Attachment 2

Economic assessment of bushfire risk management options in Western Australia: case studies in the Perth Hills and in the south-west of Western Australia

REPORT PREPARED FOR THE STATE EMERGENCY MANAGEMENT COMMITTEE SECRETARIAT

Veronique Florec and David J. Pannell

June 2016

TABLE OF CONTENTS

List of figures

LIST OF TABLES

1. BACKGROUND OF PROJECT

In February 2015 the Minister for Emergency Services requested the State Emergency Management Committee (SEMC) Secretariat undertake a strategic bushfire stocktake. The stocktake had four major components: (1) identify the full range of government activities and expenditure directed towards bushfire risk management in Western Australia (WA), (2) identify the funding sources and policy arrangements that support these activities (3) examine investment arrangements in other Australian jurisdictions, and (4) identify funding and policy options concerning the prioritisation and allocation of bushfire risk management investment. One central question that the stocktake seeks to answer is: how productive is the management of bushfire-related risk in the State? To help answer this question, a key subcomponent of the stocktake is an economic assessment of various bushfire-risk management options. UWA has been commissioned by the SEMC to conduct this economic assessment.

The main purpose of the economic assessment is to determine which fire management option or which combination of options provide the best value for money. By providing this information, the assessment may contribute to the evaluation of policy options facing the State, particularly related to the prioritisation of bushfire risk management investments. This could be very useful to fire managers and policy makers to optimise the allocation of the available resources for bushfire management in the State.

The analysis evaluates a set of management options selected with experts in the field and compares them with the *status quo* in order to determine which pathways are more likely to generate additional benefits to society. For this purpose, the analysis quantifies the costs and benefits of applying the selected management options in two different case study locations in WA and discusses the implications for other localities in the State. The study clearly explains what the management options evaluated involve, how the costs were derived, and the opportunity costs of not applying those options in the current bushfire management program. It also elucidates the trade-offs between available options, which may help policy makers and fire managers weight one alternative against another when making investment decisions in fire management activities.

There is a pressing need for this type of analysis. Funds for bushfire-risk management are limited but the bushfire threat to society continuous to increase (Bowman *et al.* 2009; Morgan 2009; Williams *et al.* 2011), particularly with predictions for climate change (Bradstock *et al.* 2012; Cary *et al.* 2012) and the increasing population living in fire-prone areas (Gill and Williams 1996; Morgan *et al.* 2007; Mutch *et al.* 2011). As a consequence, fire managers face a challenging resource allocation problem and they would greatly benefit from knowing which strategies generate the most significant net benefits. However, economic analyses of bushfire management options that illustrate the implications of different uses of the resources available are rare. Despite the significant amounts of money invested in bushfire risk mitigation activities every year, there is little information on the value for money that each option provides and the trade-offs between them to assist fire managers in their decision making. This study aims to provide insights into these issues in the south-west of WA and infer state-wide implications from these insights.

The south-west of WA presents an interesting case of study because of the complexity of management in the area. In this part of the State, there are numerous areas where highly flammable vegetation and human assets are intermingled, which makes the protection of those assets more difficult because of the spatial interactions between housing and fuels (Bar Massada *et al.* 2011). These urban-rural interface areas have become a real challenge for fire managers and policy makers (Marzano *et al.* 2008). In addition, the south-west is located within an internationally recognised biodiversity hotspot and the environmental significance of the area needs to be taken into account in land management (Burrows 2008; Burrows and McCaw 2013). This produces a complex fire-management environment, where there are multiple objectives that compete against each other for the use of resources, and knowing which investments provide the highest returns becomes all the more important.

The results of this analysis may be used for three main purposes: (1) identify the options that provide the best value for money, which may help in the prioritisation of different investments in fire management, (2) elucidate trade-offs between the available options, which will assist in decision making, and (3) identify areas of high uncertainty, where it is necessary to collect additional information in order to make better informed decisions. This type of economic assessment is useful for estimating what is gained or what is lost by making a particular decision and identifying the parameters that may significantly influence the results.

The economic assessment of bushfire management options is complex. It requires the combination of different types of information (technical, economic, social) and the consolidation of large amounts of data. The approach taken in this study uses a quantitative analysis that integrates information about bushfire risk, bushfire spread, expected damages, management costs, the different assets a risk in the landscape and their values, to create a spatially-explicit model that calculates benefit-cost ratios for each of the management options evaluated. In this way, the model identifies the management option or options that generate the highest expected benefits per dollar invested. The approach was inspired by INFFER (the Investment Framework for Environmental Resources) (Pannell *et al.* 2012), a framework designed to develop, assess and prioritise environmental and natural resource projects. From its application to the Gippsland Lakes (Roberts *et al.* 2012), INFFER was modified to evaluate fire management options in South Australia and in New Zealand (Gibson and Pannell 2014). The model used for the application of INFFER to fire management in South Australia and New Zealand was adapted in this study to the Western Australian context.

The contract for this research required the economic model to be applied to two locations in WA with different mixes of land uses: (1) one location was to include a mix of urban, peri-urban and natural areas; and (2) the other was to include a mix of rural, agricultural and natural areas. The locations of the case study areas were selected in conjunction with experts in fire management from the Department of Parks and Wildlife (DPaW) and the Department of Fire and Emergency Services (DFES), and participants from other relevant agencies such as the SEMC Secretariat, the Botanic Gardens and Parks Authority (BGPA), the Department of the Premier and Cabinet (DPC), and the WA WA Local Government Association (WALGA). The land uses and bushfire management contexts for different potential locations were examined during two workshops with the help of these experts in order to ensure that the land-uses mixes required for the analysis were represented in the case studies areas. The following locations were selected: (1) case study area 1 is a combination of two Shires: the Shire of Mundaring and the City of Swan. This area represents the mix of urban, peri-urban and natural areas. From this point forward, this case study area is referred to as the Perth Hills. (2) Case study area 2 corresponds to the Shire of Bridgetown-Greenbushes. This area represents the mix of rural, agricultural and natural areas. This case study area is hereafter referred to as the South-West area. Both study areas are described further in Section 3.

The management options to be evaluated in the economic assessment were also discussed and selected during the workshops with experts. Several management options were discussed, including prescribed burning, maintenance of fire breaks, community awareness campaigns, penalties for non-compliance, land-use planning, building regulations, and increased capacity for land owners to manage their own land. Of these options, three were selected for this study: (1) increased fuel reduction through the application of prescribed burning and mechanical works, (2) land-use planning to reduce future developments in high-risk areas, and (3) support for the development of community groups that provide land owners with an increased capacity to manage fuels in their own land. Each of these options is explained in more detail in Section 2.4. The model evaluates a hypothetical increase in investment in each these options separately and compares it with the *status quo* to estimate the benefits (i.e. asset losses avoided and suppression costs savings).

This report is organised as follows. Section 2 explains the method used for the analysis and how the key parameters were estimated. Section 3 describes the two case study areas, their land uses, fire history, and management context. Section 4 presents the results and Section 5 the sensitivity analysis. Section 6 summarises the conclusions and implications drawn from this study, and Section 7 suggests some recommendations for policy.

2. METHODS

2.1. Model description

The model used for the Integrated Assessment of Fire Risk Management Strategies (Gibson and Pannell, 2014) has been adapted to the Western Australian context for this analysis. The model performs a quantitative analysis of the three management options selected by simultaneously representing bushfire risk, bushfire spread, the damage caused by fires of different severities, asset values, fire suppression costs, environmental damage caused by the fires, weather conditions, the impacts of applying the management options evaluated, and the costs of those management options.

The costs of a management option correspond to the estimated increase in resources that would be required to implement the option (i.e. in addition to current expenditure). These costs were calculated using data from the management agency(ies) responsible for the implementation of the option, if it is currently implemented, or from estimates provided by Local Government, if the option is not applied at present (see more detail about data collection in Appendix 1). The benefits of a management option correspond to the reduction in asset damages and in suppression costs that may be achieved by implementing the option, compared to the level of damages and suppression costs that could be expected if the *status quo* was maintained. The *status quo* is hereafter referred to as 'business as usual'. The level of expected losses and suppression costs with and without the implementation of the options evaluated may be different for each case study area. Because of variations in weather conditions, which generate a wide range of fire severity and losses, the model represents probability distributions for the various inputs and outputs. Thus, the benefits are reported as expected values; that is to say, total benefits correspond to the weighted average, depending on the probabilities of different possible outcomes.

The model evaluates the implementation of each management option in addition to what is already done in each case study area, that is, in addition to the current scheme (business as usual). The parameters used relate to changes that can be achieved given the current management context and current fuel loads. If those changes were applied to a different context or a different initial situation, they may not generate the same results. Thus, the analysis evaluates the benefits for the direction of change, using as a starting point the current scheme in both locations. It does not capture the full benefits that emerge from the long-term application of the current scheme (i.e. the benefits of the management options that are currently in place compared to doing nothing).

Each management option is evaluated at a point in the future under the assumption that it has been applied for long enough to generate its full benefits. This means that the analysis estimates the costs and benefits for each management option for a year in the future, assuming that the particular strategy has been in place for some time (e.g. 10 years) so that its performance has stabilised. Therefore, the model is not suitable for tracking a transition phase from the current management regime to a future alternative regime. The costs of transitioning from the current practice to the successful implementation of the management options evaluated are not included in this analysis. Thus the model is to be used for the strategic evaluation of various alternative future regimes and to observe the performance of each option if it is successfully implemented. The model does not evaluate if there is a need for additional investments for a particular management option to reach that point of successful implementation.

2.2. Benefits of the approach

By combining technical information on fire risk and fire management with economic and social data, this model provides a fully integrated assessment of bushfire management options. It can give fire managers and decision makers the ability to compare management options using a common unit of measure (dollars) in order to assess one option against another. With the results generated with this model, it is possible to compare the value for money generated by each option, which can greatly improve the confidence of strategic decisions in fire management.

The model can use existing knowledge in the form it is available, whether it is from the peer-reviewed literature or an informed estimate from an expert in the field. Accordingly, it can identify areas where it would be better to collect more information to improve or facilitate decision making. In addition, this model has already been successfully used in South Australia and in New Zealand (Gibson and Pannell 2014) to answer similar questions in fire management.

2.3. Assets at risk

The assets at risk included in this analysis that can be damaged or destroyed by bushfires are:

- Human life: This is represented in the model in the form of the value of a statistical life. The Office of Best Practice Regulation recommends a value of $3.5 million per life. This value is based on international and Australian research. However, due to challenges with deriving this value, sensitivity analysis is recommended (Department of Finance and Deregulation 2008).

- Built assets: This includes residential, commercial and industrial buildings. The value of each building corresponds to the replacement value of the building; that is, the amount of money it would cost to rebuild the asset if it had been destroyed by a fire. For residential buildings, this replacement value includes the cost of replacing the contents inside the buildings and rebuilding the structures. For commercial and industrial buildings, this replacement value only includes the cost of rebuilding the structures.
- Infrastructure: This includes some of the key infrastructure assets in the Shires.[1]
- Plantations: This corresponds to pine plantation value and hardwood plantation value that may be lost due to fire.
- Biodiversity: This corresponds to the value of biodiversity per hectare that may be lost to fire, based on estimates used by Gibson and Pannell (2014) for the model used in the South Australian case study.
- Agricultural production: This corresponds to the income streams that may be lost if a fire destroys the trees or livestock that are sold as agricultural products. It also includes the value of crops and grazing at risk, as well as the replacement value of fences in each case study area.

Bushfires can also impact on other assets and resources such as tourism, the economic performance of an industry, water quality, health (e.g. impacts from smoke, anxiety) and memorabilia. However these other impacts are not included in this analysis, so the estimated benefits would tend to be lower than if they had been included. At present, there is not enough information on the value of these assets in WA to include them in the analysis.

2.4. Management options evaluated

Several management options were discussed with the expert working group in order to select the ones that were going to be evaluated. Some of the options discussed were prescribed burning, maintenance of fire breaks, community awareness campaigns, penalties for non-compliance, land-use planning, building regulations, and increased capacity for land owners to manage their own land.

---

[1] Because of the limited amount of information available on the replacement value of key infrastructure assets, the value of infrastructure in this report is considered to be conservative.

The expert working group selected the options for which they believed that more data was available and for which it was possible to create plausible scenarios to evaluate against the *status quo*. They considered that for other options there was not enough data available to estimate the effects of their implementation. The three options selected by the expert working group were: (1) increased fuel reduction through the application of prescribed burning, (2) land-use planning to reduce developments in high-risk areas, and (3) support for the development of community groups that provide land owners with an increased capacity to manage fuels in their own land.

From subsequent discussions with Local Government, there was the realisation that other options were more relevant to fire management in their area than the ones listed above. For instance in the peri-urban area (Perth Hills), both Shires do a great deal of mechanical fuel reduction, whereas in the rural-natural area (South-West), the Shire does more prescribed burning than mechanical works. Since mechanical works represents the majority of investment in fuel reduction in the Perth Hills area, investment in mechanical works was included in the first option.

From discussions with Local Government it was also apparent that the support for the development of community groups that provide land owners with an increased capacity to manage fuels in their own land would take a different form in each case study area. In the Perth Hills, it is through engagement with the community that private land owners improve their knowledge and capability for fire-risk management in their own land. In the two Shires in this case study area, local government staff inspect private properties and help landowners identify potential fire hazards in their properties.[2] With their expertise, local government staff assist land owners to develop fire management plans for their properties and encourage the implementation of the plan. In addition to local government staff, local fire brigades provide support for fuel management in private land (at the request of the landowner). In contrast, in the South-West area, the evaluated model to encourage private landowners to reduce fuels in their properties was be the creation of a "Green Army" that has the technical skills and capability to assists private owners with the management of fuels in their properties.[3] Accordingly, the management options to be evaluated are:

[2] The local government staff that inspect private properties, help landowners develop a fuel management plan and issue infringement notices are Fire Hazard Inspection Officers (FHIOs), Fire Protection Officers (FPOs) and Rangers.
[3] The Green Army model would result in the creation a group of semi-volunteers that are familiar with fire risk management issues in the area. The members of this group would receive a small payment for their services. They would be trained to have the technical skills to be able to determine the most appropriate fuel reduction method for a given property, and would have the necessary means to implement the fuel reduction method in the property. They would be able to conduct prescribed burns in a private property as well as mechanical fuel reductions.

1. Additional fuel reduction through the increased application of prescribed burning and/or mechanical works (whichever is relevant to the agency implementing the fuel reduction)
2. Improved land-use planning aimed at reducing developments in high-risk areas and improving building standards for new buildings
3. Provide land owners with an increased capacity to manage fuels in their own land through:
    a. Community engagement in the Perth Hills
    b. A “Green Army” model in the South-West

The economic model is the same for both case study areas, i.e. it has similar parameters, but certain parts of the options evaluated vary from one case study to the other.

2.4.1. Increased fuel reduction

This option has been divided into two different options, each being implemented by a different management authority:

a) DPaW fuel reduction. For this option, the hypothetical scenario that is evaluated in this study is an increase in the area prescribed-burned by DPaW in the land the Department manages in each of the Shires. The proportion of area treated by the Department is increased to 10% of DPaW managed-land per year from the current average in each case study area. For the last ten years, the average percentage of DPaW-managed land prescribed burned per year was 6% in the South-West case study area and 7% in the Perth-Hills.
b) Shires fuel reduction. For this option, there is an increase in the amount of area treated by the Shires in the reserves they manage. In this case, not all the area categorised as *Reserve* has been designated as “treatable”. Most mechanical works in the Shires are implemented on the perimeter of lands or within the lands to construct strategic firebreaks or access tracks. Although this reduces the risk for the whole reserve, only a portion of the reserve is treated (Adrian Dyson, personal communication).

When the area treated by DPaW or by the Shires is increased in either of the case study areas, the amount of area treated by other agencies/authorities in the rest of the landscape remains at the current average. Table 2.1 and Table 2.2 show the proportion of area treated and the number of hectares treated in each type of land for the different scenarios evaluated in the Perth Hills, and Table 2.3 and Table 2.4 show the same information for the South-West case study area.[4]

---

[4] The proportion of area treated and the corresponding number of hectares treated by DPaW in DPaW-managed land under the current scheme and for an increase to 10% was estimated using historical data obtained from the Department in the form of GIS layers. The proportion of area treated and the number of

Table 2.1. Proportion of area treated in each type of land (prescribed-burning and/or mechanical works), case study area 1 (Perth Hills)

Type of land	Management option				
	Business as usual	Increased fuel reduction (DPaW)	Land-use planning	Community engagement	Increased fuel reduction (Shire)
DPaW-managed land	0.070	0.100	0.070	0.070	0.070
Shire-managed land	0.100	0.100	0.100	0.100	0.200
Privately-owned land	0.005	0.005	0.005	0.010	0.005

Table 2.2. Total hectares treated in each type of land (prescribed-burning and/or mechanical works), case study area 1 (Perth Hills)

Type of land	Management option				
	Business as usual	Increased fuel reduction (DPaW)	Land-use planning	Community engagement	Increased fuel reduction (Shire)
DPaW-managed land	3,140	4,480	3,140	3,140	3,140
Shire-managed land	110	110	110	110	220
Privately-owned land	420	420	420	840	420

Table 2.3. Proportion of area treated in each type of land (prescribed-burning and/or mechanical works), case study area 2 (South-West)

Type of land	Management option				
	Business as usual	Increased fuel reduction (DPaW)	Land-use planning	Green army	Increased fuel reduction (Shire)
DPaW-managed land	0.060	0.100	0.060	0.060	0.060
Shire-managed land	0.0075	0.0075	0.0075	0.0075	0.015
Privately-owned land	0.005	0.005	0.005	0.010	0.005

hectares treated by the Shires for each scenario was estimated using data provided by the Shire of Mundaring for the Perth-Hills case study area and using data provided by the Shire of Bridgetown-Greenbushes for the South-West case study area. The proportion of area treated and the number of hectares treated by private land owners for each scenario was estimated using data provided by the Shire of Mundaring.

