on the 100A/10B/05C prescribed burning strategy in one sub-region at a time. The cost is much larger in the Conservation North sub-region than in Rural Living North, reflecting the much larger areas of burning in the former. In both sub-regions, costs of on-ground operations constitute around 75 per cent of the total costs, with administration at around 25 per cent.

Table 11. Impacts in Conservation North sub-region when each prescribed burning (PB) strategy is implemented in Conservation North sub-region.

		Strategy implemented		
	No PB	100A/10B/0C	100A/10B/05C	100A/10B/10C
Hectares burnt in Conservation North	0	112	245	378
Proportion of Conservation North burnt	0	3%	7%	11%
	Average number of fires per year in Conservation North			
Insignificant	8.01	7.70	7.34	6.80
Minor	0.62	0.57	0.52	0.47
Moderate	0.056	0.052	0.049	0.046
Major	0.011	0.010	0.010	0.010
Critical	0.0062	0.0060	0.0057	0.0056
Total	8.70	8.34	7.94	7.34
Expected suppression cost in Conservation North	$129,000	$123,000	$117,000	$111,000
	Expected asset loss in Conservation North			
Residential	$12,000	$12,000	$11,000	$11,000
Biodiversity	$16,000	$16,000	$15,000	$15,000
Life	$110,000	$106,000	$101,000	$98,000
Pine	$9,200	$8,900	$8,600	$8,400
Infrastructure	$374,000	$359,000	$347,000	$338,000
Industrial	$0	$0	$0	$0
Total	$522,000	$501,000	$483,000	$471,000
	Expected benefit of PB in Conservation North			
Saving in asset losses	-	$20,000	$38,000	$51,000
Saving in suppression cost	-	$6,300	$12,000	$18,000
Total savings	-	$27,000	$50,000	$69,000
Benefits relative to losses without PB	-	5%	10%	13%

The table shows the breakdown of benefits into four components: a reduction in the number of fire incidents in years subsequent to the prescribed burn, reduction in the spread of fires between sub-regions, reduction in the severity of fires, and an increase in fire incidents due to escaped prescribed burns (the latter factor being a negative benefit). The largest benefits are the reductions in subsequent fire incidents and reductions in the severity of consequences caused by fires. These are of similar magnitude, and are similar across these two sub-regions. The proportional reductions are smaller in the Rural Living North sub-region, reflecting lower areas of prescribed burning, but this is offset by that sub-region having greater asset values – around twice as high as Conservation North in total.

The reduction in fire spread is smaller in magnitude in both sub-regions. Although prescribed burning does reduce fire spread to some extent, this is not as large a factor as its impacts on fire incident frequency and fire severity.

Escaped prescribed burns are an important factor, particularly in the Conservation North sub-region. They are around half as costly in Rural Living North – the lower frequency of burning outweighs the higher value of assets in the sub-region. On average, escaped burns are expected to be more than offset by the benefits of prescribed burning, although this may not hold in periods when escapes are relatively frequent.

Table 12. Expected costs and benefits of prescribed burning strategy 100A/10B/05C implemented in Conservation North only and Rural Living North only. Benefits are calculated across all sub-regions.

	Conservation North	Rural Living North
Cost ($ per year for the sub-region)		
Administration	$102,000	$9,300
Operations	$334,000	$30,600
Total	**$436,000**	**$39,900**
Benefits ($ per year for the sub-region)		
Reduction in fire incidents	$49,000	$50,000
Reduction in fire spread	$13,000	$3,000
Reduction in fire consequence	$55,000	$63,000
Escaped prescribed burns	−$55,000	−$23,000
Total (combined benefits)	**$62,000**	**$94,000**

Table 13 shows the distribution of benefits from prescribed burning across the fire consequence categories, for the Conservation North and Rural Living North sub-regions. For all three strategies, the benefits of prescribed burning per fire incident increase dramatically with more damaging fires. These per-fire benefits are multiplied by the expected number of fires per year (Table 11) to calculate the benefits per year. The majority of benefits are generated for critical fires. This occurs despite the fact that critical fires occur very rarely (e.g. once every 160 years in Conservation North sub-region), and that prescribed burning reduces their impact only slightly (by around 10 percent, mainly by converting a small proportion of fires from Critical to Major). The reason is that the losses caused by critical fires are so large that even a small percentage reduction once in 160 years results in much larger average losses per year than those from much more frequent but less severe fires. In other words, moving from less severe to Critical fires, the increase in prescribed burning benefits per fire outweighs the decrease in the frequency of Critical fires.

Table 13. Distribution of fire frequencies and prescribed burning benefits (for strategy 100A/10B/05C) by fire consequence in Conservation North and Rural Living North, with prescribed burning implemented in Conservation North only and Rural Living North only.

	Fire consequence				
	Insignificant	Minor	Moderate	Major	Critical
	Conservation North				
Number of fires per year	8.01	0.62	0.056	0.011	0.0062
Benefit of PB per fire	$20	$6,700	$116,000	$446,000	$5,571,000
Benefit of PB per year	$160	$4,200	$6,400	$4,700	$35,000
	Rural Living North				
Number of fires per year	20.80	1.59	0.14	0.026	0.015
Benefit of PB per fire	$1	$4,600	$19,000	$664,000	$4,135,000
Benefit of PB per year	$22	$7,300	$2,700	$18,000	$62,000

The results up to this point have been intended to provide insights into the benefits of prescribed burning, their constituents and their determinants. Table 14 shows results when all of this information is brought together to calculate benefit: cost ratios for prescribed burning.

These results are for scenarios where the same prescribed burning strategy is applied across all sub-regions. When conducted over the whole region, results indicate that the costs of prescribed burning outweigh the benefits. For all three strategies, the costs are two to three times larger than the expected benefits.

Table 14. Impact to the study area with each prescribed burning strategy implemented in all management sub-regions.

	Strategy implemented		
	100A/10B/0C	100A/10B/05C	100A/10B/10C
Proportion of study area burnt per year	0.5%	1.5%	2.5%
Cost of PB	$611,000	$1,695,000	$2,779,000
Expected benefit of PB			
Saving in asset losses	$260,000	$578,000	$902,000
Saving in suppression costs	$32,000	$60,000	$89,000
Total	$293,000	$638,000	$991,000
Benefit: Cost Ratio	0.48	0.38	0.36

However, as we saw in earlier results, the benefits and costs are not uniform across sub-regions. Table 15 shows the calculation of Benefit: Cost Ratios for each sub-region when prescribed burning is implemented in that sub-region only. Benefits are calculated across all sub-regions, not just the sub-region where the prescribed burning occurs. The highest BCRs of around 3 are for the Urban sub-region. This finding reinforces previous findings that taking preventative action closest to assets is most beneficial (Gibbons et al., 2012). On the other hand, the amount of burning conducted in this sub-region is very small, so the absolute benefits generated are correspondingly small.

Table 15. Costs and benefits of prescribed burning (PB; $/year) in each sub-region independently. The results for each sub-region are for a scenario with prescribed burning in that sub-region only.

		Strategy		
Sub-region	Result	100A/10B/0C	100A/10B/05C	100A/10B/10C
Urban	Proportion burnt	0.04%	0.05%	0.05%
	Cost of PB	$1,600	$1,700	$1,700
	Saving in asset losses	$4,800	$4,800	$5,000
	Saving in suppression cost	$250	$250	$270
	Total expected benefit of PB	$5,000	$5,000	$5,200
	Benefit: Cost Ratio	3.1	3.0	3.0
Rural Living North	Proportion burnt	0.12%	0.34%	0.57%
	Cost of PB	$14,000	$40,000	$66,000
	Saving in asset losses	$34,000	$91,000	$154,000
	Saving in suppression cost	$800	$2,000	$3,800
	Total expected benefit of PB	$35,000	$94,000	$158,000
	Benefit: Cost Ratio	2.5	2.3	2.4
Rural Living South	Proportion burnt	0.03%	0.08%	0.13%
	Cost of PB	$2,300	$6,600	$11,000
	Saving in asset losses	$3,100	$8,200	$13,000
	Saving in suppression cost	$100	$300	$600
	Total expected benefit of PB	$3,200	$8,500	$14,000
	Benefit: Cost Ratio	1.4	1.3	1.3
Rural Living West	Proportion burnt	0.72%	0.84%	0.97%
	Cost of PB	$34,000	$41,000	$47,000
	Saving in asset losses	$45,000	$49,000	$53,000
	Saving in suppression cost	$3,300	$3,600	$4,200
	Total expected benefit of PB	$48,000	$53,000	$57,000
	Benefit: Cost Ratio	1.4	1.3	1.3
Conservation Central	Proportion burnt	7.28%	10.89%	14.51%
	Cost of PB	$325,000	$486,000	$647,000
	Saving in asset losses	$113,000	$162,000	$212,000
	Saving in suppression cost	$20,000	$27,000	$36,000
	Total expected benefit of PB	$133,000	$189,000	$248,000
	Benefit: Cost Ratio	0.41	0.39	0.38

Table 15 continued. Costs and benefits of prescribed burning (PB; $/year) in each sub-region independently. The results for each sub-region are for a scenario with prescribed burning in that sub-region only.

