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An economic evaluation of bushfire prevention and suppression[†]

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The Fire Management Program (FMP) of the Victorian Department of Natural Resources and Environment is responsible for the prevention and suppression of fires on public land in the State of Victoria. This article reports on an economic evaluation of the net benefits of these fire management activities for a representative year. The FMP is calculated to yield high net benefits to Victoria from its investment in fire suppression and prevention, through a reduction in the value of agricultural, capital and forest assets which would otherwise be lost to bushfires.

1. Introduction

Victoria's climatic conditions, vegetation and geography make it arguably one of the world's most fire-prone regions, with vegetation growth in the spring months providing fuel for wildfires as it dries during the warmer summer months. Indeed, since European settlement in the 1830s, about half of all economic damage caused by bushfires in Australia has occurred in Victoria, even though the State comprises only 3 per cent of Australia's land area (Luke and McArthur 1978).[1] Since the formation of regional fire brigades in Victoria in the 1850s, both privately provided and publicly

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[1] High fire danger periods in Victoria develop around October–November in east Gippsland and north-west Victoria, and extend to the remainder of the State by December–February, with the fire season typically lasting until April (Department of Natural Resources and Environment 1996a).

provided fire management activities have sought to minimise the risk of bushfire-induced damage to human life and assets. This article reports on an attempt to measure the returns to the State from its investment in fire management activities on Victorian public land.

Clearly, it would be erroneous to measure the efficiency of public providers of fire management activities by comparing the value of *actual* bushfire-induced losses with the cost of fire prevention activities, as the better the fire management activities, the smaller the magnitude of any actual losses. As pointed out by Hatch and Jarrett (1985), the value of publicly provided fire suppression and prevention activities is a function of the *potential* damage avoided, and is determined by such variables as: the location, timing and likely spread of bushfires; the nature and value of assets potentially damaged by bushfires; and the extent to which alternative providers of fire management activities will reduce the damage caused by unchecked bushfires. In addition, many of the assets subject to potential damage by bushfires are either non-marketed (such as flora and fauna assets) or subject to price distortions (such as water resources), and as such are inherently difficult to value. Despite the difficulties associated with valuing the counterfactual results of fire prevention and suppression activities on public land, this article undertakes such an analysis for the fire management program (FMP) of Victoria's Department of Natural Resources and Environment (DNRE) using: actual fire incidence data for a typical fire season; a simulation model of bushfire spread; market-based data on the value of assets likely to be damaged by bushfires; and allowing for a range of probabilities for the substitution by private landholders and volunteer groups of publicly provided fire management activities.

This article first calculates the upper bound of the range of likely net benefits to Victoria from publicly provided fire management activities on the State's public land, assuming there is no fire prevention or fire suppression of any kind (denoted as the non-intervention scenario). Using conservative values of likely asset losses (including losses to capital improvements, agricultural, timber, forest recreation and conservation assets), and a conservative fire growth model to generate the likely burn pattern arising from the ignition of fires in a representative fire season (1991–92), the value of losses arising under the non-intervention scenario is calculated. The net benefits of the FMP are determined by subtracting both the cost of the FMP and the value of the actual damage caused by bushfires from the value of the potential damage caused by bushfires, assuming a representative fire season. Sensitivity analyses are then conducted, which allow for varying degrees of provision of fire management activities by private landholders and volunteer groups (denoted as the private intervention scenario). This work is followed by a discussion of why these results are likely to underestimate the net benefits of the State's fire management activities. To the best of the authors' knowledge, this measurement of the net benefits to the State from its investment in fire-fighting is the first time any public or volunteer fire-fighting organisation in Australia has been so evaluated.

The article is set out as follows. Section 2 describes previous work in the economics of bushfires, and is followed in section 3 by a discussion of the institutional arrangements for the management of bushfires on public land in Victoria. Section 4 then details the fire prevention and fire suppression activities which underpin DNRE's fire management program. Section 5 sets out the methodology followed in the economic evaluation of DNRE's fire management program, and the quantitative estimates of the net benefits to Victoria from this program are presented in section 6. Finally, a summary of the article and its major conclusions are given in section 7.

2. Previous work on the economics of bushfires

Despite the frequency and ferocity of bushfire-induced economic losses in the southern States of Australia, there has been little research on the economics of bushfire suppression and prevention. Exceptions have been contributions by Luke and McArthur (1978), Hatch and Jarrett (1985), Mules (1985), and the detailed work of Loane and Gould (1986). Luke and McArthur (1978) discuss the causes and effects of bushfires in Australia, while Loane and Gould (1986) conduct a cost–benefit analysis of the aerial suppression of bushfires in Victoria, finding that the long-run ratio of *actual* bushfire-induced losses to the cost of fire (aerial and ground) suppression was about 3:1, with the bulk of the losses concentrated in property and timber assets.