Table 2.4. Total hectares treated in each type of land (prescribed-burning and/or mechanical works), case study area 2 (South-West)

Type of land	Management option				
	Business as usual	Increased fuel reduction (DPaW)	Land-use planning	Community engagement	Increased fuel reduction (Shire)
DPaW-managed land	3,960	6,590	3,960	3,960	3,960
Shire-managed land	38	38	38	38	76
Privately-owned land	270	270	270	540	270

2.4.2. Land-use planning

For land-use planning, the proportions of area treated through prescribed burning remain at their current average (in Table 2.1 and Table 2.3 the proportions treated for “Business as usual” and for “Land-use planning” are the same). What changes is the number of future developments that will be located in high-risk areas. For this management option, we took the estimated increase in the number of residential buildings for each of the Shires by 2026 and assumed that a proportion of the buildings that were going to be built in high-risk fire-prone areas are instead going to be built in more dense urban areas where the fire risk is lower.

2.4.3. Fuel management in private land

For this management option, it is assumed that with the creation of a Green Army in the South-West, or with increased community engagement in the Perth Hills, the number of compliant properties that manage their fuel is increased, resulting in an increase in the total amount of private land with low fuels from an average of 0.5% to 1%.

In the case of community engagement, there are two types of costs: the costs to the agency in charge of community engagement (the Shires), and the costs to the stakeholder in charge of fuel reduction in private land (private land owners). Land owners may choose to do the fuel reduction themselves, in which case the costs would be minimal, or they may choose to request the assistance of the volunteer fire brigades, in which case they would pay for the fuel reduction carried out in their properties by the brigades. In the case of the Green army, the cost of the strategy would be the responsibility of the Shire, who would pay the member of the Green army to conduct fuel reduction in private properties.

2.4.4. Combination of two strategies: DPaW and Shire fuel reduction

These two strategies are evaluated in combination to see what difference it would make in terms of expected damages and suppression costs in the case study areas if investments for both options were increased simultaneously.

2.5. Fire risk and spread

The probability of a fire starting in one of the sub-regions was estimated from historical fire data in public and private land obtained from DPaW and DFES fire history datasets. These datasets contained information on the fire level (level 1, 2 or 3) for each fire, which was used to categorise the fires into the five fire consequence (damage) classifications specified in the National Emergency Risk Assessment Guidelines (Commonwealth of Australia 2015). The perimeter of the fires in DPaW's GIS layers and the size in hectares of the fires in DFES's dataset were used to estimate the average number of reported incidents that spread to neighbouring sub-zones.

Historical data on daily Fire Danger Rating (FDR) was obtained from the Bureau of Meteorology. There are 6 categories of FDR: Low-Moderate, High, Very High, Severe, Extreme and Catastrophic. For the historical fires analysed (5 years), the recorded FDR on the day the fire started was used to estimate the number of reported fire incidents per FDR category.

2.6. Fire consequences

Fire consequence denotes the level of loss in the value of an asset due to fire. For each of the NERAG consequence levels, a quantitative proportion of loss was associated with each fire incident, which increases as the fires get more severe. The proportional loss in asset value changes between the different types of sub-zones, because of the differences in the continuity of flammable vegetation and the resource allocation in fire suppression. For instance, in urban areas, there is less vegetation and its distribution is patchy, which limits the spread of fires. In addition, if a fire is close to an urban area, additional suppression resources may be used to prevent damage to houses and other human assets. As a result, the proportional loss of asset value in urban areas is considered to be lower than in other types of areas. In contrast, in conservation areas, fuels are more continuous and it may be more difficult to curb the spread of the fire; thus the proportional loss of assets is likely to be higher for a fire of the same severity/consequence level than in an urban area. Table 2.5 shows the proportional loss of asset for different fire severity/consequence levels in the different types of area.

Table 2.5. Proportional loss in asset value due to fire for different fire severity/consequence levels

Fire consequence level	Urban areas	Rural Living areas	Conservation areas	Agricultural areas
Insignificant	0.000%	0.000%	0.000%	0.000%
Minor	0.000%	0.005%	0.008%	0.005%
Moderate	0.010%	0.100%	0.150%	0.100%
Major	1.000%	2.000%	3.000%	2.000%
Catastrophic	10.000%	20.000%	30.000%	20.000%

2.7. Economic model

Two economic indicators are used to assess the economic performance of each management option: the Benefit: Cost Ratio (BCR) and the Net Benefits. The BCR is the ratio of the benefits of a particular management option relative to its costs. It indicates the amount of dollars that can be gained per dollar invested in the management option. The net benefits are calculated as the benefits of implementing a management option less the cost of implementation. They indicate the total gain to the economy or to society from the implementation of a management option.

The benefits are measured as expected benefits. The benefits of reducing potential damages caused by a catastrophic fire are different from the benefits of reducing potential damages caused by a moderate fire. But the probability of each of these fires occurring is also different and needs to be taken into account. In addition, the probability of a given type of fire occurring depends partly on weather conditions. This is important because from one year to the next, the benefits can vary greatly depending on the weather conditions of that year. The expected loss in asset value per year is calculated by multiplying the number of fires per year of a given level, the probability of each type of fire occurring, the proportion of asset value lost per fire of a given level, and the replacement value of the asset affected by the fire. Thus, the model represents probability distributions, so the results are the weighted average of different outcomes given their probabilities. The results then should be interpreted as the benefits that could be expected on average per year, over a long number of years, given the current fuel loads and management strategies already in place.

3. CASE STUDY AREAS

The study was to include two contrasting case studies with a different mix of land-uses, that results in contrasting fire management issues: one peri-urban area and one rural-natural area. The case study areas needed to be of a similar size to the Adelaide case study because the model was designed for an area of that size (in which there is a possibility of fires spreading from one sub-region to the other). In the South-West, because of the size of local government, only one could be selected. In the Perth- Hills, because local government correspond to areas that are generally smaller, two adjacent local government could be selected and combined to be used as one case study area.

The case study areas were selected with the help of the experts group during the workshops. They indicated which areas were representative in the south-west of WA of the land-uses and management issues inferred by the 2 types of land-use requested for this study. In order to facilitate the data collection, the boundaries of the case study areas were selected so as to match the boundaries of local government areas. The two case study areas are:

- Peri-urban: the Shire of Mundaring and the City of Swan
- Rural-natural: the Shire of Bridgetown-Greenbushes

3.1. Case study 1 (Perth Hills)

3.1.1. Location

Case study 1 is located north-east of Perth (see Figure 3.1) and comprises an area of 168,640 hectares.

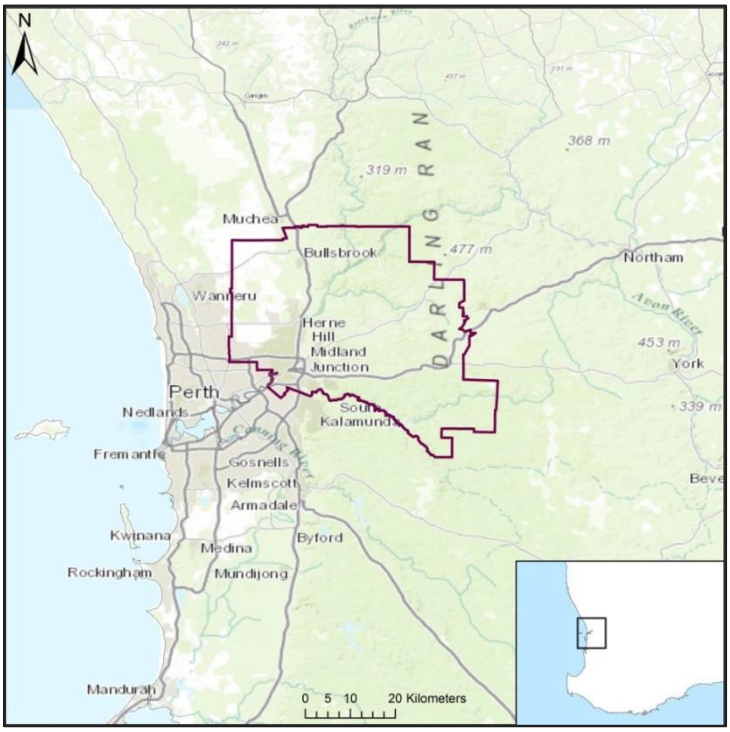

Figure 3.1. Case study area 1: Perth Hills (Shire of Mundaring and City of Swan)

3.1.2. Land use

Figure 3.2 shows current land use in the Perth Hills case study area. A large part of the area is covered with natural areas (55%), much of which has native vegetation. The second most prominent land use in the area is grazing and cropping (32%). Dense residential and/or industrial areas are mostly located to the west of the case study area and represent about 8% of the total area. Other land uses, such as plantations and horticulture/viticulture cover a smaller area.

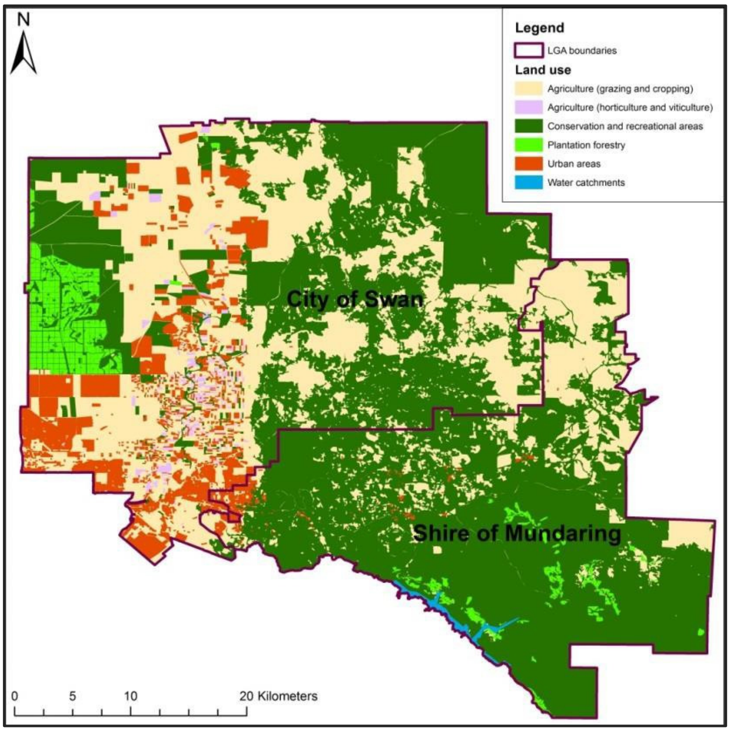

Figure 3.2. Land use and Shire boundaries in the Perth Hills case study area

3.1.3. Sub-regions

The case study area was divided into 10 sub-regions, approximately matching land use patterns. For each sub-region, one or two land uses could be classified as covering most of the sub-region. Figure 3.3 shows the division of the case study area into sub-regions and Table 3.1 shows the corresponding sub-region names, definition and size.

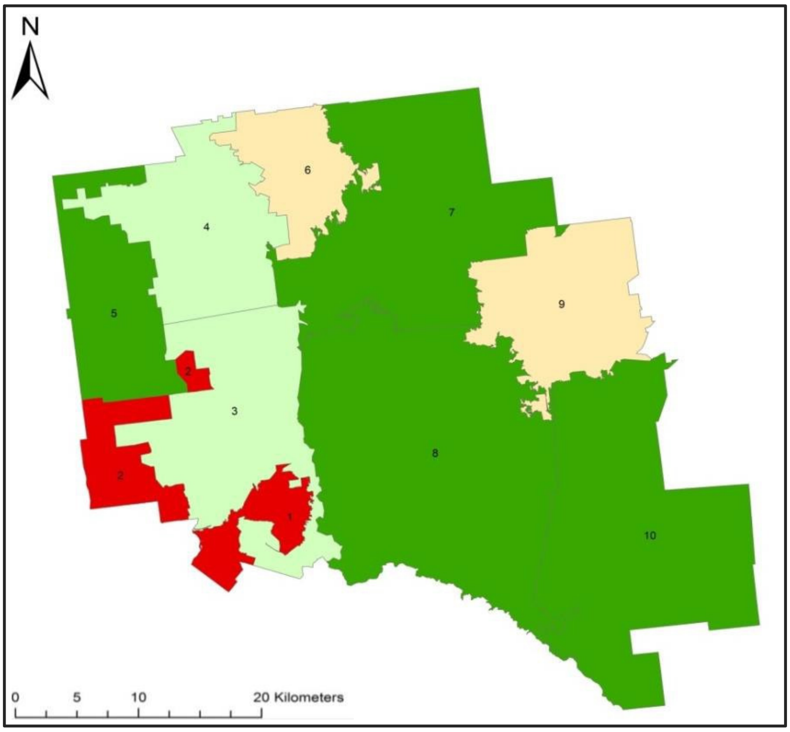

Figure 3.3. Sub-regions in the Perth Hills case study area

Table 3.1. Sub-region name, definition and size

Sub-region number	Sub-region name	Definition	Area (hectares)
1	Urban South	Dense residential	3,875
2	Urban West	Dense residential	5,489
3	Rural Living South	Less dense residential close to urban areas	18,422
4	Rural Living North	Less dense residential further north	14,730
5	Conservation North West	Conservation land adjacent to and on north side of urban areas	11,333
6	Agriculture North	Conservation land adjacent to rural living and agricultural areas	26,002
7	Conservation North East	Conservation land not adjacent to but on south-east side of the case-study region	29,848
8	Conservation East close	Conservation land adjacent to rural living and urban areas on the east side of rural living	37,612
9	Agriculture East	Agricultural land not adjacent to but on east side of case-study region	13,803
10	Conservation South East	Agricultural land adjacent to and on north-east side of rural living	7,526

3.1.4. Assets at risk per sub-region

In each sub-region, the total replacement value of assets at risk was calculated using the value per hectare or the value per asset, multiplied by the number of hectares or the number of assets in each sub-region. For plantations and biodiversity, the value per hectare of plantations (AU$9,083 obtained from Gibson and Pannell 2014) and the value per hectare of biodiversity (AU$400 in urban areas, AU$800 in rural living areas, and AU$1,100 in conservation areas) were multiplied by the number of hectares in each sub-region. For the value of agricultural assets, only the total value of agriculture for both Shires in the Perth Hills case study area was available (ABS 2011 for the Shire of Mundaring, and City of Swan 2009 economic profile report). This total was divided proportionally to the agricultural area in each sub-region. Similarly, for infrastructure, only the total value for the case study area was obtained for some of the key infrastructure assets. This total was divided between the sub-regions as follows: 30% in urban and rural living areas, 60% in conservation areas and 10% in agricultural areas.[5] The value of residential buildings and industrial/commercial buildings was calculated using data on numbers and value in the National Exposure Information System (NEXIS) designed by Geoscience

[5] For instance, one of the key infrastructure assets for the case study area, the Mundaring Weir, is located in one of the conservation sub-regions.

Australia (Dunford *et al.* 2014). The total value was divided between the different sub-zones according to the proportion of urban areas in each sub-zone and the average building density in agricultural land and in conservation areas. Table 3.2 shows the total value at risk for each type of asset in each sub-zone.

Table 3.2. Value of assets at risk in each sub-region (dollars)

Zone	Plantations	Biodiversity	Residential buildings	Industrial/ commercial buildings	Infrastructure
Urban South	0	16,200	13,719,233,017	3,943,372,045	15,982,103
Urban West	24,978	9,112	21,088,037,602	6,061,074,956	15,982,103
Rural Living South	97,642	2,115,832	14,436,059,449	4,158,621,892	15,982,103
Rural Living North	370,132	1,080,600	12,912,397,535	3,719,065,999	15,982,103
Conservation North West	40,473,848	7,391,450	89,437,792	21,323,062	31,964,205
Conservation North East	0	23,721,368	3,460,892	4,481,481	31,964,205
Conservation South East	8,070,246	28,235,658	143,949,427	43,033,884	31,964,205
Conservation East close	3,746,738	33,042,075	885,396,155	259,078,796	31,964,205
Agriculture East	15,895	1,323,376	83,821,857	32,320,053	10,654,735
Agriculture North	326,988	852,036	69,131,152	24,031,490	10,654,735
Total (case study area)	*53,126,467*	*97,787,707*	*63,430,924,878*	*18,266,403,658*	*213,094,700*

3.1.5. *Fire prone areas*

Most of the case study area has been categorised as fire prone by the Office of Bushfire and Risk Management (OBRM) (see Figure 3.4). 131.600 hectares of the Perth Hills case study area are fire prone, which corresponds to 78% of the case study area.