		Strategy		
Sub-region	Result	100A/10B/0C	100A/10B/05C	100A/10B/10C
Conservation North	Proportion burnt	3.40%	7.43%	11.45%
	Cost of PB ($/year)	$199,000	$436,000	$672,000
	Saving in asset losses	$25,000	$49,000	$69,000
	Saving in suppression cost	$6,500	$12,000	$18,000
	Total expected benefit of PB	$32,000	$62,000	$87,000
	Benefit: Cost Ratio	0.16	0.14	0.13
Conservation South	Proportion burnt	0.12%	4.71%	9.30%
	Cost of PB ($/year)	$11,000	$439,000	$867,000
	Saving in asset losses	$580	$20,000	$32,000
	Saving in suppression cost	$160	$5,500	$9,800
	Total expected benefit of PB	$740	$26,000	$42,000
	Benefit: Cost Ratio	0.068	0.058	0.048
Agriculture South	Proportion burnt	0.01%	1.01%	2.02%
	Cost of PB ($/year)	$1,200	$151,000	$301,000
	Saving in asset losses	$590	$66,000	$127,000
	Saving in suppression cost	$30	$3,400	$7,000
	Total expected benefit of PB	$620	$70,000	$134,000
	Benefit: Cost Ratio	0.51	0.46	0.45
Agriculture North-West	Proportion burnt	0.14%	0.53%	0.91%
	Cost of PB ($/year)	$22,000	$80,000	$138,000
	Saving in asset losses	$34,000	$119,000	$215,000
	Saving in suppression cost	$1,300	$4,500	$8,400
	Total expected benefit of PB	$35,000	$124,000	$224,000
	Benefit: Cost Ratio	1.6	1.6	1.6
Agriculture East	Proportion burnt	0.00%	0.04%	0.08%
	Cost of PB ($/year)	$900	$14,000	$28,000
	Saving in asset losses	$520	$8,500	$17,000
	Saving in suppression cost	$30	$400	$900
	Total expected benefit of PB	$550	$8,900	$18,000
	Benefit: Cost Ratio	0.64	0.62	0.65

The three rural living sub-regions had favourable BCRs, ranging from 1.3 to 2.5. Of these sub-regions, prescribed burning appears most attractive in Rural Living North. It generates relatively large expected benefits and modest costs, resulting in BCRs of around 2.5.

Prescribed burning in the conservation sub-regions does not appear to be worthwhile. It is least unfavourable in Conservation Central, which is close to the urban area and two rural living areas. In the other two conservation sub-regions, it appears highly unfavourable. For example, in Conservation South, the costs of prescribed burning are estimated to be 15 to 20 times larger than the benefits. Notably, the conservation areas have the largest areas of prescribed burning, with Conservation South having the largest of all.

Prescribed burning appears worthwhile in only one of the three agricultural sub-regions, Agriculture North-West. This is favoured because it has more fire incidents than Agriculture South (based on historical numbers), and because there is only a very minor area of prescribed burning conducted in Agriculture East.

1.6 Sensitivity analysis

Sensitivity analysis is applied to parameters where there is a high degree of uncertainty about the values used (and to some cost variables that are less uncertain). Benefit: cost ratios were generated for a 50 percent decrease and a 50 percent increase in most of the tested parameter values. The exception is the ecological cost of prescribed burning, which is varied from zero (the base-case assumption) to $550 per ha burnt. Results are provided in Table 16.

The parameters to which results are most sensitive are the cost of prescribed burning per hectare, the effectiveness of prescribed burning at reducing the severity of fire incidents and the number of fire incidents, and the number of escaped fires caused by prescribed burns.

At the other extreme, results are hardly affected by large proportional changes in the value of a statistical life, the effectiveness of prescribed burning at reducing fire spread across sub-region boundaries, the value of biodiversity, and fire suppression costs.

There has been debate about the ecological costs of prescribed burning. The model indicates that varying between zero and very high ecological cost per hectare makes only a minor difference to the BCR of prescribed burning in this case study.

Table 16. Benefit: cost ratio (BCR) and sensitivity of BCR for strategy 100A/10B/05C (across all sub-regions) with 50 percent decrease and 50 percent increase in key parameter values.

	-50% BCR	+50% BCR	Sensitivity
Value of a statistical life	0.36	0.40	0.04
Reductions in fire spread across sub-region boundaries due to PB	0.35	0.41	0.06
Number of fire incidents caused by PB	0.47	0.29	0.18
Reduction in fire incidents due to PB	0.17	0.40	0.23
Reduction in fire severity due to PB	0.24	0.51	0.27
Baseline proportion of fires that spread across a sub-region boundary	0.32	0.43	0.11
Suppression cost for fires	0.36	0.39	0.03
Value of biodiversity per hectare of vegetation	0.38	0.38	0.00
Cost per hectare of prescribed burning	0.75	0.25	0.50
	$0	$550	sensitivity
Ecological cost from PB ($ per ha burnt)	0.38	0.28	0.10

1.7 Conclusion

Evaluating whether prescribed burning provides sufficient benefits to justify the costs is challenging. It requires the integration of information of many different types, including information about asset values, the frequencies of different weather conditions, the frequencies of fires, the consequences of fires of different severities, the relationship between weather conditions and fire consequence, the costs of fire suppression, the costs of prescribed burning, the frequency of escapes from prescribed burns, and the effects of prescribed burning on the number of fire incidents, the spread of fires, fire severity and suppression costs.

For this case study, there were important knowledge gaps for a number of these variables, requiring us to rely on expert judgements by experts from fire and natural resource agencies. Major gaps included information about the frequencies of fires of different severities, the impact of fire on biodiversity value, probability of fire spread between management sub-regions and effectiveness of prescribed burning at reducing fire risks.

Key conclusions from the study include the following:

- The Benefit: Cost Ratio of prescribed burning varies substantially between different sub-regions, depending on the assets they contain, their proximity to other assets, and the frequency of fires in each sub-region. Prescribed burning is more attractive in sub-regions with the most valuable assets and the highest frequency of fires. In this case study, the sub-regions where the benefits of prescribed burning exceeded the costs tended to be the urban and peri-urban ("rural living") areas.
- In some sub-regions, the costs of prescribed burning greatly exceed the benefits. This was particularly so for two of the conservation sub-regions. This result is not because of damage to the conservation land due to prescribed burning, but rather is due to the low estimated benefits from preventing fire spread to other sub-regions with more valuable assets.
- If prescribed burning was applied across the entire region, the estimated costs are more than double the benefits.
- There were not large differences in the Benefit: Cost Ratios of the different prescribed burning strategies within each region.
- The majority of the benefits from prescribed burning are attributable to the more serious fires.
- Of the variables about which uncertainty was high, those to which results were most sensitive were: the reduction in fire severity due to prescribed burning, the reduction in fire numbers due to prescribed burning, and the number of escaped fires caused by prescribed burning.
- Some variables, despite being highly uncertain, would not be priorities for improvement because they have small impacts on results: the cost of fire suppression, the value of a statistical life, the reduction in fire spread due to prescribed burning, the value of biodiversity, and the ecological cost from prescribed burning.

Overall, the study indicates that prescribed burning has potential to generate benefits, but should be applied in a targeted way, rather than being a general strategy across all sub-regions. Consistent with some previous research, prescribed burning is likely to be most beneficial when applied relatively close to valuable assets.

Case study 2: Central Otago, New Zealand

Supported by New Zealand National Rural Fire Authority and Department of Conservation.

2.1 Introduction

There are many strategies that can be implemented to reduce the risk of fire damage to property, 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 issue for managers and 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 have received renewed attention. 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 Central Otago, New Zealand. We identify which management practices intended to reduce the frequency of serious fires provide the highest expected benefits per dollar of investment.

2.2 Existing fire risk and management in Central Otago

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 reported fire incidents across New Zealand from 1991/92 to 2006/07 and found that the Otago region accounted for 41.5 percent of the total national area burnt. The number of wildfires in this region increased over this time frame. There has not been a major fire affecting the Naseby town site to date, but given the high frequency of fires within its vicinity, there is clearly an ongoing risk.

Fire use by landholders and tourists within and around Naseby is highly regulated. There are several pieces of relevant legislation that interact in complex ways (see Figure 3). The core legislative documents for fire management are the *Fire Services Act 1975* and the *Forest* *and Rural Fires Act 1977*. From a landholder perspective, additional relevant legislation includes the *Crown Pastoral Land Act 1998*, the *Resource Management Act 1991*, the *Local Government Act 2002,* and the *Conservation Act 1987*. These acts constrain the actions that can be undertaken on land.