Using data from Cheney (1976) and Luke and McArthur (1978), Loane and Gould (1986) also calculate that the economic losses (to assets and lives) from bushfires of disaster magnitude in Victoria between 1915–85 had an imputed value of A$1,896 million (constant 1995 prices). The largest economic losses clearly occurred in the 1939 and 1983 bushfires (both about A$400 million, in constant 1995 prices), while serious losses also occurred in 1926 and 1944. The average period between Victorian bushfire disasters between 1915–85 was six years, with the average loss per bushfire of disaster magnitude over this period close to A$160 million (constant 1995 prices).

Mules (1985) undertook an input–output analysis of the extensive South Australian bushfires of 1983, finding that the direct economic losses to the agriculture and forestry sectors had significant flow-on effects to other sectors of the State's economy. Finally, in their assessment of the economics of bushfire prevention and suppression activities, Hatch and Jarrett (1985) make the important point that the end product of these activities is a 'regrettable' — the activities are necessary to minimise the damage which would otherwise occur from bushfires, which are an undesirable yet unavoidable event in the fire-prone areas of Australia. Hatch and Jarrett also present a discussion of the economic issues influencing the organisation, funding and functioning of volunteer fire-fighting groups in South Australia.

3. The management of bushfires on public land in Victoria

The encroachment of urban living into bushland areas has increased the potential for wildfires (defined as an unplanned grass, scrub or forest fire) to affect adversely human life and property. The worst fires recorded in Victoria occurred on Friday, 13 January 1939 (the 'Black Friday' fires). Over a period of a week hundreds of fires burned approximately 2 million hectares (about 10 per cent of the area) of the State, causing extensive damage to man-made and natural assets, and killing 71 people. In more recent times, the 1983 'Ash Wednesday' fires highlighted the destructive potential of wildfires, when 46 people lost their lives and 1100 homes were destroyed.[2]

DNRE is responsible for fire management on approximately 7.4 million hectares of public land, which is equivalent to 32.6 per cent of Victoria's total land mass. Figure 1 illustrates the extent of DNRE's responsibilities (denoted by the shaded area) across the State, which are concentrated in the east of the State, the Otways, the Grampians and in the Mallee. The fire management program (FMP) is a business unit within DNRE. Fire management has three major objectives: to reduce the incidence of wildfires on public land; to minimise the adverse impact of wildfires; and to exercise environmental care when fighting and using fire in the natural environment (DNRE 1996a).

4. The fire management program

While Victoria's public land is protected from fire by actions taken under the DNRE's FMP, its private land is protected by the Country Fire Authority (CFA), with the exception of a defined area of Melbourne which is protected by the Metropolitan Fire Brigades (MFB). DNRE has mutual support arrangements in place with the CFA to assist at wildfires in country areas of Victoria, and has obligations under Victoria's Emergency Management Act 1986 to provide assistance at any fire when required.

[2] In terms of area burned, the 'Black Thursday' fires of 1851 were the most extensive, with about 25 per cent of the then Colony of Victoria damaged by bushfire (Luke and McArthur 1978).

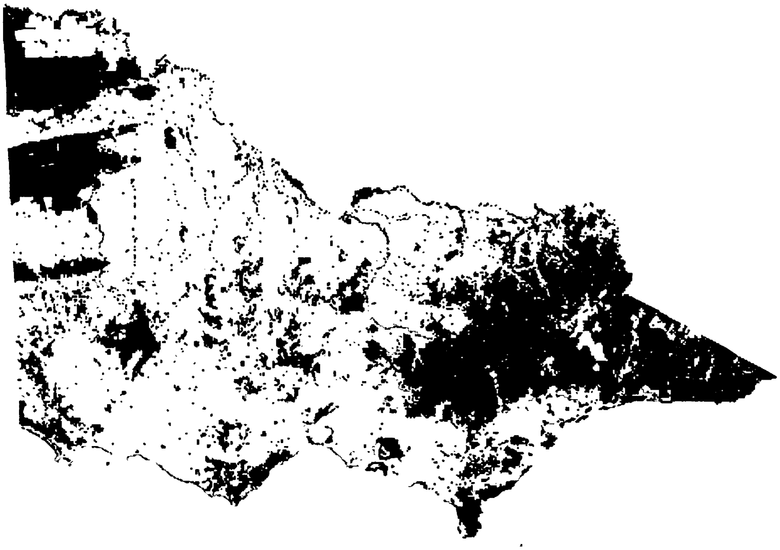

Figure 1 Public land in Victoria
Source: Victorian Department of Natural Resources and Environment.

DNRE also has mutual support arrangements with the fire services of New South Wales and South Australia to assist at wildfires in border areas and in any large-scale event.