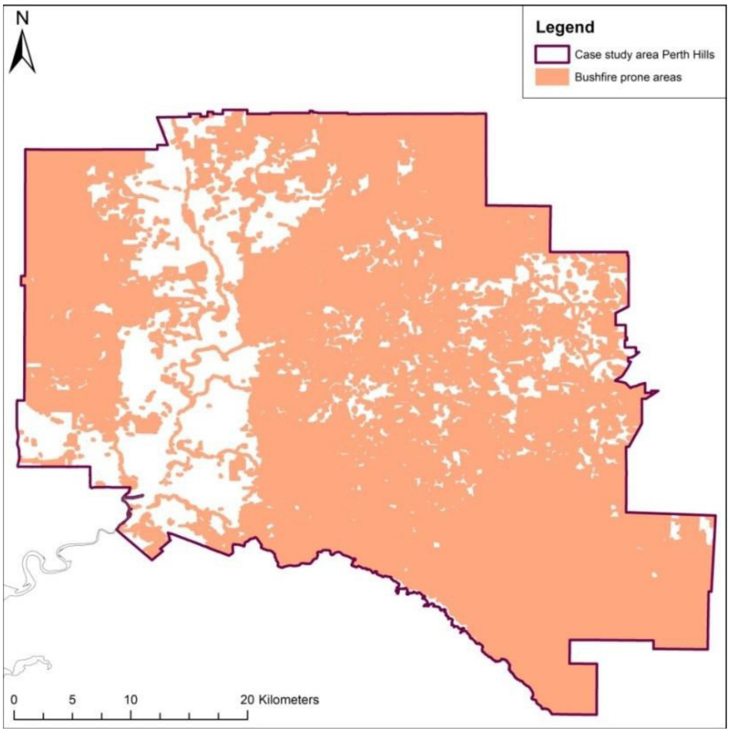

Figure 3.4. Fire-prone areas in the Perth Hills case study area

3.1.6. *Fire frequency, fire consequence and weather conditions*

The Perth-Hills case study area experiences a relatively large number of fires per year (around 479 fire incidents per year), the majority of which occur in highly populated areas or close to population centres, such as in Urban South, Rural Living South and Conservation East Close (see Table 3.3).

Table 3.3. Average number of fires per year in each sub-region

Sub-region	Average number of fires per year
Urban South	100.2
Urban West	58.6
Rural Living South	98.8
Rural Living North	20.6
Conservation North West	48.6
Conservation North East	6.4
Conservation South East	26.6
Conservation East close	98.8
Agriculture East	12.8
Agriculture North	7.2
Total	*478.6*

Most fires occur in low-moderate or high FDR, but there is a considerable proportion of fires that occur on days with a reported very high or severe FDR (see Table 3.4).

Table 3.4. Absolute number of fire incidents per year, per sub-region and Fire Danger Rating

Zone	Fire Danger Rating						Total
	Low-Mod.	High	V. High	Severe	Extreme	Catas.	
Urban South	30.06	40.04	19.04	10.02	1.00	0.04	100.20
Urban West	17.58	23.42	11.13	5.86	0.59	0.02	58.60
Rural Living South	29.64	39.48	18.77	9.88	0.99	0.04	98.80
Rural Living North	6.18	8.23	3.91	2.06	0.21	0.01	20.60
Conservation North West	14.58	19.42	9.23	4.86	0.49	0.0194	48.60
Conservation North East	1.92	2.56	1.22	0.64	0.06	0.00	6.40
Conservation South East	7.98	10.63	5.05	2.66	0.27	0.01	26.60
Conservation East close	29.64	39.48	18.77	9.88	0.99	0.04	98.80
Agriculture East	3.84	5.11	2.43	1.28	0.13	0.01	12.80
Agriculture North	2.16	2.88	1.37	0.72	0.07	0.00	7.20
Total	*143.58*	*191.25*	*90.93*	*47.86*	*4.79*	*0.19*	*478.60*

The vast majority of the fires that occur on days reporting a low-moderate, high or very high FDR result in fires of insignificant to minor consequence level. And only a small proportion of fires occurring in severe to extreme FDRs result in major or catastrophic fires (see Table 3.5). In the 5 years of historical fires used to calibrate the model, there were no fire incidents occurring on a day with a catastrophic FDR; therefore, the data used for the South Australian model on catastrophic FDR was reproduced here.

Table 3.5. Proportion of fires occurring in a given Fire Danger Rating that result in each consequence level

	FDR					
Fire consequence level	Low-Mod.	High	Very High	Severe	Extreme	Catas.
Insignificant	0.97	0.945	0.923	0.894	0.883	0.84
Minor	0.03	0.05	0.07	0.097	0.1	0.1
Moderate	0	0.005	0.007	0.008	0.015	0.0515
Major	0	0	0	0.001	0.0019	0.008
Catastrophic	0	0	0	0	0.0001	0.005
Total	*1*	*1*	*1*	*1*	*1*	*1*

3.2. Case study 2 (South-West)

3.2.1. Location

Case study 2 is located south of Perth (see Figure 3.5) and comprises an area of 133,938 hectares.

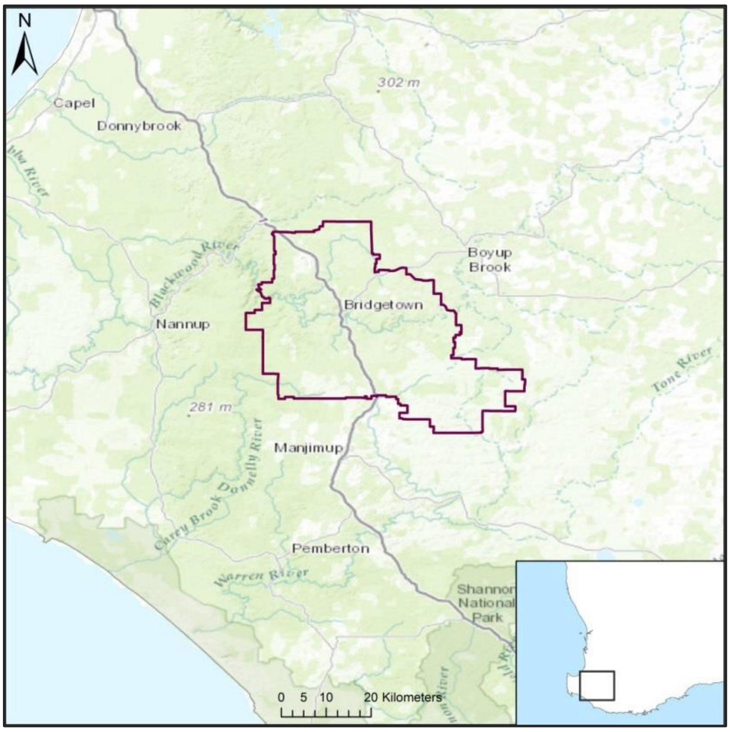

Figure 3.5. Case study area 2: South-West (Shire of Bridgetown-Greenbushes)

3.2.2. Land use

Figure 3.6 shows current land use in the South-West case study area. Similar to the Perth Hills, a large part of the area is covered with natural areas (60%), mostly comprised of native vegetation. Grazing and cropping correspond to around 31% of the area and plantations about 7%. Other land-uses such as horticulture/viticulture, dense residential and/or industrial areas and mining correspond to 1% or less of the total case study area.

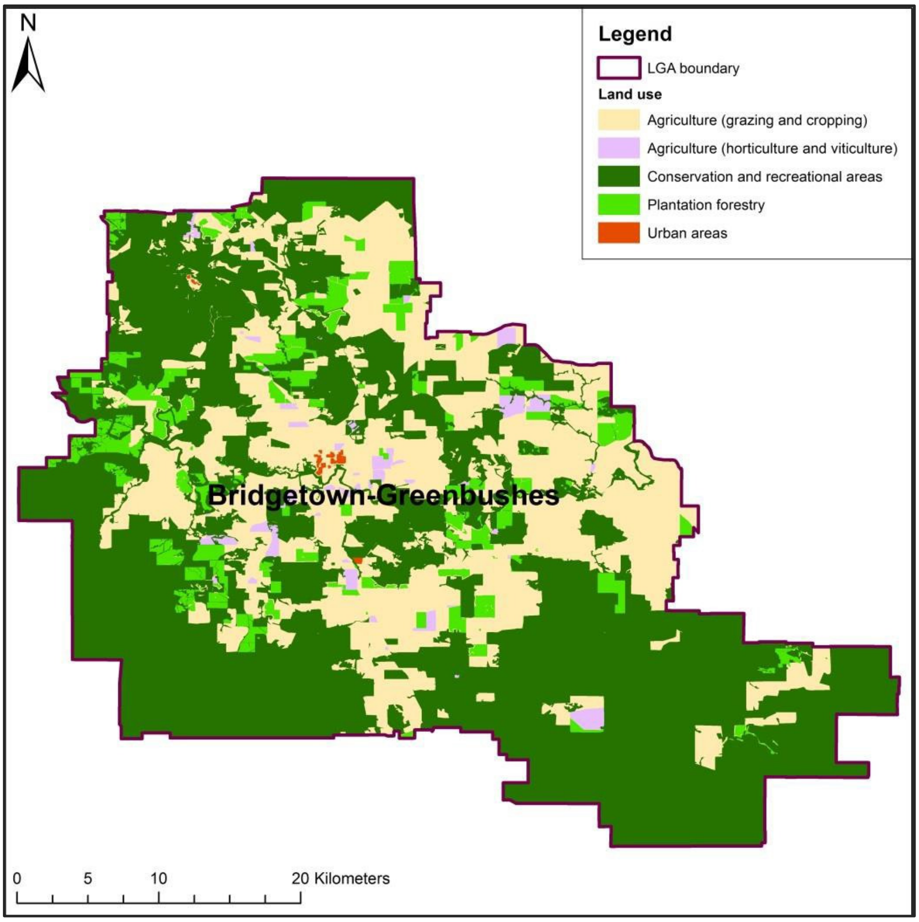

Figure 3.6. Land use in the South-West case study area

3.2.3. Sub-regions

The South-West case study area was also divided into 10 sub-regions, matching land use patterns. Figure 3.7 shows the division of the case study area into sub-regions and Table 3.6 shows the corresponding sub-region names, definition and size.

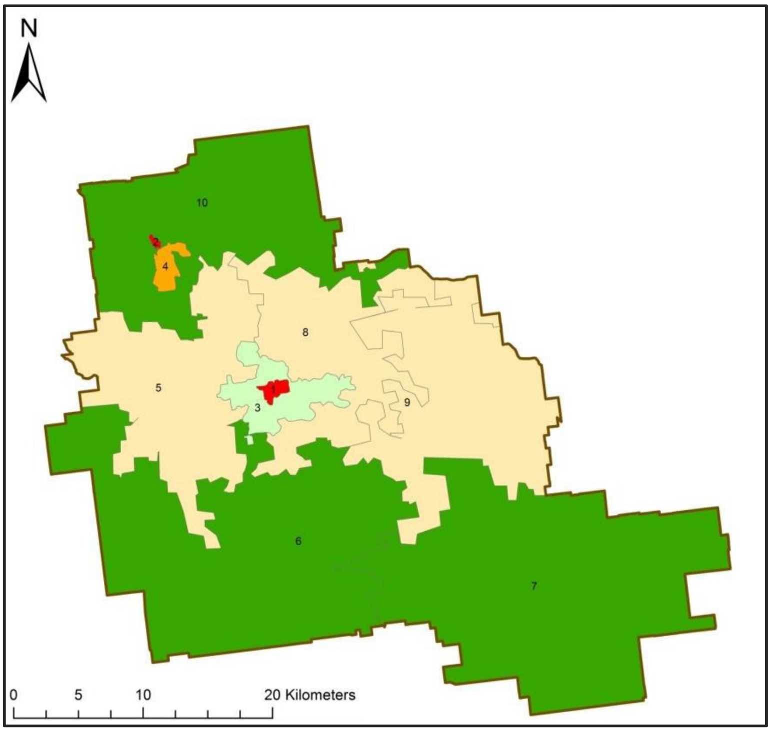

Figure 3.7. Sub-regions in the South-West case study area

Table 3.6. Sub-region name, definition and size

Sub-region number	Sub-region name	Definition	Area (hectares)
1	Urban 1 (Bridgetown)	Dense residential	260
2	Urban 2 (Greenbushes)	Dense residential	57
3	Rural Living (around Bridgetown)	Less dense residential around Bridgetown	3202
4	Mining	Non-residential area (industrial)	648
5	Agriculture West close	Conservation land not adjacent to but on north side of Bridgetown	19786
6	Conservation South West	Conservation land not adjacent to but on south-west side of Bridgetown	33396
7	Conservation South East	Conservation land not adjacent to but on south-east side of Bridgetown	31212
8	Agriculture East close	Agricultural land adjacent to and on east side of Bridgetown	12109
9	Agriculture East	Agricultural land not adjacent to but on east side of Bridgetown	17591
10	Conservation North	Agricultural land adjacent to and on west side of Bridgetown	15677

3.2.4. Assets at risk per sub-region

The same calculations used to estimate the total replacement value of assets at risk in the Perth Hills were used for the South-West case study area, using the data available for the South-West. Table 3.7 shows the total value at risk for each type of asset in each sub zone.

Table 3.7. Value of assets at risk in each sub-region (dollars)

Zone	Plantations	Biodiversity	Residential buildings	Industrial/ commercial buildings	Infrastructure	Life	Agricultural assets
Urban Bridgetown	0	6,000	1,599,809,222	438,440,567	13,005,000	16,268,000,000	102,343
Urban Greenbushes	0	3,200	500,048,399	136,161,667	13,005,000	2,394,000,000	2,161
Rural Living Bridgetown	406,464	264,400	36,293,835	16,339,400	13,005,000	962,500,000	3,051,920
Mining	0	10,000	0	47,090,000	13,005,000	0	0
Conservation North	14,162,668	12,364,825	40,326,484	29,955,567	34,680,000	1,071,000,000	7,549,460
Conservation South West	17,139,621	24,418,900	230,437,050	81,697,000	34,680,000	6,111,000,000	7,682,549
Conservation South East	3,687,698	33,583,275	11,521,853	10,892,933	34,680,000	304,500,000	2,658,607
Agriculture East close	6,344,476	2,862,200	19,587,149	16,339,400	5,780,000	518,000,000	4,597,916
Agriculture East	16,401,627	1,122,700	51,848,336	49,018,200	5,780,000	1,375,500,000	14,026,381
Agriculture West close	27,962,016	2,312,300	72,587,671	38,125,267	5,780,000	1,925,000,000	7,367,847
Total (case study area)	86,104,569	76,947,800	2,562,460,000	864,060,000	173,400,000	30,929,500,000	47,039,183

3.2.5. Fire prone areas

Similar to the Perth-Hills, most of the South-West case study area has been categorised as fire prone by OBRM (see Figure 3.8). In the South-West, 113,810 hectares are fire prone, which corresponds to 85% of the South-West case study area.

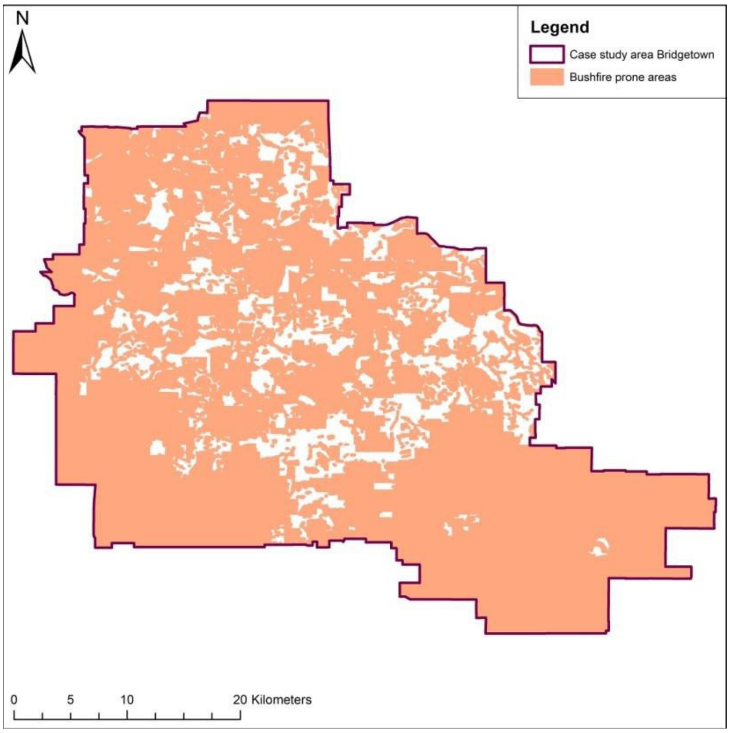

Figure 3.8. Fire-prone areas in the South-West case study area

3.2.6. Fire frequency, fire consequence and weather conditions

The South-West case study area experiences considerably less fires per year than the Perth-Hills (around 30 fire incidents per year, less than a fifteenth of the average number of fires per year in the Perth Hills), the majority of which occur in the Rural Living area surrounding Bridgetown (see Table 3.8).

Table 3.8. Average number of fires per year in each sub-region

Sub-region	Average number of fires per year
Urban Bridgetown	2.6
Urban Greenbushes	0.2
Rural Living Bridgetown	7.6
Mining	0
Conservation North	3.4
Conservation South West	4.6
Conservation South East	3.4
Agriculture East close	2.8
Agriculture East	2.4
Agriculture West close	3
Total	*30*

The vast majority of fires occur in low-moderate or high FDR, and very few occur days with a reported very high or severe FDR (see Table 3.9). This is a significant difference to the Perth-Hills case study area, in which a higher proportion of fires occur in very high, severe or extreme FDR.