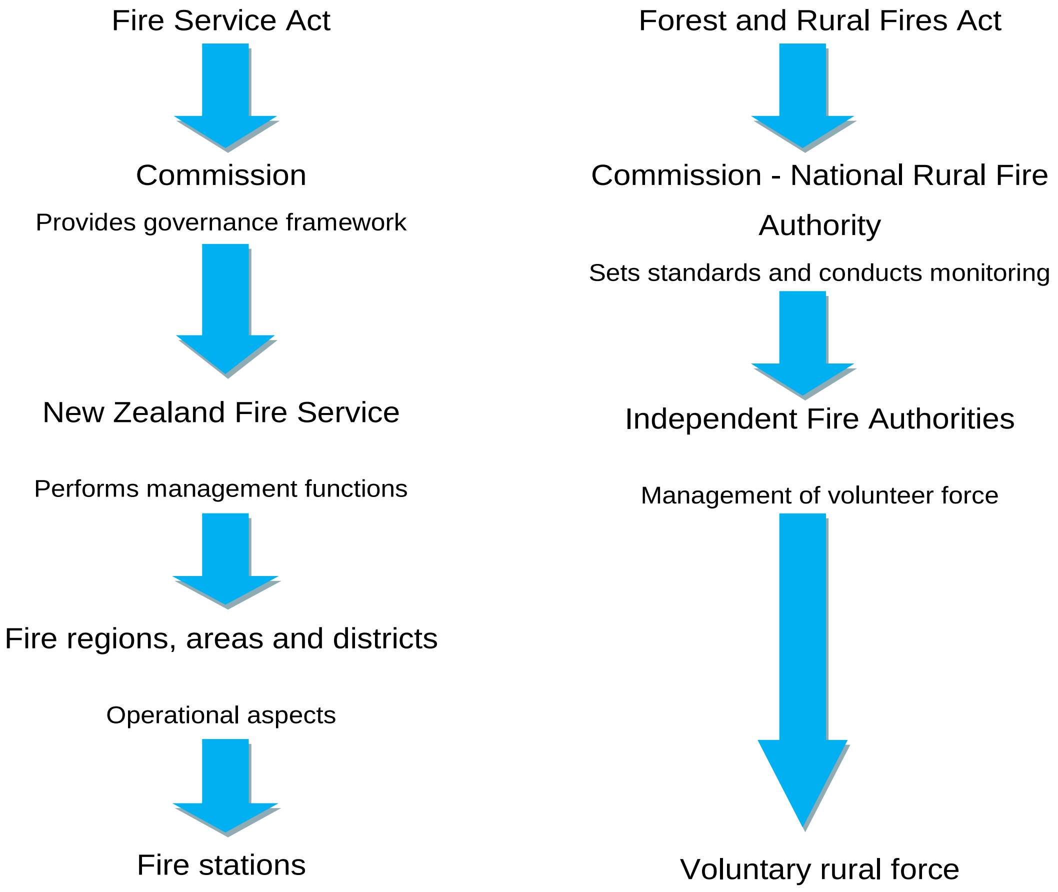

Figure 3. Operational flow for fire management in New Zealand.

Source: New Zealand Fire Service Commission Statement of Intent 2011/14.

Relevant regulations include the *Fire Safety and Evacuation of Buildings Regulations 2006* and, for rural operations, the *Forest and Rural Fires Regulations 2005*. Other relevant guidelines and planning documents that describe how agencies will act include the

Conservation General Policy of the Department of Conservation, code of practice for burning documents prepared by relevant organisations, such as regional councils, the annual *Fire Plan* of individual Fire Authorities, and the New Zealand Fire Service Commission *Statement of Intent 2011/14*.

There are three fire seasons during the calendar year: open, restricted and prohibited. In the open season no fire permit is required to light a fire in the open air. In the restricted season a permit is required to light a fire in the open air. There is a total ban on any type of fire in the open during the prohibited season.

For landowners to ignite a fire for management purposes during the restricted season a number of steps must be taken. First a permit is applied for from the Rural Fire Authority. Permit approval may be conditional on a site inspection and is only valid for 14 days. Approvals to burn may be required from various other agencies that consider different issues, as defined by the respective legislation. For example, some landowners may also need a permit from Department of Conservation (DOC), if they are within 1 kilometre of DOC land.

In the analyses conducted here, we assume that this system of fire permits and fire seasons is retained. The analysis examines additional measures on top of this system, intended to further reduce fire risks.

2.3 Research approach and stakeholder consultation

The approach to the research was highly participatory, requiring input from stakeholders at all stages. The specific research questions were developed in consultation with the funding agency (Bushfire Cooperative Research Centre), the industry partner (National Rural Fire Authority) and local stakeholders.

2.3.1 Stakeholder consultation

The project team travelled to Central Otago to hold a series of workshops with stakeholders to define the decision problem, collect data and foster ownership of the project with the industry partner and stakeholders. Two rounds of workshops were held in Alexandra, Central Otago. The first round was in November 2011.

The practitioners' workshop (17 November 2011) was attended by representatives from the farming community, regional fire authorities, and the Department of Conservation. Discussions centred on the use of fire in land management and land development, current issues in fire use and land management, alternative fire use and land management strategies, the benefits and costs from these strategies, and the strategies that could be used to encourage adoption of altered strategies for fire use in the landscape. A list of participants is provided in Appendix 1.

The researchers' workshop (18 November 2011) was attended by experts in fire behaviour and local biodiversity. Discussions centred on current research into the impacts of burning on hill and high country biodiversity assets, identification of case study sites and future fire use and land management scenarios within these case studies sites. Within the Naseby site we identified the town site and the surrounding commercial and recreational forest as the assets to be protected from wildfires. A list of participants in this workshop is provided in Appendix 1.

As part of the workshops, guidance on the management strategies was sought. The strategies suggested by participants are as follows:

- Payments to landowners to compensate or reward them for not burning for land management.
- 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.
- Regulation prohibiting fire use within Naseby town.
- Implement the Queenstown Red Zone Plan (Queenstown Lakes District Council 2011) within Naseby. 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.
- Fire breaks, of varying widths, around the northern edge of the commercial forest, or around conservation land.
- Prescribed burning of conservation land to reduce fuel load.

At the time of the first workshops, the researchers visited farms and conservation areas within the district to view the issues and the local landscape first hand, and to further discuss the issues with local stakeholders.

The project team held a third workshop with stakeholders on May 2nd 2012, in Alexandra. The workshop was attended by participants from both the practitioners' and researchers' workshops held in November 2011. The aims of the workshop was to give stakeholders an opportunity to provide feedback on the structure of the decision tool developed by the project team, to refine the management strategies tested and to provide feedback on preliminary results. After this workshop, subsequent further discussions with key stakeholders and fire researchers assisted with the finalisation of the model. Following this workshop the project leader and several local experts viewed the Naseby township and surrounds by helicopter.

2.3.2 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 4). 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.