Table 3.9. Absolute number of fire incidents per year, per sub-region and Fire Danger Rating

Zone	FDR						Total
	Low-Mod.	High	V. High	Severe	Extreme	Catas.	
Urban Bridgetown	1.62	0.65	0.26	0.07	0.01	0.00	2.60
Urban Greenbushes	0.12	0.05	0.02	0.01	0.00	0.00	0.20
Rural Living Bridgetown	4.72	1.90	0.76	0.19	0.02	0.00	7.60
Mining	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Conservation North	2.11	0.85	0.34	0.09	0.01	0.0014	3.40
Conservation South West	2.86	1.15	0.46	0.12	0.01	0.00	4.60
Conservation South East	2.11	0.85	0.34	0.09	0.01	0.00	3.40
Agriculture East close	1.74	0.70	0.28	0.07	0.01	0.00	2.80
Agriculture East	1.49	0.60	0.24	0.06	0.01	0.00	2.40
Agriculture West close	1.86	0.75	0.30	0.08	0.01	0.00	3.00
Total	*18.65*	*7.50*	*3.00*	*0.75*	*0.09*	*0.01*	*30.00*

The proportion of fires occurring in a given FDR that result in a fire of a particular consequence level is relatively similar to the Perth Hills case study area. However, to account for the fact that there are a lot more areas of continuous vegetation in the South-West case study area, a larger proportion of the fires occurring on catastrophic FDR may result in major or catastrophic fire consequence levels (see Table 3.10).

Table 3.10. Proportion of fires occurring in a given Fire Danger Rating that result in each consequence level

Fire consequence level	FDR					
	Low-Mod.	High	V. High	Severe	Extreme	Catas.
Insignificant	0.96	0.89	0.8	0.59	0.45	0.3
Minor	0.04	0.1	0.15	0.27	0.3	0.25
Moderate	0	0.01	0.04	0.1	0.14	0.15
Major	0	0	0.01	0.03	0.07	0.15
Catastrophic	0	0	0	0.01	0.04	0.15
Total	*1*	*1*	*1*	*1*	*1*	*1*

4. RESULTS

This section presents the results obtained from the model described in Section 2.

4.1. Case study 1 (Perth Hills)

In the Perth Hills case study area, nearly all strategies generate positive net benefits. Only the community engagement strategy generates benefits that are slightly smaller than the costs. Overall, reductions in asset losses for all strategies are much greater than reductions in suppression costs (savings in asset losses are 8 to 11 times larger than savings in suppression costs). These results are to be interpreted within the current fire context in the case study area; that is, the current fire risk and the current fire suppression effort are assumed to remain constant over time for business as usual. The implementation of a strategy may have an effect on the probability of occurrence for certain types of fires, but the initial probability obtained from historical data for business as usual is assumed to remain constant. Similarly, suppression effort (i.e. the number of fire-fighters, fire trucks, and other resources deployed for each fire) is assumed to remain constant over time if the current scheme continues to be implemented.[6]

In this case study area, the strategy that generates the highest expected benefits per dollar invested per year is the land-use planning strategy (see Table 4.1). This strategy, which restricts urban development in Rural Living, Conservation and Agricultural sub-regions (i.e. all sub-regions except the two Urban sub-regions in the case study area), reduces the amount of residential buildings at risk in those sub-regions and improves building standards for new developments. As a result, there is a substantial reduction in the number of buildings that can be expected to be destroyed by fires. The majority of the benefits from the implementation of this strategy stem from the reduction of assets at risk. Some losses are avoided with the improvement of building standards, but preventing developments in high risk areas has a greater effect in the reduction of residential asset losses.

[6] It is acknowledged that climate change, the growth of the rural-urban interface and other factors that increase the complexity of fire management may have an influence on fire risk and on fire suppression effort. Thus, even if the current scheme continues to be implemented, the average number of fires per year and their average intensity may increase over time. However, this is beyond the scope of this analysis and has not been evaluated.

Table 4.1. Impact on the entire case study area with each strategy implemented in all management sub-regions

Result	Strategy				Increased fuel reduction (DPaW and Shire)
	Increased fuel reduction (DPaW only)	Land-use planning	Community engagement	Increased fuel reduction (Shire only)	
Proportion of area treated (fuel reduction)	2.97%	2.17%	2.42%	2.24%	3.04%
Cost of strategy	$672,000	$600,000	$468,000	$197,000	$869,000
Saving in asset losses	$2,793,000	$9,154,000	$396,000	$320,000	$3,689,000
Saving in suppression costs	$325,000	$0	$35,000	$30,000	$377,000
Total expected benefit of strategy	$3,118,000	$9,154,000	$431,000	$351,000	$4,066,000
Benefit : Cost ratio	4.64	15.26	0.92	1.78	4.68

Additional fuel reduction in DPaW-managed land in this case study area would also generate substantial benefits per dollar invested. However, compared to the land use policy, the benefit : cost ratios (BCRs) of fuel reduction are considerably lower (3 to 8 times lower than land-use planning). The benefits of fuel reduction strategies vary greatly depending on where in the landscape the strategy is applied and the amount of area treated. For instance, an increase in the area treated by the Department of Parks and Wildlife (DPaW) generates on average AU$4.6 benefits per dollar invested per year, whereas an increase in the area treated by the Shires generates on average AU$1.8 benefits per dollar invested per year. In contrast, an increase in fuel reduction in private land as a result of additional community engagement generates benefits that are on average smaller than the costs of the strategy (i.e. BCR < 1). The benefits of Shire fuel reduction and community engagement are of the same order of magnitude (hundred-thousands rather than millions). However, the cost of Shire fuel reduction is smaller than the cost of community engagement, which results in a BCR > 1.

Overall, the total amount of area treated with fuel reduction in the whole case study area is only moderately increased with the strategies evaluated here. It increases from 2.17% of the case study area currently treated per year to 2.97% area treated per year with additional DPaW fuel reduction, or to 3.04% with additional DPaW and Shire fuel reduction. However, with this relatively small increase in the proportion of area treated, the benefits are more than 4 times greater than the costs.

The highest BCR for fuel reduction is obtained from a combination of two strategies: fuel reduction in DPaW-managed land and fuel reduction in Shire-managed land. Note that the total average expected benefits from the combination of these two strategies are higher than the sum of the benefits generated by DPaW fuel reduction and Shire fuel reduction when carried out separately (i.e. $3,118,000 + $351,000 = 3,469,000, but the total benefits of the strategies combined are $4,066,000). This suggests that there are substantial synergies that occur when multiple strategies are applied simultaneously and additional benefits may be gained from their combination.[7]

In most of the sub-regions in the case study area, the reduction in asset losses is considerably larger than the reduction in suppression costs, regardless of the strategy implemented. The only exception is for the agricultural areas (Agriculture East and Agriculture North) and for Conservation North West, for which savings in suppression costs are slightly higher than savings in asset losses for all strategies apart from land-use planning (which has no effect in fire intensity and as a result no effect on suppression expenditures) (see Table 4.2).[8]

The benefits of each strategy are distributed differently across the case study area, but the sub-region that reaps the highest benefits is the same for all strategies. Rural Living South has the highest level of benefits from any of the strategies, and the benefits in this sub-region are significantly higher than in any other sub-region: 3 to 5 times higher depending on the strategy. This is partly because more than half (60%) of the asset losses in the entire case study area under the current scheme are expected to occur in this sub-region, and any strategy that reduces asset losses in this region would generate significant benefits.

For the strategy that increases DPaW fuel reduction, about 52% of the total benefits of the strategy in the case study area are generated in Rural Living South (Table 4.2). This is more than half of the benefits for the case study area concentrated in one single sub-region (out of 10 sub-regions). The next sub-region that benefits most from the implementation of this strategy is Conservation East

---

[7] In the model, there was no modification of the parameters relating to the effectiveness of either strategy because of the application of the other (i.e. there was no assumption that increased the effectiveness of fuel reductions in Shire-managed land because fuel reductions were applied in DPaW-managed land or vice versa). Although this may occur in reality, there is not enough information to quantify the relative increase in effectiveness of one strategy due to the application of the other. The additional benefits obtained from the combination of DPaW and Shire fuel reductions are purely the result of the cumulative effects of additional area treated inside and outside the urban-rural interface.

[8] One could consider that with a land-use planning policy, because there are fewer assets at risk, then suppression costs would also be reduced, since they are partly driven by the proximity to high value assets in peri-urban scenarios. However, this was not considered in this model and only the reduction in fire intensity achieved through fuel reductions is considered to have an impact on suppression costs.

close. Approximately 18% of the benefits of DPaW fuel reduction are concentrated in this sub-region. Other sub-regions where the benefits of this strategy are concentrated are Rural Living North and Urban South, each obtaining about 9% of the total benefits. In sum, 88% of the benefits of increased DPaW fuel reduction are concentrated in 4 sub-regions, which correspond to those where there is a high proportion of a rural living lifestyle. Conservation East close also matches this description; although the majority of this sub-region is comprised of conservation and recreation areas, it is located close to Rural Living areas, and compared to other conservation areas, it has a relatively high number of residential buildings within it.

For land-use planning, the vast majority of the benefits are concentrated in Rural Living South (74% of the total benefits), and in Rural Living North (15% of the total benefits) (Table 4.2). Together, both Rural Living areas account for 89% of the benefits of land-use planning in the case study area. These results suggests that the most efficient way of reducing damages in Rural Living areas is by removing the high value assets from the area (i.e. by imposing significant restrictions on development to curb the growth in population and dwellings in the area). These areas present a significant challenge in terms of management because of the high fire risk (25% of the fires occurring in the case study area per year are ignited in these Rural Living areas), their location close to large areas of continuous vegetation, and the mix of flammable fuels and housing within the sub-regions.

The strategy involving Community engagement to increase fuel reduction in private land shows the benefits concentrated in Rural Living South (57% of the total benefits in the case study area), Conservation East close (14% of the total benefits) and Rural Living North (10%). The benefits of increased fuel reduction in Shire-managed land are concentrated in Rural Living South (57% of the total benefits), Urban Living South (15%) and Conservation East close (14%).

The largest savings in suppression costs are seen in conservation sub-regions that are located close to Rural Living or Urban areas and in which there is a relatively high number of high value human assets such as residential buildings (i.e. Conservation North West and Conservation East close). For instance, in Conservation North West, savings in suppression costs are higher than savings in asset losses. This is also the case for Conservation North East and the agricultural sub-regions (Agriculture East and Agriculture North), but not for any other sub-region.

An increase in DPaW fuel reduction (and when combined with an increase Shire fuel reduction) generates benefits mostly due to a reduction in the number of large, intense fires, usually categorised as major or catastrophic (Table 4.3), which are also those that have the highest potential to spread between sub-regions. With the implementation of this strategy, the largest proportional reduction in asset losses is observed in plantations (a reduction in asset loss of nearly 40%), followed by infrastructure (20% reduction in asset loss) and biodiversity (19% reduction) (Table 4.3). However, the value per asset of plantations and biodiversity is relatively low compared to residential and industrial/commercial buildings. Consequently, these reductions in damages do not drive the results. In contrast, the reduction in residential buildings losses (5% reduction in asset losses) and the reduction industrial/commercial buildings losses (also a 5% reduction) that result from the implementation of this strategy account for 96% of the total savings in asset losses (Table 4.3). Even though the proportional reduction in damages is comparatively smaller, any reduction in damages to these assets has a significant effect on the level of benefits generated by the strategy because they have a high value per asset and there is a large number of these high value assets in the case study area.

The combination of fuel reduction in DPaW-managed land and in Shire-managed land simultaneously has a cumulative effect that results in even greater reductions in asset losses for residential buildings, industrial/commercial buildings and life (i.e. high value assets), as well as suppression costs, thereby generating higher benefits. Note that the combination of these two strategies generates synergies in some sub-regions and not in others. In a few sub-regions the benefits of implementing both strategies together are larger than the sum of the benefits of implementing them separately (i.e. the two urban areas and the two rural living areas), but in other sub-regions, the sum is very close. This suggests that the additional benefits obtained from combining both strategies are concentrated around those areas where the high value assets are located.

Table 4.2. Distribution of the benefits of all strategies per sub-region

Sub-region	Result	Strategy: Increased fuel reduction (DPaW only)	Land-use planning	Community engagement	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Urban South	Proportion of area treated (if applicable)	0.47%	0.46%	0.85%	0.52%	0.52%
	Saving in asset losses	$244,000	$223,000	$37,000	$47,000	$434,000
	Saving in suppression costs	$23,000	$0	$4,000	$4,000	$41,000
	Total expected benefit of strategy	$267,000	$223,000	$41,000	$51,000	$475,000
Urban West	Proportion of area treated (if applicable)	1.12%	0.84%	1.20%	0.89%	1.17%
	Saving in asset losses	$81,000	$202,000	$14,000	$700	$97,000
	Saving in suppression costs	$4,000	$0	$1,000	$500	$5,000
	Total expected benefit of strategy	$85,000	$202,000	$15,000	$1,200	$102,000
Rural Living South	Proportion of area treated (if applicable)	0.48%	0.47%	0.86%	0.52%	0.54%
	Saving in asset losses	$1,579,662	$6,731,130	$241,402	$197,056	$2,181,383
	Saving in suppression costs	$28,541	$0	$4,346	$3,624	$39,527
	Total expected benefit of strategy	$1,608,203	$6,731,130	$245,748	$200,680	$2,220,910
Rural Living North	Proportion of area treated (if applicable)	9.31%	5.60%	5.63%	5.61%	9.32%
	Saving in asset losses	$288,500	$1,329,925	$43,843	$24,922	$322,834
	Saving in suppression costs	$5,453	$0	$856	$507	$6,148
	Total expected benefit of strategy	$293,953	$1,329,925	$44,699	$25,430	$328,982
Conservation North West	Proportion of area treated (if applicable)	4.55%	2.83%	3.06%	2.86%	4.58%
	Saving in asset losses	$96,526	$30,536	$8,713	$8,330	$104,027
	Saving in suppression costs	$124,287	$0	$10,951	$10,379	$133,418
	Total expected benefit of strategy	$220,813	$30,536	$19,664	$18,708	$237,445

Table 4.2. Contd.

Sub-region	Result	Strategy: Increased fuel reduction (DPaW only)	Land-use planning	Community engagement	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Conservation North East	Proportion of area treated (if applicable)	6.31%	3.86%	4.01%	3.88%	6.33%
	Saving in asset losses	$8,449	$1,049	$756	$696	$9,104
	Saving in suppression costs	$34,562	$0	$3,026	$2,748	$37,126
	Total expected benefit of strategy	$43,011	$1,049	$3,782	$3,444	$46,231
Conservation South East	Proportion of area treated (if applicable)	9.17%	5.52%	5.55%	5.52%	9.18%
	Saving in asset losses	$13,296	$11,227	$1,165	$962	$14,204
	Saving in suppression costs	$10,223	$0	$807	$648	$10,805
	Total expected benefit of strategy	$23,519	$11,227	$1,972	$1,610	$25,009
Conservation East close	Proportion of area treated (if applicable)	4.26%	2.67%	2.90%	2.70%	4.30%
	Saving in asset losses	$479,516	$614,295	$49,102	$40,816	$524,665
	Saving in suppression costs	$90,678	$0	$9,097	$7,550	$98,991
	Total expected benefit of strategy	$570,194	$614,295	$58,199	$48,366	$623,656
Agriculture East	Proportion of area treated (if applicable)	0.74%	0.62%	1.00%	0.67%	0.79%
	Saving in asset losses	$1,032	$6,286	$210	$87	$1,122
	Saving in suppression costs	$2,197	$0	$494	$214	$2,419
	Total expected benefit of strategy	$3,229	$6,286	$704	$300	$3,542
Agriculture North	Proportion of area treated (if applicable)	1.93%	1.31%	1.64%	1.36%	1.98%
	Saving in asset losses	$799	$4,056	$142	$67	$891
	Saving in suppression costs	$1,782	$0	$346	$166	$2,005
	Total expected benefit of strategy	$2,581	$4,056	$488	$233	$2,895

If the increase in population and dwellings in the case study area follows the forecasted trend and there are 60% more dwellings by 2026 in the case study area (i.e. business as usual), the expected average level of damages to residential buildings per year may approach AU$39 million (see Table 4.3). This amount would be significantly reduced if development is highly restricted in the area and only half of the forecasted increase is allowed to occur and building standards are improved for new developments. With this policy, a reduction of AU$7.4 million in residential asset losses per year (after 2026) may be achieved. Because the land use policy has a direct effect on the number of high value assets and significantly reduces the number of assets at risk, this policy generates more benefits than any of the other policies evaluated in this study. With land-use planning, residential buildings losses are reduced by 19% and industrial/commercial buildings losses are reduced by 15% (Table 4.3). These substantial reductions in high value asset losses for assets that are abundant in the case study area drive the results: 99% of savings in asset losses are attributed to savings in residential and industrial/commercial buildings losses.

The Community engagement strategy results in small reductions in losses of high value assets (i.e. residential and industrial/commercial buildings), between 1 and 2% reduction in asset losses. Consequently, the benefits of the strategy are relatively low compared to DPaW fuel reduction and land-use planning. Similarly, fuel reduction in Shire-managed land result in small savings in losses of high value assets and thus, the benefits are relatively low.

For most of the strategies evaluated in this study, the total benefits of implementing the strategy are generally low relative to the damages caused under the current scheme (business as usual), except for land-use planning. With the implementation of land-use planning, the benefits represent about 18% of the total expected asset losses under the current scheme. For the other strategies, the benefits represent 8% or less of the current expected losses. This gives an idea of the magnitude of the benefits of each strategy.

A table like the one presented in Table 4.3 exists for each sub-region, showing the detail of the impacts of each strategy on annual fire numbers, expected suppression costs and expected asset losses in the sub-region only. However, not all tables are presented here and in the following tables, only the results for 3 sub-regions are presented: Urban South, Rural Living South and Conservation East close. The purpose of showing these 3 sub-regions is to illustrate the contrast in the results between different types of zones within the case study area.

Table 4.3. Impacts in the whole case study area of implementing each strategy across the entire case-study area

		Strategy implemented				
	Benchmark (business as usual)	Increased fuel reduction (DPaW only)	Land-use planning	Community engagement	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Additional hectares treated in the whole case study area	-	1,344	-	419	109	1,454
	Average number of fires per year in the entire case study area					
Insignificant	454.94	444.65	454.94	452.91	455.25	444.19
Minor	25.733	22.743	25.733	25.365	25.450	22.261
Moderate	2.1005	1.8403	2.1005	2.0741	2.0761	1.7986
Major	0.06270	0.05556	0.06270	0.06195	0.06197	0.05437
Catastrophic	0.00228	0.00201	0.00228	0.00225	0.00225	0.00197
Total	*482.8*	*469.3*	*482.8*	*480.4*	*482.8*	*468.3*
	Expected suppression costs in the entire case study area					
Suppression costs	$2,760,163	$2,435,217	$2,760,163	$2,725,388	$2,729,712	$2,383,292
	Expected asset loss in the entire case study area					
Residential	$39,279,564	$37,205,409	$31,872,929	$38,984,059	$39,024,205	$36,516,780
Biodiversity	$73,805	$59,704	$73,805	$72,429	$72,603	$58,438
Life	$1,299,559	$1,248,529	$1,204,354	$1,290,690	$1,314,071	$1,245,582
Plantations	$39,222	$23,862	$39,222	$37,825	$37,898	$22,652
Infrastructure	$192,857	$153,890	$192,857	$189,062	$189,445	$150,068
Industrial	$11,319,422	$10,722,263	$9,667,242	$11,234,308	$11,245,906	$10,523,974
Agriculture	$20,146	$18,146	$20,146	$19,915	$19,954	$17,827
Total	*$52,224,574*	*$49,431,803*	*$43,070,555*	*$51,828,289*	*$51,904,082*	*$48,535,320*

Table 4.3. Contd.

	Benchmark (business as usual)	Strategy implemented: Increased fuel reduction (DPaW only)	Land-use planning	Community engagement	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
	Expected benefits for the entire case study area of implementation of the strategy in the entire case-study area					
Saving in asset losses	-	$2,792,771	$9,154,018	$396,285	$320,492	$3,689,254
Saving in suppression expenditures	-	$324,946	$0	$34,775	$30,451	$376,871
Total savings	-	$3,117,717	$9,154,018	$431,060	$350,943	$4,066,125
Benefits relative to losses without implementation of the strategy	-	6%	18%	1%	1%	8%

The results shown in each of the tables for one single sub-region correspond to the expected outcome for the sub-region of the implementation of each strategy across the entire case study area. This is important, because some of the benefits generated in a sub-region may result from the implementation of the strategy in other sub-regions. In other words, if any of the strategies was only implemented in the sub-region presented, the results would be entirely different. For instance, the additional area treated by DPaW with fuel reduction in Rural Living South is relatively small (22 additional hectares) (Table 4.5), but the strategy results in a 5% reduction in damages of residential buildings that generates AU$1.2 million savings in residential asset losses. These benefits are partly the result of a decrease in the number of the most costly fires (major and catastrophic) in the sub-region, and partly the result of a reduction in the number of fires that spread from other sub-regions into Rural Living South.

The results for the 3 sub-regions presented in Table 4.4, Table 4.5 and Table 4.6 show that expected asset losses are considerably higher in Rural Living South, both under the current scheme and with the application of any of the strategies. Expected asset losses in Rural Living South are approximately 5 times higher than in Urban South, and around 800 times higher than in Conservation South East. In Rural Living South and in Urban South, the majority of expected asset losses correspond to residential building damages (between 72% and 76% of total expected asset losses), whereas in Conservation North East residential asset losses correspond to only 6% of total expected asset losses. Suppression costs are similar in Rural Living South and Urban South, and about 4 times smaller in Conservation North East.

The benefits of each strategy relative to asset losses under the current scheme vary greatly between the sub-regions. In Urban South, the benefits are relatively low for all strategies compared to current expected asset losses (between 4% and 8%). In Rural Living South, the benefits of land-use planning are relatively large compared to current asset losses (around 22%), but for all other strategies the benefits are relatively low. In Conservation North East, the benefits of increased DPaW fuel reduction exceed current expected asset losses, mainly because this strategy generates substantial suppression costs savings in this sub-region (23% reduction in suppression costs), which are in fact greater than savings in asset losses. However, for the other strategies, the benefits are relatively low compared to current asset losses in Conservation North East. Thus in this case study, a land-use planning policy has a more significant impact in Rural Living areas, where there is a large number of high value human assets that are intermingled with flammable vegetation and where fire risk is high, and a broad-scale fuel reduction strategy has a more significant impact in conservation areas where more savings in suppression costs may be achieved.

Table 4.4. Impacts in Urban South of implementing each strategy across the entire case-study area

		Strategy implemented				
	Benchmark (business as usual)	Increased fuel reduction (DPaW only)	Land-use planning	Community engagement	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Additional hectares treated in the sub-region	-	0.8	0	8	20	21
	Average number of fires per year in Urban South					
Insignificant	94.70	94.05	94.70	94.26	94.74	93.65
Minor	5.337	5.124	5.337	5.292	5.298	4.960
Moderate	0.4336	0.4150	0.4336	0.4309	0.4303	0.4008
Major	0.01253	0.01204	0.01253	0.01246	0.01243	0.01166
Catastrophic	0.00036	0.00034	0.00036	0.00036	0.00035	0.00033
Total	*100.5*	*99.6*	*100.5*	*100.0*	*100.5*	*99.0*
	Expected suppression costs in Urban South					
Suppression costs	$568,849	$545,779	$568,849	$565,062	$564,765	$528,048
	Expected asset loss in Urban South					
Residential	$4,467,848	$4,291,093	$4,244,456	$4,441,162	$4,433,790	$4,153,453
Biodiversity	$3	$3	$3	$3	$3	$3
Life	$403,265	$386,798	$403,265	$400,347	$400,284	$374,089
Plantations	$0	$0	$0	$0	$0	$0
Infrastructure	$5,205	$4,999	$5,205	$5,174	$5,165	$4,839
Industrial	$1,284,211	$1,233,405	$1,284,211	$1,276,540	$1,274,421	$1,193,843
Agriculture	$145	$139	$145	$144	$144	$135
Total	*$6,160,677*	*$5,916,438*	*$5,937,285*	*$6,123,370*	*$6,113,807*	*$5,726,363*

Table 4.4. Contd.

		Strategy implemented				
	Benchmark (business as usual)	Increased fuel reduction (DPaW only)	Land-use planning	Community engagement	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
	Expected benefits for Urban South of implementation of the strategy in the entire case-study area					
Saving in asset losses	-	$244,239	$223,392	$37,307	$46,870	$434,315
Saving in suppression expenditures	-	$23,070	$0	$3,787	$4,084	$40,801
Total savings	-	$267,309	$223,392	$41,094	$50,954	$475,116
Benefits relative to losses without implementation of the strategy	-	4%	4%	0.7%	1%	8%

Savings in residential and industrial/commercial building losses account for most of the benefits in Urban South and Rural Living South (between 83% and 100% of total benefits depending on the strategy), but not in Conservation North East (only about 3% of total benefits are attributed to savings in residential and industrial/commercial building losses in this sub-region for all strategies except for land-use planning).

Table 4.5. Impacts in Rural Living South of implementing each strategy across the entire case-study area

	Benchmark (business as usual)	Strategy implemented: Increased fuel reduction (DPaW only)	Land-use planning	Community engagement	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Additional hectares treated in the sub-region	-	21.9	0.0	54	53	75
	Average number of fires per year in Rural Living South					
Insignificant	93.66	92.85	93.66	93.23	93.70	92.64
Minor	5.289	5.027	5.289	5.239	5.255	4.925
Moderate	0.4308	0.4078	0.4308	0.4276	0.4279	0.3990
Major	0.01266	0.01205	0.01266	0.01258	0.01258	0.01181
Catastrophic	0.00041	0.00039	0.00041	0.00041	0.00041	0.00039
Total	*99.4*	*98.3*	*99.4*	*98.9*	*99.4*	*98.0*
	Expected suppression costs in Rural Living South					
Suppression costs	$565,611	$537,070	$565,611	$561,265	$561,987	$526,084
	Expected asset loss in Rural Living South					
Residential	$23,724,965	$22,516,810	$18,342,102	$23,540,502	$23,566,418	$22,049,291
Biodiversity	$2,182	$2,071	$2,182	$2,165	$2,168	$2,028
Life	$423,952	$402,377	$348,239	$420,442	$431,365	$403,589
Plantations	$101	$96	$101	$100	$100	$94
Infrastructure	$26,266	$24,928	$26,266	$26,062	$26,090	$24,411
Industrial	$6,834,494	$6,486,458	$5,561,940	$6,781,355	$6,788,821	$6,351,779
Agriculture	$8,695	$8,252	$8,695	$8,627	$8,636	$8,081
Total	*$31,020,654*	*$29,440,992*	*$24,289,524*	*$30,779,252*	*$30,823,598*	*$28,839,272*

Table 4.5. Contd.

	Benchmark (business as usual)	Strategy implemented: Increased fuel reduction (DPaW only)	Land-use planning	Community engagement	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
	Expected benefits for Rural Living South of implementation of the strategy in the entire case-study area					
Saving in asset losses	-	$1,579,662	$6,731,130	$241,402	$197,056	$2,181,383
Saving in suppression expenditures	-	$28,541	$0	$4,346	$3,624	$39,527
Total savings	-	$1,608,203	$6,731,130	$245,748	$200,680	$2,220,910
Benefits relative to losses without implementation of the strategy	-	5%	22%	0.8%	1%	7%

Table 4.6. Impacts in Conservation North East of implementing each strategy across the entire case-study area

		Strategy implemented				
	Benchmark (business as usual)	Increased fuel reduction (DPaW only)	Land-use planning	Community engagement	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Additional hectares treated in the sub-region	-	324	0	106	20	344
	Average number of fires per year in Conservation North East					
Insignificant	25.13	24.07	25.13	25.02	25.16	24.10
Minor	1.416	1.095	1.416	1.385	1.390	1.071
Moderate	0.1150	0.0872	0.1150	0.1126	0.1128	0.0852
Major	0.00331	0.00258	0.00331	0.00325	0.00325	0.00252
Catastrophic	0.00009	0.00007	0.00009	0.00009	0.00009	0.00007
Total	*26.7*	*25.3*	*26.7*	*26.5*	*26.7*	*25.3*
	Expected suppression costs in Conservation North East					
Suppression costs	$150,822	$116,261	$150,822	$147,796	$148,074	$113,696
	Expected asset loss in Conservation North East					
Residential	$2,238	$1,722	$1,730	$2,192	$2,195	$1,682
Biodiversity	$9,627	$7,406	$9,627	$9,428	$9,444	$7,233
Life	$10	$7	$8	$10	$10	$7
Plantations	$0	$0	$0	$0	$0	$0
Infrastructure	$20,669	$15,900	$20,669	$20,242	$20,276	$15,530
Industrial	$2,898	$2,229	$2,358	$2,838	$2,843	$2,177
Agriculture	$1,179	$907	$1,179	$1,155	$1,157	$886
Total	*$36,620*	*$28,171*	*$35,571*	*$35,864*	*$35,924*	*$27,516*

Table 4.6. Contd.

	Benchmark (business as usual)	Strategy implemented: Increased fuel reduction (DPaW only)	Land-use planning	Community engagement	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
	Expected benefits for Conservation North East of implementation of the strategy in the entire case-study area					
Saving in asset losses	-	$8,449	$1,049	$756	$696	$9,104
Saving in suppression expenditures	-	$34,562	$0	$3,026	$2,748	$37,126
Total savings	-	$43,011	$1,049	$3,782	$3,444	$46,231
Benefits relative to losses without implementation of the strategy	-	117%	3%	10%	9%	126%

4.2. Case study 2 (South-West)

In the South-West case study area, only two strategies generate positive net benefits: increased fuel reduction in DPaW-managed land and increased fuel reduction in DPaW and Shire-managed land simultaneously. For other strategies (i.e. land use planning, green army and increased fuel reduction in Shire-managed land only) the benefits generated are smaller than the costs (i.e. BCR < 1, see Table 4.7). In this case study area, reductions in asset losses are also greater than reductions in suppression costs for all strategies. However, the strategy that generates the highest BCR (i.e. the highest benefit per dollar invested per year) is fuel reduction in DPaW-managed land (Table 4.7). It is important to note that the benefits obtained in this case study area from the different strategies evaluated are of a different order of magnitude compared to the benefits obtained in the Perth Hills. In the South-West the benefits are of the order of AU$20,000 to AU$570,000 (Table 4.7); whereas in the Perth-Hills they are of the order of AU$350,000 to AU$9.1 million (Table 4.1). The main reason for this is the difference in the number of high value assets. In the Perth-Hills case study area, which has a total area of 168,640 hectares, there were 105,568 residential buildings in 2011 and 5,262 industrial/commercial buildings. In contrast, in the South-West case study area, for a similar size area (133,938 hectares), there were 4,448 residential buildings in 2011 and 304 industrial/commercial buildings (Dunford *et al*. 2011).

Land-use planning does not generate as many benefits in this case study area as it does in the Perth Hills. There are two main reasons for this difference: (1) the assumptions made for the implementation of the strategy in the South-West are different from the assumptions made in the Perth-Hills, and (2) there is a substantially higher number of residential and industrial/commercial buildings in the Perth-Hills case study area. For the implementation of land-use planning in the Perth Hills, it is assumed that the policy restricts development of residential buildings in high risk areas and, as a consequence, a significant number of the buildings that would have been built in those areas by 2026 are not built. Thus, the overall impact of the strategy is to curb population and dwellings growth for both the Shire of Mundaring and the City of Swan. In the South-West, the assumption is that the implementation of a land-use policy would still allow the construction of all buildings by 2026, but only in some areas (urban areas). Thus, the forecasted growth in population and dwellings is realised by 2026, but the spatial distribution of the buildings is different to what it would have been under the current scheme (business as usual). This has a significant impact on the results and is a major source of difference between both case study areas, because in one case study area it removes the assets at risk from the case study area, whereas in the other it changes the level of risk for the assets, but does not remove them from the case study area.[9]

Table 4.7. Impact to the entire case study area with each strategy implemented in all management sub-regions

Result	Strategy				
	Increased fuel reduction (DPaW only)	Land-use planning	Green army	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Proportion of area treated (fuel reduction)	5.15%	3.18%	3.38%	3.21%	5.18%
Cost of strategy	$243,000	$150,000	$54,000	$46,000	$288,000
Saving in asset losses	$380,000	$20,000	$18,000	$20,000	$427,000
Saving in suppression costs	$129,000	$0	$4,000	$6,000	$144,000
Total expected benefit of strategy	$509,000	$320,000	$22,000	$27,000	$571,000
Benefit : Cost ratio	2.09	0.13	0.41	0.59	1.98

In this case there are also synergies between fuel reduction in DPaW-managed land and fuel reduction in Shire-managed land that result in higher benefits when both strategies are applied simultaneously than the sum of the benefits when applied separately. However, the BCR obtained for the combination of fuel reduction in DPaW and Shire-managed land is smaller than the BCR for fuel reduction in DPaW-managed land only, even though the net benefits of the combination of DPaW and Shire fuel reduction are higher. This is because the costs of Shire fuel reduction are larger than the benefits generated by the strategy.

[9] The residential buildings that are not built within the Perth Hills case study area are assumed to be built in other urban areas (other suburbs) where the fire risk is close to zero.

Table 4.8. Distribution of the benefits of all strategies per sub-region

Sub-region	Result	Strategy				
		Increased fuel reduction (DPaW only)	Land-use planning	Green army	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Urban Bridgetown	Proportion of area treated (if applicable)	0.47%	0.46%	0.85%	0.52%	0.52%
	Saving in asset losses	$39,366	-$58,955	$3,062	$4,395	$66,795
	Saving in suppression costs	$3,830	$0	$119	$398	$6,476
	Total expected benefit of strategy	$43,196	-$58,955	$3,181	$4,793	$73,271
Urban Greenbushes	Proportion of area treated (if applicable)	1.12%	0.84%	1.20%	0.89%	1.17%
	Saving in asset losses	$2,526	$8,113	$149	$188	$3,425
	Saving in suppression costs	$594	$0	$20	$42	$815
	Total expected benefit of strategy	$3,121	$8,113	$169	$230	$4,240
Rural Living Bridgetown	Proportion of area treated (if applicable)	0.48%	0.47%	0.86%	0.52%	0.54%
	Saving in asset losses	$8,181	$8,626	$565	$878	$13,598
	Saving in suppression costs	$11,268	$0	$338	$1,145	$18,789
	Total expected benefit of strategy	$19,449	$8,626	$903	$2,023	$32,387
Mining	Proportion of area treated (if applicable)	9.31%	5.60%	5.63%	5.61%	9.32%
	Saving in asset losses	$423	$51	$19	$20	$442
	Saving in suppression costs	$534	$0	$23	$24	$556
	Total expected benefit of strategy	$957	$51	$43	$43	$997
Conservation North	Proportion of area treated (if applicable)	4.55%	2.83%	3.06%	2.86%	4.58%
	Saving in asset losses	$37,963	$7,399	$1,610	$1,673	$39,544
	Saving in suppression costs	$18,210	$0	$553	$752	$18,898
	Total expected benefit of strategy	$56,173	$7,399	$2,162	$2,424	$58,443

Table 4.8. Contd.