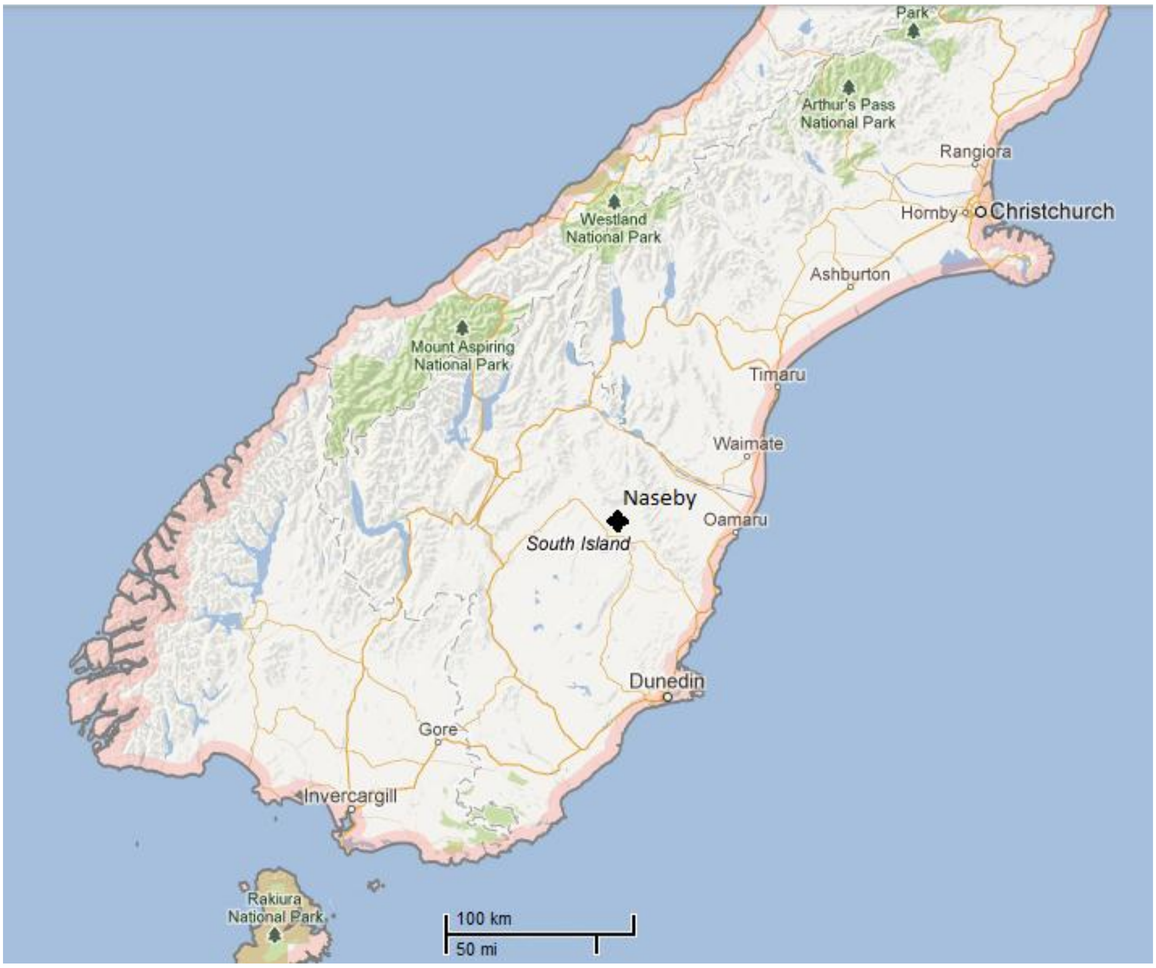

Figure 4. Central Otago case study location.

The population of Naseby swells to over 3,000 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).

2.4 Model description

2.4.1 Overview

The model integrates fire risk, fire spread, the damage caused by fires of different severities, asset values, weather conditions, impacts of fire-prevention options (and costs of those management options). It estimates the benefits and costs of various fire risk management strategies that aim to protect Naseby and the adjacent commercial forest. The benefits are calculated as reduced damage to the assets and reduced suppression costs. A base-line level of expected losses due to fire is estimated on the assumption that the existing management and regulatory regime is maintained but there is no additional management in place. The level of these losses depends on the magnitudes of, and interactions between, all of the factors listed above (from ‘fire risks’ to ‘management costs’). The calculations are repeated with a particular management regime in place. The difference between the two results (with and without management) indicates expected net benefits of introducing the additional management regime. The benefits are measured as *expected* benefits, meaning a weighted average, depending on the probabilities of different possible outcomes. This information is combined with the cost of the management regime to calculate a Benefit: Cost Ratio (BCR) for each modelled management strategy. The model allows the user to simulate many different strategies for fire risk management and observe the estimated BCRs for each.

As noted earlier, 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.

2.4.2 Management zones

The study area is categorised into ten zones, detailed in Table 17. The assets being protected are the town of Naseby (Zone T), its residents and the adjacent commercial and recreational forest (Zone F). The remaining management zones are distinguished by land use, distance and direction to the assets, allowing different fire risks to be specified.

The agricultural zones are PC and PF. The PC zone (“C” for close) denotes land within 5 kilometres of the assets (i.e. the town and forest) and contains two subzones representing land to the north or south of the town. Fires escaping closer to the assets are more likely to spread to the assets than are more distant fires. Also, fires to the north of the assets are more likely to spread to the asset than are fires in the south, due to the prevailing winds coming from the north. The PF zone (“F” for far) denotes agricultural land greater than 5 kilometres and less than 20 kilometres from the assets and contains two subzones representing land to the north or south of the town. 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 would be unlikely to reach it given suppression efforts and natural/man-made fire breaks.

The CC and CF zones are conservation estate relatively ‘close’ to (within 5 km) and ‘far’ from (more than 5 km) the assets. Each has two subzones representing land to the north or south of the town.

Table 17. The management zones, fire risk reduction strategies proposed to be implemented in each zone, total cost of each strategy and percentage likelihood of strategy success.

Management zone(s)	Description	Area (ha)
Town (T)	The town site of Naseby	62
Forest (F)	The commercial forest adjoining Naseby	2100
Private close (PC)	Private land close (within 5 km) to the town and forest. Includes two subzones: private land south and private land north.	5311
Private far (PF)	Private land far (5km> and <20km) from the town and forest. Includes two subzones: private land south and private land north.	94207
Conservation close (CC)	Conservation land close (within 5km) to the town and forest. Includes two subzones: conservation land south and conservation land north.	176
Conservation far (CF)	Conservation land far (5km> and <20km) from the town and forest. Includes two subzones: conservation land south and conservation land north.	35051

2.4.3 Fire risk

Fires may start in any zone. Only a proportion result in a fire incident: a fire requiring a fire crew to extinguish it. The probability of a fire incident depends on the weather conditions, which are broken into five categories consistent with the locally used Fire Danger Class (FDC): Low, Medium, High, Very High and Extreme fire risk. For each FDC and for each zone, the probability of a fire incident per day is specified, based on historical numbers of fires in each zone. Then, based on the historically observed frequencies of different FDC days across the year, the expected number of fires starting per year is calculated for each zone, broken down by weather conditions.

The next stage is accounting for fire spread. A fire that starts in any zone can spread to any other zone in the model. The number of fires occurring in a zone during a year is the sum of the number of fire incidents that commence in that zone and the number of fires that spread into that zone from another zone. The probabilities of fire spread from each zone to each other zone are specified, depending on weather conditions, the distance between zones and the prevailing wind direction. Combining these probabilities with the number of fire incidents commencing in each zone (calculated as described above) allows calculation of the absolute number of fires spreading from each zone to each other zone, per year, on average.

2.4.4 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 level of damage defined for each severity category was developed with participants at the stakeholder workshops. The categories are Low, Medium, High, Very high and Extreme. A description of each severity category, the estimated number of fires in each severity category per century, and the proportional losses of asset value per fire are provided in Table 18. Different percentage losses are specified for Zone T (the town) and Zone F (the commercial forest). These percentage losses are relative to the value of the entire asset (i.e. all buildings and infrastructure in the town, or the entire commercial forest). For example, it is assumed that in future there will be five High-severity fires per century in Zones T and/or F, and that each of these fires will result in loss of 0.28 per cent loss of building and infrastructure values within the town, and/or 17 per cent loss of the commercial forest.

Table 18. Fire severity category, severity description, frequency of fires per century and per year and percentage of asset damaged.

Severity	Description	Estimated fires per century (per year) in Zone T/F	Percentage of entire asset damaged	
			Zone T	Zone F
Low	20 percent of a single property or 10 ha forest	140 (1.4)	0.01	0.48
Medium	One property or 50 ha of forest	20 (0.2)	0.06	2.4
High	Five properties or 350 ha forest	4 (0.04)	0.28	16.7
Very high	30 properties and two lives or 1050 ha forest	2 (0.02)	3.00	50.0
Extreme	320 properties and 30 lives or 1800 ha forest	1 (0.01)	40.7	85.7

2.4.5 Fire risk management strategies

The management strategies detailed in Table 19 can affect the number of fire incidents and the extent of fire spread between zones. The strategies for community education and regulation of burning in Zone T are designed to reduce fire incidents originating from human activity. These strategies affect 80 per cent of fires within Zone T (the other 20 per cent being due to factors other than human causes). The management strategy of reducing vegetation and rubbish within the town is designed to reduce fire spread. Fire breaks are proposed around Zone F to protect it from fires spreading in from other zones and to protect Zone T from fires spreading from Zone F.

The payments, regulation to ban land burns, on-ground support and training management strategies are designed for the agricultural regions, to reduce fire incidents resulting from land clearing burns. According to Doherty et al. (2008), approximately 40 per cent of fire incidents in the area originate from land-clearing burns.

The fire break and prescribed burning strategies implemented in CC and CF are designed to reduce spread from or across these zones to the asset zones.

Table 19. Fire risk reduction strategies for Naseby and the surrounding region.

Strategy	Zone	Description
Community education	Town	Based on the Queenstown Red Zone Plan, the strategy aims to change people’s behaviour through awareness and knowledge of fire risks within Naseby and is targeted at permanent residents or those who own property within the town. The strategy affects the number of fire incidents.
Regulation to ban rubbish burning	Town	Regulation banning all lit fires within Naseby, including household and vegetation fires. This strategy reduces the number of fire incidents.
Council vegetation removal	Town	The Central Otago District Council provides a vegetation and rubbish removal service to reduce fuel load within Naseby. This strategy affects fire incidents and fire spread.
Fire break	Forest	A fire break on agricultural land adjacent to the northern side of the commercial forest. Various widths, 6, 10 and 15 meters, are tested in the model. This strategy affects fire spread.
Fire break	Conservation Close and Far	A fire break on agricultural land around all conservation land. Various widths, 6, 10 and 15 meters, are tested in the model. This strategy affects fire spread.
Payment to cease land burning	Private Close and Far	Payments to farmers to contract them to undertake alternative land clearing approaches to burning. This strategy affects the number of fire incidents.
Regulation to ban land burning	Private Close and Far	Regulation banning all land-management burns on farms. This strategy affects the number of fire incidents.
On-ground support when burning	Private Close and Far	Local fire crew provided to assist farmers when undertaking land management burning. This strategy affects the number of fire incidents.
Training in best-practice burning	Private Close and Far	Two optional one day training courses to provide farmers with information and practical experience in undertaking best practice weed management burns. This strategy affects fire incidents.
Prescribed burning of conservation land	Conservation Close and Far	Planned application of fire within the conservation land, with the aim of reducing fuel load. This strategy affects fire spread.