Sub-region	Result	Strategy				
		Increased fuel reduction (DPaW only)	Land-use planning	Green army	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Conservation South West	Proportion of area treated (if applicable)	6.31%	3.86%	4.01%	3.88%	6.33%
	Saving in asset losses	$213,834	$35,346	$9,121	$9,626	$222,279
	Saving in suppression costs	$34,602	$0	$1,241	$1,476	$35,830
	Total expected benefit of strategy	$248,436	$35,346	$10,362	$11,102	$258,109
Conservation South East	Proportion of area treated (if applicable)	9.17%	5.52%	5.55%	5.52%	9.18%
	Saving in asset losses	$51,079	$3,382	$2,172	$2,263	$53,209
	Saving in suppression costs	$34,505	$0	$1,148	$1,435	$35,796
	Total expected benefit of strategy	$85,584	$3,382	$3,320	$3,699	$89,005
Agriculture East close	Proportion of area treated (if applicable)	4.26%	2.67%	2.90%	2.70%	4.30%
	Saving in asset losses	$9,447	$2,491	$411	$418	$9,869
	Saving in suppression costs	$15,276	$0	$471	$631	$15,886
	Total expected benefit of strategy	$24,724	$2,491	$882	$1,049	$25,755
Agriculture East	Proportion of area treated (if applicable)	0.74%	0.62%	1.00%	0.67%	0.79%
	Saving in asset losses	$4,094	$5,391	$213	$185	$4,293
	Saving in suppression costs	$2,545	$0	$1	$117	$2,667
	Total expected benefit of strategy	$6,639	$5,391	$214	$302	$6,960
Agriculture West close	Proportion of area treated (if applicable)	1.93%	1.31%	1.64%	1.36%	1.98%
	Saving in asset losses	$12,794	$8,231	$601	$582	$13,460
	Saving in suppression costs	$7,559	$0	$168	$324	$7,906
	Total expected benefit of strategy	$20,352	$8,231	$769	$906	$21,366

Another important difference between the two case study areas that also contributes to the difference in the results is the relative proportion of DPaW-managed land. In the Perth-Hills, the proportion of DPaW-managed land in the entire case study area is 26%. In the South-West this proportion is much higher: DPaW-managed land in the Shire of Bridgetown-Greenbushes is around 49% of the Shire. Because of this, an increase in the proportion of area treated by DPaW in the South-West corresponds to a larger increase in the number of hectares treated than in the Perth-Hills. This partly explains why additional DPaW fuel reduction have a greater impact in this case study are than in the Perth-Hills. An increase in DPaW fuel reduction generate high benefits compared to the expected asset losses under the current scheme: average expected benefits per year correspond to about 34% of expected asset losses under the current scheme (Table 4.8).

The distribution of the benefits between sub-regions is different in this case study area, but like in the Perth-Hills, most of the benefits are concentrated in one sub-region (see Table 4.8). For the South-West, the majority of the benefits from all strategies are concentrated in a conservation area: Conservation South West. This area has a relatively large number of high value human assets, such as residential buildings, compared to other conservation areas (approximately 400 residential buildings compared to approximately 70 in Conservation North and only 20 in Conservation South East). In addition, around 60% of Conservation South West is managed by DPaW; thus a strategy that increases the proportion of area treated by DPaW has a significant impact in this sub-region compared to other sub-regions where DPaW manages a smaller area (such as agricultural, rural living and urban areas). Other sub-regions that benefits greatly from additional DPaW fuel reduction are Conservation South East and Conservation North. The 3 conservation areas account for 77% of the total benefits generated by additional DPaW fuel reduction.

The majority of the benefits from land-use planning are also concentrated in Conservation South West and a few other sub-regions. But in this case, the strategy generates additional potential losses for Urban Bridgetown. This is because the buildings that would have otherwise be constructed in rural living, conservation and agricultural areas are relocated to urban areas with the implementation of the land-use policy in this case study area. As a result, there is an increase in the number of assets at risk in Urban Bridgetown, but the land-use policy does not reduce the risk of fire occurrence in the area or the potential fire intensity.

The Green army strategy also generates more benefits in Conservation South West than in any other sub-region, and about 72% of the total benefits of the strategy are concentrated in the conservation areas. The fact that most of the benefits from this strategy are concentrated in the conservation areas suggests that private properties located in more remote natural areas surrounded by flammable vegetation are those that would benefit the most from additional fuel maintenance inside their properties, and not necessarily the properties located in rural living areas. However, the benefits generated by this strategy are not high enough to compensate for the increase in costs.

Conservation South West obtains a large part of the benefits from increased Shire fuel reduction (about 41%). Similarly, when combined with DPaW fuel reduction, most of the benefits are concentrated in Conservation South West. The increase in benefits that results from the combination of the two strategies is driven by substantial increases in the benefits for urban areas (Urban Bridgetown and Urban Greenbushes) and rural living (Rural Living Bridgetown). The combination of the two strategies in these sub-regions increases the benefits by 27% to 53% (i.e. the benefits of implementing both strategies together are 27% to 53% higher than the sum of the benefits of applying each strategy separately). For the other sub-regions however, the combination of the two strategies generates benefits that are close to the sum of the benefits it the two strategies were applied separately. Thus the synergies obtained from the combination of the two strategies are concentrated in a few sub-regions only, primarily those where the high value assets are concentrated.

With only a few exceptions, in most sub-regions savings in asset losses are higher than savings in suppression costs for all strategies involving additional fuel reduction (Table 4.8). Exceptions to this are found in Rural Living Bridgetown, Mining, and Agriculture East close.

Table 4.9. Impacts in the whole case study area of implementing each strategy across the entire case-study area

	Benchmark (business as usual)	Strategy implemented: Increased fuel reduction (DPaW only)	Land-use planning	Green army	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Additional hectares treated in the whole case study area	-	2,637	-	268	38	2,675
	Average number of fires per year in the whole case study area					
Insignificant	27.55	26.82	27.55	28.26	27.58	26.83
Minor	2.204	1.683	2.204	2.210	2.178	1.624
Moderate	0.2936	0.2277	0.2936	0.2915	0.2905	0.2203
Major	0.06486	0.05103	0.06486	0.06439	0.06418	0.04945
Catastrophic	0.01554	0.01157	0.01554	0.01533	0.01533	0.01111
Total	*30.1*	*28.8*	*30.1*	*30.8*	*30.1*	*28.7*
	Expected suppression costs in the whole case study area					
Suppression costs	$572,708	$443,786	$572,708	$568,625	$566,364	$429,089
	Expected asset loss in the whole case study area					
Residential	779,793	587,449	759,545	770,327	768,799	556,434
Biodiversity	69,413	39,098	69,413	68,121	68,061	37,839
Life	9,291	7,232	9,149	9,199	9,171	6,860
Plantations	52,964	36,777	52,964	52,261	52,237	36,068
Infrastructure	142,963	90,813	142,963	140,687	140,525	87,540
Industrial	303,370	225,067	303,687	299,647	299,166	215,025
Agriculture	29,912	21,564	29,912	29,543	29,521	21,028
Total	*$1,387,708*	*$1,007,999*	*$1,367,633*	*$1,369,785*	*$1,367,480*	*$960,793*

Table 4.9. Contd.

	Benchmark (business as usual)	Strategy implemented: Increased fuel reduction (DPaW only)	Land-use planning	Green army	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
	Expected benefits for the whole case study area of implementation of the strategy in the entire case-study area					
Saving in asset losses	-	$379,708	$20,074	$17,923	$20,228	$426,914
Saving in suppression expenditures	-	$128,922	$0	$4,083	$6,344	$143,619
Total savings	-	$508,630	$20,074	$22,006	$26,572	$570,533
Benefits relative to losses without implementation of the strategy	-	37%	1%	2%	2%	41%

Similar to the Perth Hills, in the South-West case study area the majority of the benefits stem from reductions in residential building losses, industrial/commercial building losses and infrastructure losses (see Table 4.9). For the strategy that increases DPaW fuel reduction, a large part of the benefits are the results of a reduction in the number of fires, particularly major and catastrophic fires, which are the most costly fires. This explains why this strategy generates the highest benefits per dollar invested in the South-West. Fires are less frequent in this case study area, and most of the damages are generated by a very small number of severe fires. Thus reducing the number and/or intensity of those fires has a significant impact on the expected level of damages. Other strategies do not result in a similar reduction in the number of fires, and may in fact result in a slight increase in the number of fires caused by escaped burns if some of the fuel reduction involve planned burns.

With the implementation of additional DPaW fuel reduction, the largest proportional reduction in asset losses for the entire case study area occurs for biodiversity. This strategy reduces biodiversity losses by 44%, while other asset losses are reduced by 22% to 36%. However, savings in losses for high value assets still account for the majority of the benefits: the reduction in residential and industrial/commercial buildings resulting from additional DPaW fuel reduction represents around 53% of the total benefits of the strategy. In comparison, other strategies, if applied independently, achieve a reduction in asset losses of only 1% to 3%.

The benefits of DPaW fuel reduction are relatively high compared to the expected asset losses in the case study area under the current scheme (business as usual). They represent about 37% of the total expected asset losses under the current scheme. When combined with Shire fuel reduction, the benefits of implementing both strategies together represent about 41% of current expected damages. For the other strategies however, the benefits represent 2% or less of current expected damages. Thus, in the South-West case study area, concurrent increases in fuel reduction in DPaW-managed land and in Shire-managed land can significantly improve bushfire risk management in the area.

Table 4.10. Impacts in Urban Bridgetown of implementing each strategy across the entire case-study area

		Strategy implemented				
	Benchmark (business as usual)	Increased fuel reduction (DPaW only)	Land-use planning	Green army	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Additional hectares treated in the sub-region	-	0.02	0	1	2	2
	Average number of fires per year in Urban Bridgetown					
Insignificant	2.39	2.37	2.39	2.45	2.39	2.36
Minor	0.191	0.175	0.191	0.192	0.189	0.164
Moderate	0.0253	0.0233	0.0253	0.0252	0.0251	0.0220
Major	0.00556	0.00514	0.00556	0.00554	0.00551	0.00486
Catastrophic	0.00131	0.00119	0.00131	0.00130	0.00129	0.00111
Total	*2.6*	*2.6*	*2.6*	*2.7*	*2.6*	*2.6*
	Expected suppression costs in Urban Bridgetown					
Suppression costs	$49,095	$45,266	$49,095	$48,976	$48,697	$42,619
	Expected asset loss in Urban Bridgetown					
Residential	$365,531	$335,122	$404,941	$363,160	$362,136	$313,934
Biodiversity	$1	$1	$1	$1	$1	$1
Life	$4,541	$4,166	$4,801	$4,518	$4,500	$3,905
Plantations	$0	$0	$0	$0	$0	$0
Infrastructure	$2,971	$2,724	$2,971	$2,952	$2,944	$2,552
Industrial	$100,177	$91,843	$119,462	$99,527	$99,246	$86,036
Agriculture	$19	$18	$19	$19	$19	$17
Total	*$473,240*	*$433,874*	*$532,195*	*$470,178*	*$468,845*	*$406,445*

Table 4.10. Contd.

	Benchmark (business as usual)	Strategy implemented				
		Increased fuel reduction (DPaW only)	Land-use planning	Green army	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
	Expected benefits for Urban Bridgetown of implementation of the strategy in the entire case-study area					
Saving in asset losses	-	$39,366	-$58,955	$3,062	$4,395	$66,795
Saving in suppression expenditures	-	$3,830	$0	$119	$398	$6,476
Total savings	-	$43,196	-$58,955	$3,181	$4,793	$73,271
Benefits relative to losses without implementation of the strategy	-	9%	-12%	0.7%	1%	15%

For the strategies that involve fuel management (i.e. all strategies except land use planning), the source of the benefits is different in each sub-region. In Urban Bridgetown and Conservation South West, most of the benefits are the result of reductions in high value asset losses (residential and industrial/commercial buildings), whereas in Rural Living Bridgetown the majority of the benefits are the result of savings in suppression costs for most of the strategies involving fuel reduction, except for the Green army strategy. In Urban Bridgetown, between 90 to 95% of the benefits in the sub-region are attributed to savings in residential and industrial/commercial building losses (see Table 4.10). In Conservation South West, this proportion is smaller: between 69% to 71% of the benefits (Table 4.12). In Rural Living Bridgetown, savings in suppression costs generated by DPaW and Shire fuel reduction (applied together or independently) account for almost 60% of the benefits in the sub-region, but with the Green army strategy, savings in suppression account for 37% of the benefits and 48% stem from reduction in high value asset losses (Table 4.11).

In the South-West case study area, land use planning changes the distribution of future buildings across sub-regions, but the total number of forecasted buildings in the entire case study area by 2026 remains the same. This results in an increase in the number of residential buildings, industrial/commercial buildings and people located in Urban Bridgetown. Because the strategy is assumed to have no impact on fire risk or fire severity, with an increase in the number of asset at risk in Urban Bridgetown, total asset losses increase in the sub-region (i.e. it generates negative benefits for the sub-region).

The proportional reduction in total expected asset losses and suppression costs changes by strategy and sub-region. For instance, additional DPaW fuel reduction or additional DPaW and Shire fuel reduction (applied together) may reduce total expected asset losses and suppression costs between 8% and 14% in Urban Bridgetown and Rural Living Bridgetown (Table 4.10 and Table 4.11). The proportional reduction in asset losses and suppression costs achieved in Conservation South West with these strategies is considerably higher. DPaW only or DPaW and Shire fuel reduction may reduce asset losses and suppression costs between 57% and 61% in Conservation South West (Table 4.12). The proportional reduction in asset losses and suppression costs achieved with the Green army strategy or additional Shire fuel reduction only in the 3 sub-regions is more comparable: between 0% and 3%.

Table 4.11. Impacts in Rural living of implementing each strategy across the entire case-study area

		Strategy implemented				
	Benchmark (business as usual)	Increased fuel reduction (DPaW only)	Land-use planning	Green army	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Additional hectares treated in the sub-region	-	0.4	0.0	13	24	25
	Average number of fires per year in Rural living					
Insignificant	6.97	6.93	6.97	7.15	6.97	6.90
Minor	0.555	0.509	0.555	0.559	0.550	0.478
Moderate	0.0731	0.0673	0.0731	0.0729	0.0726	0.0633
Major	0.01585	0.01463	0.01585	0.01581	0.01573	0.01382
Catastrophic	0.00358	0.00325	0.00358	0.00355	0.00354	0.00304
Total	*7.6*	*7.5*	*7.6*	*7.8*	*7.6*	*7.5*
	Expected suppression costs in Rural Living					
Suppression costs	$140,343	$129,076	$140,343	$140,005	$139,199	$121,555
	Expected asset loss in Rural living					
Residential	$49,817	$45,530	$43,209	$49,521	$49,357	$42,692
Biodiversity	$300	$274	$300	$298	$297	$257
Life	$752	$687	$686	$748	$745	$645
Plantations	$461	$421	$461	$458	$457	$395
Infrastructure	$17,851	$16,315	$17,851	$17,745	$17,686	$15,297
Industrial	$22,428	$20,498	$20,476	$22,294	$22,220	$19,220
Agriculture	$3,460	$3,162	$3,460	$3,440	$3,428	$2,965
Total	*$95,068*	*$86,887*	*$86,443*	*$94,503*	*$94,190*	*$81,470*

Table 4.11. Contd.

	Benchmark (business as usual)	Strategy implemented				
		Increased fuel reduction (DPaW only)	Land-use planning	Green army	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Expected benefits for Rural living of implementation of the strategy in the entire case-study area						
Saving in asset losses	-	$8,181	$8,626	$565	$878	$13,598
Saving in suppression expenditures	-	$11,268	$0	$338	$1,145	$18,789
Total savings	-	$19,449	$8,626	$903	$2,023	$32,387
Benefits relative to losses without implementation of the strategy	-	20%	9%	1.0%	2%	34%

Table 4.12. Impacts in Conservation South West of implementing each strategy across the entire case-study area

	Benchmark (business as usual)	Strategy implemented: Increased fuel reduction (DPaW only)	Land-use planning	Green army	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
Additional hectares treated in the sub-region	-	820	0	51	2	822
Average number of fires per year in Conservation South West						
Insignificant	3.12	2.88	3.12	3.20	3.13	2.89
Minor	0.249	0.104	0.249	0.246	0.242	0.099
Moderate	0.0328	0.0149	0.0328	0.0322	0.0321	0.0143
Major	0.00714	0.00341	0.00714	0.00700	0.00698	0.00328
Catastrophic	0.00163	0.00062	0.00163	0.00158	0.00158	0.00057
Total	*3.4*	*3.0*	*3.4*	*3.5*	*3.4*	*3.0*
Expected suppression costs in Conservation South West						
Suppression costs	$63,157	$28,555	$63,157	$61,916	$61,682	$27,327
Expected asset loss in Conservation South West						
Residential	$215,026	$88,610	$186,500	$209,632	$209,334	$83,618
Biodiversity	$18,821	$7,756	$18,821	$18,349	$18,322	$7,319
Life	$2,160	$896	$1,972	$2,108	$2,104	$847
Plantations	$13,210	$5,444	$13,210	$12,879	$12,861	$5,137
Infrastructure	$32,361	$13,336	$32,361	$31,549	$31,504	$12,584
Industrial	$76,233	$31,415	$69,600	$74,321	$74,215	$29,645
Agriculture	$5,921	$2,440	$5,921	$5,773	$5,765	$2,303
Total	*$363,731*	*$149,897*	*$328,385*	*$354,610*	*$354,105*	*$141,453*

Table 4.12. Contd.

	Benchmark (business as usual)	Strategy implemented				
		Increased fuel reduction (DPaW only)	Land-use planning	Green army	Increased fuel reduction (Shire only)	Increased fuel reduction (DPaW and Shire)
	Expected benefits for Conservation South West of implementation of the strategy in the entire case-study area					
Saving in asset losses	-	$213,834	$35,346	$9,121	$9,626	$222,279
Saving in suppression expenditures	-	$34,602	$0	$1,241	$1,476	$35,830
Total savings	-	$248,436	$35,346	$10,362	$11,102	$258,109
Benefits relative to losses without implementation of the strategy	-	68%	10%	3%	3%	71%

5. SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to test the robustness of the results and identify the variables that most influence the results. Because there is a high degree of uncertainty about the range of some of the variables, all variables were increased and decreased by 50%.

5.1. Case study 1 (Perth Hills)

For the strategy that increases DPaW fuel reduction in the Perth Hills, the results are robust. Changes to the different parameters have varying impact on the amount of benefits per dollar invested, but the BCRs remain > 1. The results of this strategy are most sensitive to changes in the cost per hectare of fuel reduction (Table 5.1). However, even if the costs per hectare of fuel reduction are increased by 50%, the BCR for this strategy is still > 1. For this strategy to result in a breakeven solution (i.e. costs = benefits, BCR = 1), cost per hectare of fuel treatments would have to be increased by 370% (from an average of AU$500 per hectare per year to an average of AU$2,350 per hectare per year).

Other parameters that also affect the results are the assumed proportion of assets destroyed per fire and the assumed reduction in fire severity that is achieved by the fuel reduction. However, even when these parameters are reduced by 50%, the expected benefits are more than double the costs of the strategy. Even with larger reductions in these parameters (of more than 90%), the BCR for additional DPaW fuel reduction remains > 1. Thus, even if all fires are assumed to cause relatively little damages or if the effectiveness of DPaW fuel reduction is assumed to be considerably lower, the benefits of this strategy still exceed the costs. Even if both the cost per hectare of fuel reduction is increased by 50% and assumed reduction in fire severity is reduced by 50% simultaneously, the BCR of this strategy is still > 1.

Changes in the value or the forecasted growth in high value assets also affect the results of increased DPaW fuel reduction. But for other parameters, changes in their values have little impact on the results. For instance, an increase or a decrease of 50% in the number of DPaW escaped burns, does not have a significant influence on the results. This is mostly due to the fact that in this case study area, historically few bushfires have been the caused by escaped DPaW burns.

Ecological costs can have a significant impact on the results, but even if they are assumed to be AU$550 per hectare treated, the benefits are more than double the costs. For the strategy to break even (costs = benefits), ecological costs would have to be equal to AU$1,800 per hectare treated. If ecological costs are higher than this amount, then the BCR for this strategy would be < 1.

Table 5.1. Sensitivity analysis: increased fuel reduction (DPaW only)

Benchmark (business as usual)	BCR		
	4.64		
Parameter	**Decrease/increase in parameter: -50% (new BCR)**	**+50% (new BCR)**	**Sensitivity**
Value of a statistical life	4.60	4.68	0.08
Value of a residential building	3.10	6.18	3.08
Forecast growth in population and dwellings for 2026	3.87	5.40	1.53
Reduction in fire spread across sub-region boundaries	4.13	5.14	1.01
Increase in the number of fire incidents caused by prescribed burning*	4.64	4.64	0.00
Baseline proportion of fire incidents caused by prescribed burning*	4.64	4.64	0.00
Reduction in fire incidents achieved by the strategy	4.17	5.11	0.95
Reduction in fire severity	2.87	6.41	3.54
Baseline proportion of fires that spread across a sub-region boundary	4.49	4.79	0.29
Proportion of assets destroyed per fire	2.60	6.68	4.08
Suppression cost for fires	4.40	4.88	0.48
Value of biodiversity per hectare of vegetation	4.63	4.65	0.02
Cost per hectare of fuel reduction*	9.28	3.09	6.18
Ecological cost of fuel reduction ($ per ha treated)	$0	$550	Sensitivity
	new BCR		
	4.64	2.21	2.43

* Only the parameter for the agency/stakeholder applying the strategy is modified

The results are also robust for the land use planning strategy in the Perth Hills (Table 5.2). The parameter that has the largest impact on the results is the costs of applying the strategy, but even if the costs of applying the strategy are increased by 50%, the BCR is still significantly > 1. For the results of this strategy to break even (costs = benefits), the cost of the strategy would have to be 15 times more expensive.

Other parameters that have a considerable impact on the results are the proportion of assets destroyed by different fires of different severities, the value of a residential building, and the forecast growth in population and dwellings for 2026. However, even if these parameters are reduced by 50%, the BCRs remain substantially > 1.

Table 5.2. Sensitivity analysis: land-use planning

Benchmark (business as usual)	BCR		
	15.26		
Parameter	Decrease/increase in parameter		Sensitivity
	-50%	+50%	
	new BCR		
Value of a statistical life	15.18	15.34	0.16
Value of a residential building	9.08	21.43	12.35
Reduction in buildings destroyed due to improved building materials	13.86	16.65	2.80
Forecast growth in population and dwellings for 2026	8.66	21.86	13.20
Baseline proportion of fires that spread across a sub-region boundary	14.87	15.65	0.78
Proportion of assets destroyed per fire	7.71	22.81	15.10
Total cost of applying the strategy	30.51	10.17	20.34

The results for the community engagement strategy are less robust than for the previous two strategies (Table 5.3). Changes to some parameters can reverse the results and generate a BCR > 1. However, overall, this strategy does not generate BCRs that are substantially larger or substantially smaller than 1. The parameter that most affect the results of this strategy is the cost per hectare of fuel reduction. If the costs of applying the strategy are assumed to be 50% lower, then the strategy would generate benefits that are double the costs. However, even if the costs are reduced by 50%, the BCR of this strategy does not reach the levels of the BCRs for increased DPaW fuel reduction or land-use planning.

The results of this strategy are also sensitive to the assumed proportion of assets destroyed per fire, the assumed reduction in fire severity and the value of a residential building. Changes to these parameters can change the BCR to be > 1. This suggests that to make appropriate investment decisions regarding community engagement, it is necessary to improve the information available for those parameters. Other parameters have a smaller impact on the results and when increased or decreased by 50%, the BCR remains ≤ 1.

Table 5.3. Sensitivity analysis: community engagement

Benchmark (business as usual)	BCR		
	0.92		
Parameter	Decrease/increase in parameter		Sensitivity
	-50%	+50%	
	new BCR		
Value of a statistical life	0.91	0.93	0.02
Value of a residential building	0.61	1.24	0.63
Forecast growth in population and dwellings for 2026	0.77	1.08	0.31
Reduction in fire spread across sub-region boundaries	0.91	0.93	0.02
Increase in the number of fire incidents caused by prescribed burning*	0.97	0.88	0.09
Baseline proportion of fire incidents caused by prescribed burning*	1.06	0.78	0.27
Reduction in fire incidents achieved by the strategy	0.91	0.93	0.02
Reduction in fire severity	0.52	1.33	0.81
Baseline proportion of fires that spread across a sub-region boundary	0.90	0.94	0.04
Proportion of assets destroyed per fire	0.51	1.34	0.83
Suppression cost for fires	0.88	0.96	0.07
Value of biodiversity per hectare of vegetation	0.92	0.92	0.00
Cost per hectare of fuel reduction*	2.03	0.60	1.43
Ecological cost from prescribed burning ($ per ha treated)	$0	$550	Sensitivity
	new BCR		
	0.92	0.57	0.35

* Only the parameter for the agency/stakeholder applying the strategy is modified

The results for increased Shire fuel reduction are fairly robust (Table 5.4). In most cases, increases or decreases of 50% in the parameter values maintain a BCR > 1, except for the assumed reduction in fire severity. The key parameters that affect the results of other strategies also have an influence on the results of additional Shire fuel reduction. Those key parameters are: cost per hectare of fuel reduction, the assumed reduction in fire severity achieved by the treatments, the assumed proportion of assets destroyed per fire and the value of residential buildings.

Table 5.4. Sensitivity analysis: increased fuel reduction (Shire only)

Benchmark (business as usual)	BCR		
	1.78		
Parameter	**Decrease/increase in parameter**		**Sensitivity**
	-50%	+50%	
	new BCR		
Value of a statistical life	1.82	1.75	0.07
Value of a residential building	1.13	2.43	1.30
Forecast growth in population and dwellings for 2026	1.52	2.05	0.53
Reduction in fire spread across sub-region boundaries	1.78	1.78	0.01
Increase in the number of fire incidents caused by prescribed burning*	1.78	1.78	0.00
Baseline proportion of fire incidents caused by prescribed burning*	1.78	1.78	0.00
Reduction in fire incidents achieved by the strategy	1.78	1.78	0.01
Reduction in fire severity	0.84	2.73	1.89
Baseline proportion of fires that spread across a sub-region boundary	1.74	1.82	0.08
Proportion of assets destroyed per fire	0.93	2.63	1.70
Suppression cost for fires	1.70	1.86	0.15
Value of biodiversity per hectare of vegetation	1.78	1.79	0.01
Cost per hectare of fuel reduction*	3.56	1.19	2.38
Ecological cost from prescribed burning ($ per ha treated)	$0	$550	Sensitivity
	new BCR		
	1.78	1.37	0.42

* Only the parameter for the agency/stakeholder applying the strategy is modified

The combination of DPaW and Shire fuel reduction has similar results to DPaW only fuel reduction. The results are robust and the BCR remains substantially > 1 with increases and decreases of 50% to all the parameter analysed here (Table 5.5). The parameters that make the largest difference are the same key parameters that affect the results of other strategies.

Table 5.5. Sensitivity analysis: increased fuel reduction (DPaW and Shire)

Benchmark (business as usual)	BCR		
	4.68		
Parameter	**Decrease/increase in parameter**		**Sensitivity**
	-50%	+50%	
	new BCR		
Value of a statistical life	4.65	4.71	0.06
Value of a residential building	3.09	6.27	3.18
Forecast growth in population and dwellings for 2026	3.90	5.45	1.55
Reduction in fire spread across sub-region boundaries	4.22	5.14	0.92
Increase in the number of fire incidents caused by prescribed burning*	4.68	4.68	0.00
Baseline number of fire incidents caused by prescribed burning*	4.68	4.68	0.00
Reduction in fire incidents achieved by the strategy	4.24	5.12	0.87
Reduction in fire severity	2.83	6.53	3.69
Baseline proportion of fires that spread across a sub-region boundary	4.54	4.82	0.27
Proportion of assets destroyed per fire	2.59	6.77	4.18
Suppression cost for fires	4.46	4.90	0.43
Value of biodiversity per hectare of vegetation	4.67	4.69	0.02
Cost per hectare of fuel reduction*	9.36	3.12	6.24
Ecological cost from prescribed burning ($ per ha treated)	$0	$550	Sensitivity
	new BCR		
	4.68	2.44	2.24

* Only the parameter for the agency/stakeholder applying the strategy is modified

5.2. Case study 2 (South-West)

The results of increased DPaW fuel reduction are also robust in the South-West case study area. With changes to parameter values of ±50%, the BCR remains > 1 (Table 5.6). However, the South-West case study area has a larger proportion of conservation and natural areas, and as a result, there is one parameter that can reverse the results and generate a BCR < 1: the ecological costs of fuel reduction per hectare treated. Depending on what these costs are assumed to be, the strategy may cost more than the benefits it generates. The results breakeven (BCR = 1) when ecological costs per hectare treated are equal to AU$100. Thus if the ecological cost per hectare treated by DPaW exceeds this value, the costs of the strategy would be higher than the benefits generated. This suggests that as the proportion of natural and conservation areas increases in a region, it is increasingly important to consider ecological impacts of fuel reduction.

The same key parameters that most influence the results of the strategies in the Perth Hills, generally also have a significantly impact on the results of the strategies in the South-West case study area. For instance, the parameter that most affect the results of DPaW fuel reduction is the cost per hectare of fuel reduction. If increased by 50%, the BCR is still > 1. The results break even if costs per hectare for DPaW fuel reduction in the area are AU$195; if fuel reduction per hectare are more expensive, then the strategy costs would be greater than the benefits generated. Other parameters that significantly influence the results are the assumed reduction in fire severity and the assumed proportion of assets destroyed by fires. However, even if these parameters are reduced by 50%, the BCR of DPaW fuel reduction in the South-West case study area is still > 1. Because the number of high value assets (residential and industrial/commercial buildings) in the South-West is considerably smaller than the number of high value assets in the Perth Hills area, a change in the value of residential buildings in the South-West has a relatively small impact on the results.

Table 5.6. Sensitivity analysis: increased fuel reduction (DPaW only)

Benchmark (business as usual)	BCR		
	2.09		
Parameter	Decrease/increase in parameter		Sensitivity
	-50%	+50%	
	new BCR		
Value of a statistical life	2.09	2.10	0.004
Value of a residential building	1.71	2.52	0.81
Forecast growth in population and dwellings for 2026	2.00	2.24	0.24
Reduction in fire spread across sub-region boundaries	1.94	2.25	0.31
Increase in the number of fire incidents caused by prescribed burning*	2.10	2.09	0.002
Baseline proportion of fire incidents caused by prescribed burning*	2.10	2.09	0.002
Reduction in fire incidents achieved by the strategy	1.95	2.24	0.30
Reduction in fire severity	1.27	2.92	1.65
Baseline proportion of fires that spread across a sub-region boundary	1.99	2.20	0.21
Proportion of assets destroyed per fire	1.33	2.91	1.58
Suppression cost for fires	1.98	2.21	0.23
Value of biodiversity per hectare of vegetation	2.02	2.17	0.14
Cost per hectare of fuel reduction*	4.19	1.40	2.79
Ecological cost of fuel reduction ($ per ha treated)	$0	$550	Sensitivity
	new BCR		
	2.09	0.30	1.79

* Only the parameter for the agency/stakeholder applying the strategy is modified

The benefits of land-use planning in the South-West case study area are smaller than the costs of implementing the strategy (i.e. BCR < 1). Changes to the different parameters do not change the results and the BCR remains < 1 (Table 5.7). Even if the forecasted growth in the number of buildings by 2026 for the case study area is reduced and some of those buildings were built outside the case study area (in an area with zero fire risk), the BCR for this strategy remains < 1. Similarly, if the forecasted growth in buildings in the case study area is reduced to zero in both urban areas and rural-natural areas, the BCR for this strategy remains < 1. The contrasting results between the two case studies for the land use planning policy is mostly explained by the difference in the number of residential assets at risk. In the South-West, there were approximately 4,400 residential buildings in

2011, forecasted to increase to approximately 5,400 by 2026; whereas in the Perth Hills there were approximately 105,500 residential buildings in 2011, forecasted to increase to approximately 168,200 by 2026. The number of high value assets at risk in the Perth Hills is more than 30 times higher than in the South-West, and consequently, a land use planning policy generates major benefits in the Perth Hills, and little benefits in the South-West.

Table 5.7. Sensitivity analysis: land-use planning

Benchmark (business as usual)	BCR		
	0.13		
Parameter	Decrease/increase in parameter		Sensitivity
	-50%	+50%	
	new BCR		
Value of a statistical life	0.13	0.13	0.001
Value of a residential building	0.13	0.34	0.22
Reduction in buildings destroyed due to improved building materials	0.09	0.38	0.30
Forecast growth in population and dwellings for 2026	0.08	0.39	0.31
Baseline proportion of fires that spread across a sub-region boundary	0.11	0.16	0.06
Proportion of assets destroyed per fire	0.12	0.35	0.23
Total cost of applying the strategy	0.27	0.09	0.18

For the Green army, the benefits are also smaller than the costs of implementing the strategy. Changes to the different parameters have very little impact on the results. Only changing the cost per hectare of fuel reduction results in a BCR > 1, but in this case, the benefits would only be 9% greater than the costs (Table 5.8).