2.4.6 Economics

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

$$EL = \alpha\beta V \tag{1}$$

where α is the expected number of fires per year that reach the asset, β is the proportion of asset value that is lost per fire, and *V* is the value of the assets in the zone. This is calculated for each asset (Zone T and Zone F) and each fire severity level, and weighted by the frequency of each severity level (Table 18Table 18. Fire severity category, severity description, frequency of fires per century and per year and percentage of asset damaged.).

The suppression effort (*SE*) is calculated by zone as:

$$SE = \alpha S \tag{1}$$

where *S* is the cost of suppression effort per fire. For the asset zones (Zone T and Zone F) suppression cost is weighted by the frequency fires of each severity level. For the remaining zones suppression cost is assumed to be uniform across fire severity level.

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 benefit: cost ratio (BCR). The *BCR* for strategy *N* is calculated as:

$$BCR_N = \frac{[(SE_N - SE_0) + (EL_N - EL_0)] \times P_N}{C_N} \tag{2}$$

where SE_N is the total cost of suppression effort across all zones for the management strategy being evaluated (*N*), SE_0 is the total cost of suppression effort for the base case, EL_N is the expected total loss of asset value under the management strategy, EL_0 is the expected loss under the base-case, P_N is the probability that strategy *N* will deliver the intended benefits (accounting for technical and social risks), and C_N is the cost of strategy *N*. 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 policy with the highest BCR.

2.4.7 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 the calculation of expected benefits. Feedback on the model parameters and model results was elicited from stakeholders in documents and workshops. Sensitivity analysis is used to provide a guide to the robustness of the results and to identify the parameters to which results are most sensitive (Pannell, 1997).

2.5 Data collection

Various data sources were employed: existing research literature, official databases, existing models, and expert opinion. There were a number of information limitations in the available literature and databases. For example, in specific cases data was missing or known to be inaccurate; or data was aggregate spatially, or across weather conditions, or across fire severity levels, rather than being available at a disaggregated level. In these cases we relied on the expertise of fire experts and land managers, elicited at the three workshops or in discussions subsequent to the workshops. The following subsections present key data and assumptions used in the analysis.

2.5.1 Asset value

The combined value of the assets is estimated to be $252 million. This includes the improved value of 306 buildings of – $42 million (obtained from Central Otago District Council); 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 management zones in the model, as the focus of the analysis is on protection of the town and the forest.

2.5.2 Management strategy effectiveness and cost

There was no published literature or existing modelling available on the effectiveness of the management strategies (excluding fire breaks) in reducing fire incidents and spread. Therefore parameter values were elicited from participants at the workshops and through follow-up discussions with experts, particularly Trevor Mitchell (Department of

Conservation) and Mike Grant (Southern Rural Fire Authority). The values used are shown in Table 20. For example, the Regulation strategy in zone T is assumed to reduce the number of fire incidents starting in the town by 90 per cent. The 6-metre fire break in zone F is assumed to reduce the number of fires spreading from zone F to other zones by 40 to 85 per cent depending on weather conditions.

Table 20. Likely adoption (compliance), probability of success, fire ignition effectiveness and fire spread effectiveness for each management strategy.

Management strategies	Adoption/ compliance	Probability of success	Fire ignition effectiveness[1]	Fire spread effectiveness[2]
Zone T				
Regulation	90%	0.90	90%	0%
Community education	50%	0.80	50%	0%
Rubbish removal	100%	0.95	10%	0%
Zone F				
6 metre fire break	80%	0.90	0%	85 – 40%
10 metre fire break	80%	0.90	0%	96 – 62%
15 metre fire break	80%	0.90	0%	99 – 84%
Zones PC and PF				
Payments	80%	0.81	90%	0%
Regulation	90%	0.64	90%	0%
On-ground support	20%	0.90	75%	0%
Landowner training	65%	0.90	80%	0%
Zone CC and CF				
6 metre fire break	100%	0.36	0%	85 – 40%
10 metre fire break	100%	0.36	0%	96 – 62%
15 metre fire break	100%	0.36	0%	99 – 84%

[1] The proportion of fires incidents reduced by the management strategy.

[2] The proportion of fires that the management strategy prevents from spreading to a neighbouring zone

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 (Grant 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 F, PC and PF 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.

Table 21 shows the cost break down for each management strategy when implemented in a single management zone. The costs are assumed to be uniform across zones. The administration cost is a combination of burn planning, such as an employee’s time to plan or supervise the on-ground works, and on-ground works, such as contractor fee for rubbish removal. Environmental damage cost is a measure of the loss in environmental value directly attributable to the on-ground works. In the absence of data on environmental values for this region we assumed an approximate cost of $50 per hectare of conservation land damaged by fire breaks ($50 per year) and prescribed burning strategies ($50 in the year that it is burnt).

The opportunity cost is the difference between the net profit to farmers from their current farming strategy that includes burning, and the net profit of the best strategy that excluded burning (e.g. reliance on herbicides). The farmers suggested $200 per hectare of land burned per year for this cost. The compliance cost compensates the individual for the cost of complying with a new regulation. In the case of regulation banning rubbish removal, this is approximately $200 per hectare per year and for the fire break in Zone F (implemented on the adjacent agricultural land) this is $200 per hectare of fire break per year (i.e. the opportunity cost).

2.5.3 Fire risk

The frequency of fire incidents per year in each management zone in each weather category in the study area was sourced from the New Zealand Fire Service (NZFS) database.

Data was available from January 1 1998 to June 30 2012 (14.5 years). The data consists of reported incidents where a fire crew was called to control a fire. In total there were 223 reported fire incidents distributed across zones as follows: 24 in Zone T; three in Zone F; two in Zone PC (north); one in Zone PC (south); 27 in Zone PF (north); 45 in Zone PF (south); four in Zone CC (north); zero in Zone CC (south); 54 in Zone CF (north) and 63 in Zone CF (south). The zone with the most reported fires per year was CC, with 8.1; the least fires occurred in CC, with 0.

Table 21. Break-down of fire management activity costs for a individual zone. Costs are uniform across management zones.

	Administration	Environment damage	Opportunity cost	Compliance cost
Regulation banning rubbish burning	$200,000/yr	0	0	$200/ha/yr[1]
Community education	$20,000/yr	0	0	0
Rubbish removal	$3,000/yr	0	0	0
Incentive payments	$65/ha/yr	0	$200/ha/yr	0
Regulation	$50/ha/yr	0	0	$200/ha/yr
On-ground support	$100/ha/yr[2]	0	0	0
Landowner training Zone PC	$2,000/yr	0	0	0
Landowner training Zone PF	$7,000/yr	0	0	0
Fire break in Zone F	$5,530/yr[3]	0	$200/ha/yr	0
Fire break in Zone CC/ CF	$5,530/yr[3]	$50/ha/yr	0	0
Prescribed burning	$1780/ha/yr[4]	$50/ha/yr	0	0

[1] The cost of paying a contractor to remove native vegetation around houses.

[2] Approximate cost of one fire crew.

[3] A fixed planning/ supervision of works cost of $5400 per year and an annuity for establishment and maintenance of $130 per year ($750 in year 0 and $40 maintenance for 10 years).

[4] Planning cost of $416 per hectare per year, monitoring cost of $235 per hectare per year and implementation cost $1127 per hectare per year. Based on Department of Environment, Water and Natural Resources figures for Mount Lofty region.

Evidence about the probabilities of fire spread from zone to zone was not strong or comprehensive. Selection of parameters was informed by mapped results from the

Prometheus model (Tymstra et al., 2010) for a number of fire weather conditions, moderated by expert opinion.

2.5.4 Fire severity

There was a general lack of reporting on area burnt, economic loss, suppression expenditure and impact on life for each historic fire. Whilst there are no historical records showing fire severities greater than medium severity, the workshop participants agreed that fires of greater severity are possible. Frequencies for the low and medium fire severities were able to be estimated from historical data. We relied on expert opinion to define the probabilities for high, very high and extreme fire severity.

Also challenging was estimating the relationship between fire weather conditions and fire severity. The model design is based on recognition that there is not a one-to-one correspondence between weather conditions and fire severity. Within a set of fires occurring at a given Fire Danger Class, losses may vary significantly, depending, for example, on weather changes, on fuel loads, on the location and timing of the fire and on the success of suppression efforts. Therefore, there is a probability distribution of fire severity levels for each FDC. In consultation with experts, we made the following assumptions (Table 22). The proportion of fires that are more severe goes up under more adverse FDC conditions. The numbers of total fires increases at higher FDCs, but the proportion of fires that are of low severity goes down. At low FDC, any fires that occur are assumed to be of low severity. At medium FDC, a very small proportion of fires reach high severity. Similarly, at high FDC, a very small proportion of fires reach very high severity. Extreme severity fires are rare, and only occur under very high or extreme FDCs.

2.5.5 Suppression

Suppression effort is stipulated for each zone (Table 23). Data on suppression was not available for many of the fires recorded in the NZFS database. Instead we used the suppression cost estimates from a case study of the Mount Lofty Ranges in South Australia, moderated using the limited examples of suppression costs available within the Central Otago region. . Within Zones T and F we allow suppression costs to vary across fire severity categories. However within the remaining zones we apply a uniform suppression cost.

Table 22. Relative frequencies of fire severities in each Fire Danger Class rating.

	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 23. Suppression costs by zone and fire severity.

Severity	Town	Forest	Private and conservation land (close)	Private and conservation land (far)
Low	$300	$150	$20,000	$10,000
Medium	$20,000	$10,000	$20,000	$10,000
High	$500,000	$250,000	$20,000	$10,000
Very high	$1,200,000	$500,000	$20,000	$10,000
Extreme	$3,000,000	$1,000,000	$20,000	$10,000

2.6 Results and discussion

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: $38,000 in Zone T and $6,000 in Zone F (Table 24). At the other end of the spectrum, extreme-severity fires have extremely low frequency, but extremely high losses. Given the assumptions of this analysis, the high losses outweigh the low frequency, so that for Zone T they provide the highest expected loss ($879,000).

Table 24. Expected loss in asset value per year given the probability of each fire severity occurrence. These results are for the base case (without fire reduction strategies).

	Expected loss ($/year)	
Fire severity	Zone T	Zone F
Low	$38,000	$6,000
Medium	$28,000	$14,000
High	$27,000	$18,000
Very high	$143,000	$38,000
Extreme	$879,000	$32,000
Total	$1,116,000	$108,000

Thus, most of the losses that are avoided by management actions occur only very occasionally. In strategies where expected benefits outweigh the costs, the general pattern is that in most years costs are larger than benefits, but occasionally benefits are much larger than costs. These high losses are largely due to loss of life in extreme fires.

Table 25 shows information about the baseline, number of fires per year, asset losses and suppression costs per year in Zone T and benefits of three specific management strategies in particular zones: a community education program for the town's residents, a 15 m fire break around the commercial forest and regulation to prohibit the use of fire by private land managers. The benefits shown in this table are only for Zone T, the town site.

The baseline frequency of fires declines significantly from less severe to more severe fires. The frequency of each fire type represents the average frequency over a long time period. The frequencies range from 1.65 insignificant fires per year to 0.00894 extreme fires per year. In other words, the long-term average frequency of fires would be: one low-severity fire per 9 months, a medium-severity fire per 5 years, a high-severity fire per 25 years, a very high-severity fire per 55 years and an extreme-severity fire per 107 years.

Of the three strategies, the community education program delivers the largest savings in asset loss and suppression activity ($438,000 and $72,000 respectively), primarily due to the reduction in the average numbers of fires per year in the town. The education program is assumed to result in a notable reduction in fires within the town – down from 1.66 to 0.48

fires per year, on average. The reduction is in fires that would have started within the town itself.

Table 25. Impacts in the Naseby town (Zone T) when selected strategies are implemented.

		Strategy implemented		
	Baseline	Community education in Zone T	15 m fire break in Zone F	Increased regulation in Zones PC and PF
	Average number of fires per year in Zone T			
Low	1.384	0.394	1.380	1.383
Medium	0.205	0.0633	0.202	0.205
High	0.0389	0.0119	0.0382	0.0387
Very high	0.0177	0.00591	0.0171	0.0176
Extreme	0.00894	0.00306	0.00862	0.00888
Total	1.66	0.48	1.65	1.65
Expected asset loss in Zone T	$1,116,000	$705,000	$1,078,000	$1,108,000
Expected suppression cost in Zone T	$72,000	$45,000	$70,000	$72,000
	Expected benefit of management strategies in Zone T			
Saving in asset losses	-	$411,000	$37,000	$7,200
Saving in suppression cost	-	$27,000	$2,000	$390
Total savings	-	$438,000	$39,300	$7,600
Benefits relative to losses without fire management	-	39%	4%	0.7%

The firebreak around the forest has a much smaller impact on fires within the town. This reduction is in fires that start in the forest or start in another zone and spread to the forest and then spread to the town. Clearly, this is a much smaller number of fires. In the base-case scenario, there is an average of 0.21 fires in the forest per year, most of which are of low severity and so easily extinguished before they can spread. The expected number of fires spreading from Zone F to Zone T is 0.008 per year. The effect of the firebreak is to reduce that latter number, which is already small. That is why the benefits of the fire break are so much smaller than for community education.

The third strategy is further regulation of land managers. Since these areas are further from the town than the forest (which is immediately adjacent to the town), the expected number of fires reaching the town from the agricultural zones is lower still: 0.005 per year in total from all of the agricultural zones. As well as the greater distance from the town, fire use in the agricultural zones is already controlled by stringent regulations, meaning that the baseline threat to the town from these zones is low. This puts a cap on the potential benefits of even more stringent regulation. A further factor is that less than half of the fire incidents in the agricultural zones are due to burning by landholders. Overall, the estimated expected benefits to the town of further regulation of agricultural burning are very small ($7,600 per year).

Table 25 also shows the relative importance of losses of assets and suppression costs. On average, asset losses are much larger, and constitute the great majority of savings from management.

The benefit, probability of success (project risk), cost and BCR for each management strategy are provided in Table 26, for standard parameter values. Each strategy has an effect on the zone where it is implemented and additional (smaller) effects on other zones. Results in this table reflect the combination of all these effects. Benefits consist of reduced asset losses and reduced suppression costs for zones T and F, combined. In calculating the BCR, benefits are weighted by the probability of success, which reflects the probability that technical and/or social factors will cause a strategy to fail. The costs shown are the annual cost of implementing each management strategy.

The three largest benefits are for strategies conducted within the town site. Factors contributing to this result are: (a) most fires occur in the town, (b) only a small proportion of fires spread from other zones to the town, and (c) all fires that occur in the town pose a potential risk to the town’s assets.

The three most costly management options are payments to landholders and additional regulation of landholders in the agricultural zones, and prescribed burning in the conservation zones. These strategies are very costly because they involve significant costs per hectare over large areas. For example, the estimated cost of payments in zone PF is $200 per hectare per year over almost 19,000 hectares that would otherwise be burnt by landholders.

Table 26. Estimated benefits (total for all management zones), probability of project success, costs and benefit: cost ratios (BCRs) for each management strategy.

Management strategies	Benefit	Probability of success	Cost	BCR
Zone T				
Regulation	$800,000	0.90	$211,000	3.41
Community education	$445,000	0.80	$20,000	17.79
Rubbish removal	$94,000	0.95	$186,000	0.48
Zone F				
6 metre fire break	$35,000	0.90	$7,700	4.10
10 metre fire break	$54,000	0.90	$9,000	5.26
15 metre fire break	$72,000	0.90	$11,000	5.86
Zone PC and PF				
Payments	$28,000	0.81	$4,220,000	0.0054
Regulation	$28,000	0.64	$4,578,000	0.0039
On-ground support	$23,000	0.90	$398,000	0.053
Landowner training	$25,000	0.90	$9,000	2.48
- Zone PC	$1,700	0.95	$2,000	0.79
- Zone PF	$23,000	0.95	$7,000	3.14
Zone CC and CF				
Prescribed burning	$13,000	0.81	$6,439,000	0.002
6 metre fire break	$28,000	0.90	$98,000	0.26
10 metre fire break	$42,000	0.90	$156,000	0.24
15 metre fire break	$54,000	0.90	$229,000	0.21

Looking at the Benefit: Cost Ratios, the strategies can be placed into several categories:

1. Large benefits, smaller costs, so favourable BCR (Zone T, Regulation and Community education.

2. Large benefits, larger costs, so adverse BCR (Zone T, Rubbish removal)
3. Small benefits, smaller costs, so favourable BCR (Zone F, all fire breaks; Zone PF, Landowner training)
4. Small benefits, large costs, so adverse BCR (Zone PC/PF, Payments, Regulation, On-ground support; Zone CC/CF, Prescribed burning and all fire breaks)

There appears to be a strong argument in favour of implementing strategies in the first category. The model indicates that combining the two strategies results in a BCR of 3.2 (Table 27).

Table 27. Estimated benefits (total for all management zones), probability of project success, costs and benefit: cost ratios (BCRs) for combinations of management strategies.