Table 5.8. Sensitivity analysis: green army

Benchmark (business as usual)	BCR		
	0.41		
Parameter	**Decrease/increase in parameter**		**Sensitivity**
	-50%	+50%	
	new BCR		
Value of a statistical life	0.41	0.41	0.001
Value of a residential building	0.32	0.50	0.18
Forecast growth in population and dwellings for 2026	0.39	0.44	0.05
Reduction in fire spread across sub-region boundaries	0.40	0.42	0.02
Increase in the number of fire incidents caused by prescribed burning*	0.45	0.36	0.09
Baseline proportion of fire incidents caused by prescribed burning*	0.55	0.27	0.28
Reduction in fire incidents achieved by the strategy	0.40	0.42	0.02
Reduction in fire severity	0.05	1.00	0.95
Baseline proportion of fires that spread across a sub-region boundary	0.38	0.43	0.05
Proportion of assets destroyed per fire	0.25	0.58	0.34
Suppression cost for fires	0.39	0.42	0.03
Value of biodiversity per hectare of vegetation	0.39	0.42	0.03
Cost per hectare of fuel reduction*	1.09	0.25	0.84
Ecological cost from prescribed burning ($ per ha treated)	$0	$550	Sensitivity
	new BCR		
	0.41	0.09	0.32

* Only the parameter for the agency/stakeholder applying the strategy is modified

The results of Shire fuel reduction are also fairly robust. Only changes to two parameters values can reverse the results and generate a BCR > 1 (Table 5.9). These parameters are the assumed reduction in fire severity and the cost per hectare of fuel treatments. But even when these parameters values are modified, the benefits are only moderately larger than the costs.

Table 5.9. Sensitivity analysis: increased fuel reduction (Shire only)

Benchmark (business as usual)	BCR		
	0.59		
Parameter	Decrease/increase in parameter		Sensitivity
	-50%	+50%	
	new BCR		
Value of a statistical life	0.59	0.59	0.001
Value of a residential building	0.46	0.71	0.24
Forecast growth in population and dwellings for 2026	0.55	0.62	0.07
Reduction in fire spread across sub-region boundaries	0.59	0.59	0.003
Increase in the number of fire incidents caused by prescribed burning*	0.59	0.59	0.0001
Baseline proportion of fire incidents caused by prescribed burning*	0.59	0.59	0.0001
Reduction in fire incidents achieved by the strategy	0.59	0.59	0.003
Reduction in fire severity	0.15	1.32	1.17
Baseline proportion of fires that spread across a sub-region boundary	0.56	0.62	0.06
Proportion of assets destroyed per fire	0.36	0.81	0.44
Suppression cost for fires	0.56	0.62	0.06
Value of biodiversity per hectare of vegetation	0.57	0.60	0.03
Cost per hectare of fuel reduction*	1.17	0.39	0.78
Ecological cost from prescribed burning ($ per ha treated)	$0	$550	Sensitivity
	new BCR		
	0.59	0.40	0.18

* Only the parameter for the agency/stakeholder applying the strategy is modified

The results of the sensitivity analysis for the combination of DPaW and Shire fuel reduction are similar to the results of the sensitivity analysis of DPaW only fuel reduction. A few key parameters have a greater impact on the results (i.e. the cost per hectare of fuel reduction, the assumed reduction in fire severity, and the assumed proportion of assets destroyed per fire). In any case, with changes of ±50t% to all parameter values the BCR of this combination of strategies remains > 1 (Table 5.10). However most of the benefits are generated by the increase in DPaW fuel reduction and the combination with Shire fuel reduction results in a small reduction in the benefits generated per dollar invested.

Table 5.10. Sensitivity analysis: increased fuel reduction (DPaW and Shire)

Benchmark (business as usual)	BCR		
	1.98		
Parameter	**Decrease/increase in parameter**		**Sensitivity**
	-50%	+50%	
	new BCR		
Value of a statistical life	1.98	1.98	0.004
Value of a residential building	1.61	2.40	0.79
Forecast growth in population and dwellings for 2026	1.89	2.11	0.23
Reduction in fire spread across sub-region boundaries	1.84	2.12	0.28
Increase in the number of fire incidents caused by prescribed burning*	1.98	1.98	0.003
Baseline number of fire incidents caused by prescribed burning*	1.98	1.98	0.003
Reduction in fire incidents achieved by the strategy	1.85	2.12	0.27
Reduction in fire severity	1.18	2.83	1.65
Baseline proportion of fires that spread across a sub-region boundary	1.88	2.08	0.20
Proportion of assets destroyed per fire	1.25	2.75	1.49
Suppression cost for fires	1.88	2.09	0.21
Value of biodiversity per hectare of vegetation	1.92	2.04	0.12
Cost per hectare of fuel reduction*	3.97	1.32	2.64
Ecological cost from prescribed burning ($ per ha treated)	$0	$550	Sensitivity
	new BCR		
	1.98	0.32	1.66

* Only the parameter for the agency/stakeholder applying the strategy is modified

6. CONCLUSION

The aim of this study was to determine which fire management option (amongst those here evaluated) provided the best value for money. In order to do so, an existing model was adapted to the Western Australian context. This model evaluated the additional costs of implementing the different strategies in two case study areas and estimated the benefits compared to the *status quo*. It presented the benefits as expected values, which correspond to the weighted average that depends on the probabilities of different possible outcomes.

The analysis shows that the strategies evaluated have different impacts in each case study area and the strategy that generates the highest benefit per dollar invested is different for each location. In the Perth Hills case study area, the strategy that generates the highest benefits per dollar invested is the land use policy, whereas in the South-West it is additional fuel reduction in DPaW-managed land. In the Perth Hills, because of the large number of high value assets at risk in the area and the large number of fire incidents per year, the strategy that reduces the number of asset at risk generates the greatest benefits. In contrast, the South-West has a much lower number of high value assets, lower numbers of fire incidents per year, and a large proportion of natural and conservation areas; thus the strategy that reduces the chances of large, intense and costly bushfires occurring generates the greatest benefits.

The strategies for which the benefits exceed the costs, most of the benefits stem from avoided damages to high value assets such as residential buildings and industrial/commercial buildings. The sharp contrast in the results of the land use planning policy in both case studies is primarily due to the considerable difference in the number of residential buildings in each case study area.

The expected level of damages is very different for both case study areas under the current scheme and with the application of any of the strategies. Average expected asset losses per year from fires of different types in the Perth Hills are in the order of AU$30 million, whereas in the South-West they are in the order of AU$1.5 million. This is not only due to the difference in the number of high value assets between the two case studies, but also due to the differences in fire numbers, prevalent climate and land uses. The Perth Hills are subject to a higher number of severe to extreme fire weather days than the South-West and the areas where flammable vegetation are intermingled with housing and other high value human assets are larger in the Perth Hills than in the South-West.

The results from this study seem to indicate a tendency: in areas where there are high numbers of people, dwellings, commercial buildings and infrastructure (i.e. high value human assets), the highest value for money for additional investments in fire management is obtained from land use planning; while in areas where there is an abundance of natural areas, high values for biodiversity and a smaller concentration of high value human assets, the highest value for money for additional investments is obtained from fuel management. However, this observation is to be appreciated with caution. Each area is unique in its context and the results cannot be generalised to the whole State, even for similar areas. When the bushfire management context changes, the source of the costs and benefits also changes and the results between two seemingly similar areas can differ. Given the size of the State and the variability in land use, vegetation, weather patterns, numbers of people and bushfire management between the different regions, these results may not necessarily apply to other regions.

In terms of fuel reduction, additional DPaW fuel reduction generate more benefits per dollar invested than additional fuel reduction by the Shires and private landowners, mainly because of the large amount of land that DPaW can treat. It is by treating large areas of land that the treatment can reduce the chances of major or catastrophic fires occurring, which are the fires responsible for most of the damages.

For all strategies, most of the benefits come from reductions in asset losses rather than reductions in suppression costs. A large proportion of the benefits arise from reduced losses to high value assets: residential buildings, industrial/commercial buildings, and infrastructure.

The benefits from the combination of DPaW and Shire fuel reduction are larger than the sum of the benefits generated by each strategy when implemented independently. This suggests that there are synergies in simultaneously applying several strategies and managing the risk across the landscape in all the land tenures (private vs. DPaW-managed land vs. Shire-managed land). These synergies would need to be explored further to understand what the best combinations are for bushfire management.

It is important to note that the risk is never reduced to zero and that significant damages my still occur despite the implementation of any of the fire management strategies tested here. In the Perth Hills asset losses remain in the order of AU$30 to AU$40 million, no matter which strategy is applied, and in the South-West in the order of AU$600,000 to AU$800,000. Thus, it is important for people living in fire prone areas to understand that the risk cannot be eliminated.

It is important to remember that the benefits of the strategies evaluated are calculated against the *status quo*. This is important, it means that the results of this analysis are valid for a scenario where the current investment is kept at current levels and additional investments are directed towards one of the options evaluated here. In other words, if the current scheme is changed, the results of this analysis would also change. Therefore, some of the results may suggest that management is already being done appropriately in the area. The fact that for some strategies the benefits do not exceed the costs does not mean that the strategy should be abandoned; it may mean that the appropriate investment is already in place in the area for that particular strategy. Since for this study the counterfactual is the current scheme (business as usual), the analysis is testing where it would be more profitable to direct additional investments, not where the investments are currently generating most benefits.[10] Thus, if the benefits of a particular strategy reported in this study are high, that indicates that additional investments in that option are likely to improve fire management in the area and reduce potential damages from bushfires. However, this will only occur as long as what is being done at the moment is kept in place (i.e. the exclusion of one strategy to replace it with another has not been tested in this study).

There are some key parameters that have a significant influence in the results in both case study areas and for most of the strategies, for which it is worth collecting more information and conducting more research in order to make better investment decisions in bushfire management and maximise benefits to society. These key parameters are: the cost per hectare of fuel reduction, the assumed reduction in fire severity achieved by the treatments, the assumed proportion of assets destroyed per fire and the value of residential buildings (or the number of residential buildings).

The study has a number of limitations. First, the land-use planning does not include the costs to society of not being able to build in the restricted areas or the costs to developers and construction companies that would benefit from the forecasted growth in dwellings in the case study areas. Furthermore, these building restrictions could cause considerable discontent and may also have also political implications. The support for such a strategy may be limited. These costs may be substantial and, if taken into account, they may significantly reduce the benefit per dollar invested for the land use planning strategy.

[10] To test which strategies currently generate the highest benefits, the strategies need to be evaluated against a different counterfactual without any intervention and a comparison of with and without intervention would be necessary. In this study, the scenario of no-intervention was not considered since the purpose was to determine where to direct additional investments in fire management and which information is required in order to make better decisions about those additional investments.

Second, the model assumes that all strategies can be successfully implemented. However, this may not be the case. For instance, a reduction in the number of suitable days for the application of prescribed burning due to climate change, may significantly limit the feasibility of the DPaW fuel reduction strategy. But there was not information available on the probability of success of each strategy to be able to include this information in the model. In addition, climate change and the potential increase in extreme weather days and higher fire risk were beyond the scope of this study and have not been taken into account.

Third, the model assumes a linear increase in the benefits of fuel reduction with additional area treated. However, this relationship is unlikely to be linear. A logistic function may better describe the relationship between area treated and level of benefits.

Finally, only 5 years of complete data were available from the different sources of data. Several sources were used, including DPaW datasets, DFES datasets, and Shire information, and the largest number of years for which all datasets were available is 5 years. Consequently, the fire statistics generated for this study are based on a relatively short period of time.

7. RECOMMENDATIONS

A number of recommendations can be drawn from the process followed to complete the analysis and from the results of this study:

1. The regions with the highest priority for investment in fire management tend to be those with the highest asset values at risk in fire prone areas.
2. In areas with a very large number of high value human assets (i.e. Perth Hills), strategies that remove the assets at risk from the areas concerned have a potential to generate significant benefits. Since a policy that restricts development in certain areas may not be possible or politically feasible, policies that generate disincentives for people to choose to live in the area may be an alternative way of limiting development in fire prone areas.
3. It is likely that the existing fuel reduction policy of the Department of Parks and Wildlife generates benefits in excess of costs. We have determined that increasing the investment in this strategy would also generate benefits in excess of costs.
4. Fuel reduction treatments are most beneficial when large areas are treated in a coordinated manner. This is likely to be achieved by agencies that manage large areas in the landscape and have the resources and the specialised expertise necessary to achieve so.
5. Priority strategies for fire management can vary by region. Therefore, it is important not to apply fire management strategies uniformly across the state.
6. It is important to be selective in the allocation of resources to fire management. Not all additional investments in fire management strategies are worthwhile.
7. Better data needs to be collected in certain areas to improve decisions about fire management. As this study showed, the particular characteristics of an area entirely change the fire management landscape and the results from one area cannot be generalised to another. Thus, location specific data for the key parameters that most affect the results is essential to improve decisions about the allocation of resources for fire management.
8. The collection of additional data by fire management agencies that can later be used for this type of economic evaluation is necessary to improve strategic fire management decisions. Some of the data that is collected is not available in agency databases or sporadically recorded in the databases (e.g. asset destroyed by each fire). Information on the cost of each strategy is often aggregated at the regional level and the differences in cost for different locations cannot easily be assessed. The collection of data by an independent agency in all

types of tenure would be greatly beneficial for this type of study. This dataset should include information on fire events and their consequences, as well as the management options implemented and their costs.

REFERENCES

Bar Massada, A, Radeloff, VC, Stewart, SI (2011) Allocating fuel breaks to optimally protect structures in the wildland–urban interface. *International Journal of Wildland Fire* **20**, 59–68.

Bowman, DMJS, Balch, JK, Artaxo, P, Bond, WJ, Carlson, JM, Cochrane, MA, D'Antonio, CM, DeFries, RS, Doyle, JC, Harrison, SP, Johnston, FH, Keeley, JE, Krawchuk, MA, Kull, CA, Marston, JB, Moritz, MA, Prentice, IC, Roos, CI, Scott, AC, Swetnam, TW, van der Werf, GR, Pyne, SJ (2009) Fire in the earth system. *Science* **324**, 481-484.

Bradstock, RA, Cary, GJ, Davies, I, Lindenmayer, DB, Price, OF, Williams, RJ (2012) Wildfires, fuel treatment and risk mitigation in Australian eucalypt forests: Insights from landscape-scale simulation. *Journal of Environmental Management* **105**, 66-75.

Burrows, N, McCaw, L (2013) Prescribed burning in southwestern Australian forests. *Frontiers in Ecology and the Environment* **11**, e25-e34.

Burrows, ND (2008) Linking fire ecology and fire management in south-west Australian forest landscapes. *Forest Ecology and Management* **255**, 2394-2406.

Cary, G, Bradstock, R, Gill, A, Williams, RJ (2012) Global change and fire regimes in Australia. In 'Flammable Australia: Fire Regimes, Biodiversity and Ecosystems in a Changing World.' (Eds R Bradstock, MA Gill, RJ Williams.) pp. 149-169. CSIRO Publishing: Melbourne.

Commonwealth of Australia (2015) National Emergency Risk Assessment Guidelines. Australian Government Attorney-General's Department, Canberra, ACT.

Dunford, MA, Power, L, Cook, B, 2014. National Exposure Information System (NEXIS) Building Exposure - Local Government Area (LGA). Geoscience Australia, Canberra, ACT.

Gibson, FL, Pannell, DJ (2014) 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, Bushfire CRC, Melbourne.

Gill, AM, Williams, JE (1996) Fire regimes and biodiversity: the effects of fragmentation of southeastern Australian eucalypt forests by urbanisation, agriculture and pine plantations. *Forest Ecology and Management* **85**, 261-278.

Marzano, R, Camia, A, Bovio, G (2008) Wildland-urban interface analysis for fire management planning. In 'Gonzalez-Caban, A. (technical coordinator) 'Proceedings of the second international symposium on fire economics, planning, and policy: a global view'. Cordoba, Spain, 19-22 April 2004', 19-22 April 2004. pp. 311-318. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, General Technical Report PSW-GTR-208.

Morgan, G (2009) Asia and Australasia wildfire management: a regional perspective. In 'Gonzalez-Caban, A. (Technical Coordinator) Proceedings of the third international symposium on fire economics, planning, and policy: common problems and approaches. Carolina, Puerto Rico', 29 April - 2 May 2008. pp. 8-23. General Technical Report PSW-GTR-227, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Morgan, G, Bartlett, T, Leonard, M (2007) Fire management and the bush – from an ad hoc seasonal pre-occupation to 'policy centre-stage'. In 'Tassie Fire Conference Proceedings. Hobart, Tasmania', 18 - 20 July 2007.

Mutch, RW, Rogers, MJ, Stephens, SL, Gill, MA (2011) Protecting lives and property in the wildland–urban interface: communities in Montana and southern California adopt Australian paradigm. *Fire Technology* **47**, 357-377.

Pannell, DJ, Roberts, AM, Park, G, Alexander, J, Curatolo, A, Marsh, S (2012) Integrated assessment of public investment in land-use change to protect environmental assets in Australia. *Land Use Policy* **29**, 377-387.

Roberts, AM, Pannell, DJ, Doole, G, Vigiak, O (2012) Agricultural land management strategies to reduce phosphorus loads in the Gippsland Lakes, Australia. *Agricultural Systems* **106**, 11-22.

Williams, J, Albright, D, Hoffmann, AA, Eritsov, A, Moore, PF, Mendes De Morais, JC, Leonard, M, San Miguel-Ayanz, J, Xanthopoulos, G, van Lierop, P (2011) Findings and implications from a coarse-scale global assessment of recent selected mega-fires. In 'FAO at the Vth International Wildland Fire Conference. Sun City, South Africa', 9-13 May 2011. pp. 27-40. Forestry Department, Fire Management Division Working Paper FM/27/E, Food and Agriculture Organization of the United Nations.