Combined management strategies	Benefit	Probability of success	Cost	BCR
1. Community education in Zone T, 15 m firebreak in Zone F	$511,000	0.72	$31,000	11.84
2. Community education in Zone T, 15 m firebreak in Zone F, training in Zones PC and PF	$533,000	0.65	$40,000	8.64
3. Increased regulation and Community education in Zone T	$845,000	0.88	$231,000	3.22
4. Increased regulation and Community education in Zone T, 15 m firebreak in Zone F	$906,000	0.79	$242,000	2.96
5. Increased regulation and community education in Zone T, 15 m firebreak in Zone F, training in Zones PC and PF	$928,000	0.71	$251,000	2.64

The strategies in the third category may also be of interest, as they have expected benefits in excess of costs. However, the level of expected benefits is small for these strategies, so there may not be a strong motivation to pursue them.

The strategies in the second and fourth categories are clearly not worth pursuing.

The model allows assessment of combinations of fire management strategies. Table 27 shows brief overall results for a selection of five combined strategies, constructed from individual strategies that were assessed favourably in earlier results (Table 26). Strategies 1 and 2 are by far the most favourable. This is because their costs are substantially lower than those for strategies 3, 4 and 5.

For the most comprehensive strategy in Table 27 (strategy 5), Table 28 shows a breakdown of the estimated expected annual benefits on three dimensions: by zone (T or F), by type of benefit (reduced losses or reduced suppression costs) and by fire severity (low to extreme). The benefits shown are weighted by the average frequencies of the fire severities over a long period. Benefits are shown only for those zones. Not shown in the table is $160,000 savings in annual suppression costs in other zones.

The savings in asset losses and suppression costs increase with more severe fires. In Zone T, particularly for asset loss, the savings increase dramatically. For Zone F, the savings in asset loss are similar for medium and high fire severity, and for very high and extreme fire severity. Also, similar to the results in Table 25, asset losses, on average, constitute the great majority of savings from management.

Table 28. Breakdown of expected annual benefits in Zones T and F from the combined strategy: Increased regulation and community education in Zone T, 15 m firebreak in Zone F, training in Zones PC and PF (Table 27).

Fire severity	Zone T		Zone F		
	Saving asset losses	Saving suppression cost	Saving asset losses	Saving suppression cost	Total
Low	$29,000	$320	$780	$2	$30,000
Medium	$21,000	$3,000	$3,300	$140	$27,000
High	$20,000	$15,000	$4,100	$600	$40,000
Very high	$106,000	$16,000	$12,000	$1,200	$135,000
Extreme	$647,000	$20,000	$11,000	$1,300	$679,000
Total	$823,000	$53,000	$31,000	$3,300	$910,000

2.7 Sensitivity analysis

Given the high levels of uncertainty about aspects of the model, sensitivity analysis provides a useful tool for exploring whether that uncertainty is likely to have affected the results, and which uncertain variables have the greatest influence. Benefit: cost ratios were generated for a 50 percent decrease and a 50 percent increase in the tested parameter values. We show the impacts on BCRs from changes in five key variables for two favourable combined strategies (Table 29) and two unfavourable strategies (Table 30).

For the combined strategy 1 (community education in Zone T and 15 metre fire break in Zone F) the BCR does not fall below 1 given a 50 per cent increase or decrease in the parameters assessed. Results are relatively insensitive to changes in the spread-between-zones parameters. The sensitivity of BCRs to parameter changes is similar for the frequency of extreme fire days, the frequency of fires and the effectiveness of strategies. Project cost has the biggest impact on the BCR for strategy 1.

Table 29. Sensitivity of BCR results to changes in key parameters for select favourable strategies.

Variable(s)	BCR for combined strategy 1 (Table 27)			BCR for combined strategy 5 (Table 27)		
	+50%	−50%	Difference	+50%	−50%	Difference
Spread between zones	12.50	11.10	1.4	2.72	2.55	0.17
Frequency of extreme fire days	17.13	6.49	10.81	3.80	1.47	2.33
Frequencies of all fires	17.77	5.92	11.85	3.96	1.32	2.64
Project cost	7.90	23.69	15.79	1.76	5.28	3.52
Effectiveness of strategies	17.29	5.96	11.33	3.46	1.33	2.13

The BCR for strategy 5 (increased regulation and community education in Zone T, 15 m firebreak in Zone F, training in Zones PC and PF) also remains positive given 50 percent increases or decreases in parameter values. Again, changing the spread between zones has the least impact on the BCR and project cost the greatest. The differences between plus and minus 50% are smaller for this combined strategy than for the previous one, largely because costs are much larger for combined strategy 5.

In Table 30 we test the sensitivity of results to changes in key parameters for unfavourable strategies. The key result is that changes in these parameters do not alter any of these strategies to have favourable BCRs. Similar to the results in Table 29, changing the parameter value for spread between zones has the least impact on the BCR and changing the parameter for project costs has the greatest. This finding is consistent across both strategies shown.

2.8 Information gaps

The project has highlighted a number of information gaps that suggest the desirability of changes in current information-recording procedures. For example, excluded from most incident reports in the NZFS database is information about the severity or impact of the fire, its cause and the suppression effort expended. This made it difficult to determine the frequencies of fires of different severities. Being able to do this is important because losses occur disproportionately in more severe fires.

Table 30. Sensitivity of BCR results to changes in key parameters for select unfavourable strategies.

Variable(s)	BCR for regulation in Zone PC/PF (Table 26)			BCR for prescribed burning in Zone CC/CF (Table 26)		
	+50%	−50%	Difference	+50%	−50%	Difference
Spread between zones	0.0045	0.0033	0.0012	0.0023	0.00084	0.0015
Frequency of extreme fire days	0.0046	0.0032	0.0014	0.0023	0.00088	0.0014
Frequencies of all fires	0.0058	0.0019	0.0039	0.0024	0.00081	0.0016
Project cost	0.0026	0.0078	0.0052	0.0011	0.0032	0.0021
Effectiveness of strategies	0.0058	0.0019	0.0039	0.0024	0.00086	0.0015

Further, reports lacked a measure of the impact of a fire on life and property, such as the fire consequence rating in the Risk Management Procedure, South Australia Department of Water, Environment and Natural Resources. For the purpose of this analysis, this information was sourced from technical experts and stakeholders. However, for future analysis and fire risk management it would be useful to record and categorise the impacts from fires in incident reports.

Knowing the cause of fires was important for determining how much difference a risk management strategy would make to total fire incidents and fire spread within the study area. The report by Doherty et al. (2008) was useful for this purpose; however, their analysis was done at a regional level, not a local level. Farmers at the workshop informed the group that the usage of fire by landholders varies greatly within the region. Our assumption that 40 per cent of fire incidents in the agricultural zones are caused by landholders may be reasonable for some parts of the study area but it may be too high or low for other parts.

It was difficult to determine the causes of fires from the NZFS database. There are three sections in the database where the incident reporter can specify a fire’s cause, choosing from a number of options: incident type, fire cause and heat source. Unfortunately, within each of these three sections the fire cause options available are different, meaning that the fire cause is not reported consistently. This made determining the actual cause of the fire difficult.

The suppression effort expended (i.e. number of trucks/crew, time taken to extinguish fire and chemicals used) was not recorded in the NZFS database. It was not possible to accurately ascertain suppression effort for each fire as only some vegetation fires are directed to the NRFA for cost recovery; urban fires are often dealt with by volunteer crews. It would be useful for analysis and planning for suppression effort to be recorded.

Quantitative information on probabilities of fire spread from different zones seemed, at first, possible to obtain from the Prometheus model. However, a number of factors contributed to limitations in the Prometheus results obtained. One factor was the limited capability of the software to represent spotting and breaching, suppression activity and multiple ignition sources. In addition, several programming issues were encountered. Fire behaviour models should ideally be the main source of information on probabilities of fire spread between zones and the effectiveness of some management activities. However, this we were unable to rely on modelling for this analysis. Fortunately, results were not sensitive to changes in the assumptions about spread (Table 29 and Table 30).

2.9 Conclusion

Evaluating whether a fire risk management strategy provides sufficient benefits to justify the costs is challenging. It requires the integration of information of many different types, including information about asset values, the frequencies of different weather conditions, the frequencies of fires, the consequences of fires of different severities, the relationship between weather conditions and fire consequence, the costs of fire suppression, the costs of management strategy, and the reductions in fire incidents and spread from management strategy.

Key conclusions from this study include the following:

- The Benefit: Cost Ratios of the various management strategies vary substantially between strategies and between different management zones, depending on their proximity to other management zones and the costs of the management strategies. Favourable strategies tended to be in the asset zones T and F.
- Strategies with small costs were more likely to have favourable BCRs (Zone T Regulation and Community education; Zone F fire breaks; Zone PC/PF landowner training; combination Strategies 1 and 2).
- Strategies with large costs were less likely to be favourable (Zone T rubbush removal; Zone PC/PF payments, regulation and on-ground-support; Zone CC/CF prescribed burning and fire breaks; combination Strategies 3, 4 and 5).
- The asset losses, on average, constitute the majority of savings from management strategies, with savings in suppression costs being the secondary benefit.
- In some management zones, the costs of management strategies greatly exceed the benefits. This was particularly so for payments and regulation in the agricultural zones and prescribed burning in the conservation zones. This result is partly because the strategies involve significant costs per ha, over large areas. It is also because benefits from these zones are small, due to low probabilities of fire spread to zones T and F.

- Of the variables about which uncertainty was high, those to which results were most sensitive were: the cost of management strategies, frequency of fire incidents and effectiveness of management strategies.
- One variable, despite being highly uncertain, would not be a priority for improvement because they have small impacts on results: the reductions in fire spread due to the management strategy.

Overall, the study indicates that alternative fire risk management in the study region has potential to generate benefits, but should be applied in a targeted way. Targeting landowners and managing fuel loads on conservation land, although popular solutions by some stakeholders, did not provide benefits in excess of costs. Fire risk management in the study area is likely to be most beneficial when applied relatively close to valuable assets.

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Appendix 1: List of participatns in each case study.

Mount Lofty Ranges expert working group

Name	Organisation
Mike Wouters	Department of Environment, Water and Natural Resources
David McKenna	Department of Environment, Water and Natural Resources
Alex Otterbach	Department of Environment, Water and Natural Resources
Ian Tanner	Department of Environment, Water and Natural Resources
Amanda Slipper	Department of Environment, Water and Natural Resources
Richard Munn	SA Water
David Loveder	SA Water
Justin Cook	ForestrySA
Jackie Crampton	ForestrySA

Central Otago practitioners workshop

Name	Organisation
Briana Pringle	Queenstown Lakes District Council
Owen Burgess	Central Otago District Council
Mike Grant	Southern Rural Fire District
Graeme Still	Dunedin City Council
Phil Melhopt	Central Otago District Council
Bruce Monaghan	Otago Regional Council
Trevor Mitchell	Department of Conservation
Louise Van Der Voort	Central Otago District Council
Andrew Paterson	Farmer
Richard Burdon	Farmer
Peter Hore	Farmer
Jonathan Wallis	Farmer
Randall Aspinall	Farmer

Bob Douglas	Federation Farmers
John Kerr	Forester
Greg Kendall	Forester (Ernslaw One)
Heath Lunn	Forester (Ernslaw One)
Dave Hunt	Department of Conservation
Marcus Simons	Department of Conservation
John Barkla	Department of Conservation
Tony Perrett	Department of Conservation
Rob Wardle	Department of Conservation
Mike Tubbs	Department of Conservation
Paul Hellebrekers	Department of Conservation
Marian van der Goes	Department of Conservation
Stuart Anderson	MAF
Murray Dudfield	National Rural Fire Authority
Russell Barclay	National Rural Fire Authority

Central Otago researchers workshop

Name	Organisation
Dave Hunt	Department of Conservation
Grant Pearce	Scion (Crown Research Institute)
Veronica Clifford	Scion (Crown Research Institute)
Karen Bayne	Scion (Crown Research Institute)
Geoff Rogers	Department of Conservation
Ian Payton	Landcare
Barbara Barratt	AgResearch
Grant Norbury	Landcare
Marcus Simons	Department of Conservation
Nick Ledgard	Private

Appendix 2: Data needs for integrated economic assessment of bushfire prevention strategies.

This study has provided valuable experience in the conduct of integrated economic assessment of bushfire prevention strategies. Being the first study of its kind in Australia or New Zealand, we faced a number of new challenges. One such challenge was the availability of suitable data. Integrated economic assessment is, by its nature, data intensive. In particular, it requires data of a variety of different types to be brought together. Experience in other contexts (e.g. natural resource management, agriculture) shows that, even for issues where technical research has been conducted, it is common for that research not to provide the specific data required for integrated economic assessment. Commonly, technical research is not formulated and conducted with the needs of management decision making in mind, and the standard scientific outputs often do not meet these needs without further adjustment or extrapolation. This proved to be the case in these fire case studies as well.

However, as the case studies show, integrated economic assessments have great potential to contribute to thinking and decision making about fire management. They can help to identify fire management strategies that can deliver the best value for public money, and strategies that should be avoided because their costs are much greater than their benefits. We hope that the examples of these case studies can lead to additional such studies in Australia and New Zealand.

However, for that to happen, the same sorts of data will be required. To assist agencies prepare for or conduct similar integrated economic assessments, we have prepared a brief outline of the data requirements. The hope is that this may influence future data collection efforts.

Setting the context for the analysis

Before determining specific data requirements, it is necessary to define certain aspects of the analysis.

1. Define the baseline regime. Usually this consists of the current fire prevention and fire management regime. In other words, it is a business-as-usual scenario, as it was, for example, in the New Zealand case study. However, the baseline may be a scenario where there are fewer management actions than in the current real-world regime. For

example, in the South Australian case study, the baseline was defined as no prescribed burning. The choice between these two options determines the interpretation of the results, because benefits and costs are estimated relative to the baseline.

2. Define alternative regime. These are the new management or policy regimes that are to be assessed. For example, in the South Australian case study, several prescribed burning strategies were defined. The analysis then evaluates whether these alternative management or policy regimes are superior to the baseline regime, in terms of value for money.
3. Define the case-study region and sub-regions, and identify their characteristics. Capture this information in a map.

Data requirements

The data requirements are outlined, in broad terms, in the following series of small tables. The tables are structured as a hierarchy. The numbers show the levels of the elements within that hierarchy. For example, the first table shows that the overall assessment has three constituents: benefits, risks and costs. Subsequent tables show how these constituents are further broken down into sub-constituents. For example, benefits are broken down into two types: the reduction in asset losses resulting from the alternative regime (relative to the baseline) and the reduction in suppression costs.

At each level in the hierarchy, elements are further broken down until eventually we reach a description of a specific data requirement. Here is one example of a pathway through the hierarchy to a specific data requirement:

Overall assessment → Benefits → Reduction in suppression costs → Suppression costs for baseline scenario → Quantify levels of each element of suppression cost for different levels of fire severity/consequence → Quantify the expected number of days per year of each level of fire severity/consequence → The probabilistic relationship between weather conditions and fire severity/consequence, from which we can determine the probability distribution of weather conditions.

1. Overall assessment (e.g. Benefit: Cost Ratio)	2. Benefits 2. Risks 2. Costs

2. Benefits	Breakdown of benefit types 3. Reduction in asset losses 3. Reduction in suppression costs

3. Reduction in suppression costs	4. Suppression costs for baseline scenario 4. Suppression costs for alternative scenario

4. Suppression costs for baseline scenario Quantify all of the elements of suppression costs • Vehicles • Incident management FTE • Aircraft • Foam • Food/accommodation	5. Quantify levels of each element of suppression cost for different levels of fire severity/consequence

5. Quantify levels of each element of suppression cost for different levels of fire severity/consequence	6. Quantify the expected number of days per year of each level of fire severity/consequence • The probabilistic relationship between weather conditions and fire severity/consequence • The probability distribution of weather conditions

4. Suppression costs for alternative scenario	5. Reduction in the suppression cost in the alternative regime relative to the baseline regime.

5. Reduction in the suppression cost in the alternative regime relative to the baseline regime.	6. Reduction in fire numbers due to the alternative regime 6. Reduction in fire severity/consequence due to the alternative regime

	6. Reduction in spread of fires due to the alternative regime These could be obtained from a fire simulator.

3. Reduction in asset losses	Breakdown of losses by asset types 4. Life 4. Houses 4. Commercial property 4. Infrastructure 4. Environmental assets

4. Asset types	5. Asset losses for each asset type for baseline regime 5. Asset losses for each asset type for alternative regime

5. Asset losses for each asset type for baseline scenario	6. Asset losses for each level of fire severity/consequence, for each asset type, in different regions or sub-regions

6. Asset losses for each level of fire severity/consequence	7. Quantify the expected number of days per year of each level of fire severity/consequence • The probabilistic relationship between weather conditions and fire severity/consequence • The probability distribution of weather conditions

5. Asset losses for each asset type for alternative regime	6. Break down the effect of the alternative regime into constituents • Reductions in the number of fires • Reductions in spread of fires • Reductions in severity/consequence of fires • Possible adverse side effects of the regime (e.g. escaped prescribed burns)

6. The effect of the alternative regime	7. Technical effectiveness of the alternative regime at reducing asset losses (e.g. depends on how many of the fires are caused by factors that the new regime addresses) 7. Predicted level of uptake/compliance with the alternative regime 7. Time lags between taking action and generating benefits (delayed implementation, impact, adoption, threat)

2. Risks (these are risks associated with successful implementation of the new management/policy regime, not risks of damage, which are already accounted for above)	3. Technical risks 3. Socio-political risks 3. Financial risks 3. Management risks

2. Costs (of implementing the new management /policy regime)	3. Administration costs 3. Operations costs 3. Environmental costs (e.g. adverse environmental outcomes from prescribed burning) 3. Compliance cost 3. Opportunity cost