DNRE's FMP can be separated into two main activities, fire prevention and fire suppression. The 1996–97 budget (about A$29 million) allocates approximately 38 per cent of funding to prevention and 52 per cent to suppression. The remaining 10 per cent of funding is split into 9 per cent for access to the State Mobile Radio Network, and 1 per cent for research and development (DNRE 1996a).

4.1 Fire prevention

The fire prevention activities of the FMP aim to minimise the number of fire outbreaks, and the damage caused, with particular emphasis on fires of human origin. The number of fires of both natural (lightning strikes) and human origin can be reduced by extensive fuel management.[3] Fuel management is effective as a means of minimising fire damage to the extent that when the quantity of vegetation available has been reduced, wildfires

[3] Fuel management refers to fuel reduction in an ecologically sustainable manner. The most common types of fuel to be reduced include: grasses, forest litter and bark, and excess vegetation.

will decline in intensity and slow in rate of spread, thus providing firefighters with an opportunity to be more effective in wildfire suppression. The size of a fire and the damage it causes to public and private assets are a function of: the location (remoteness and accessibility); the terrain; the nature and quantity of the fuel available (fuel hazard); the weather at the time of fire ignition; and the ability of the fire organisation to respond appropriately given the potential seriousness of the fire incident. Clearly, an important factor that can be modified by the FMP is a reduction in the fuel hazard.

DNRE's FMP undertakes a range of fuel management works, each with different objectives in mind. One of the first priorities is in localities adjacent to settlements, and other areas containing significant private or public assets. The second area of priority is in areas of strategic importance within large tracts of forested land, where the effect of a large fuel-reduced area will slow the passage of wildfire. In both cases this is done primarily by prescribed burning, which is a cost-effective means of reducing the forest litter, understorey and bark fuels, particularly on a broad scale.[4] Fuel management by means other than burning include: traditional grazing; slashing (reducing the height of vegetation); pruning; and mulching. Other than fuel management, fire prevention activities include: constructing and maintaining a network of access tracks to allow ready and safe access for fire vehicles; constructing and maintaining a network of water points in remote areas for fire appliances; constructing and maintaining a network of helipads and airstrips in remote areas to support aerial fire suppression operations; purchasing and maintaining fire equipment and facilities; training and accrediting fire personnel; and minimising the incidence of preventable wildfires (which are unplanned fires of human origin).[5] The latter activity would occur through: the collection of information regarding ignition sources; education on the careful and responsible use of fire by the community; legislation relevant to controlling the use of fire; communication and coordination activities to ensure a rapid response to fire; and enforcement of legislation on illegal fires.

4.2 Fire suppression

Fire suppression aims to control all fires on, or threatening, public land with the primary objective of controlling the fire in the shortest possible time, consistent with financial and environmental constraints. The fire suppression

[4] Prescribed burning is the controlled application of fire under specified environmental conditions to a predetermined area, at the time, intensity and rate of spread required to attain planned resource management objectives.

[5] It is important to note that access tracks, water points and the network of aviation facilities can also be regarded as fire suppression assets.

technique is chosen after considering: safety of personnel; assets threatened; available resources; fuel hazard; weather; topography; management objectives; and the likely environmental consequences of the actions taken (for example, erosion risks, landscape impacts and the spread of pests and diseases).

There are two main types of attack. A direct attack aims to control the fire by employing a control line[6] directly on the fire perimeter. This method usually involves the construction of a bulldozer or rake hoe line immediately adjacent to the fire, and/or directing the water from tankers onto the fire edge or immediate environs. An indirect attack is where the control line is located some considerable distance from the fire's active edge. This method usually involves lighting a backburn[7] along established control lines, and then burning-out any unburned areas between the control line and the main fire. These attacks can adopt either a dry fire-fighting technique, where there is little if any water available and hence (using a rake hoe or a bulldozer) a mineral earth break is constructed to halt the fire, or a wet fire-fighting technique (i.e. the use of water, foam and retardants). The FMP also engages up to 700 additional employees each summer for fire fighting. These employees are strategically located throughout Victoria, and are specifically trained for the efficient and effective first attack of forest fires.

5. Methodology used in the economic evaluation of the FMP

A benefit–cost analysis was performed to evaluate the FMP of the DNRE. To determine the benefits of the FMP it was necessary to estimate first the amount of damage that wildfires could cause in the absence of any (public or private) intervention — this is denoted as the 'non-intervention scenario'. The non-intervention scenario assumes that in the event of a wildfire threatening public land, no intervention by the FMP, volunteer groups or private landholders would occur.

Given a fire ignition point (denoted I), the benefits of the FMP can then be represented as the difference between the value of the assets lost under the non-intervention scenario and the actual amount of fire-induced damage that occurred with DNRE intervention (see figure 2). The benefits of the FMP as measured under this non-intervention scenario represent an upper bound

[6] A control line refers to a natural or constructed barrier, or treated fire edge, used in fire suppression and prescribed burning to limit the spread of the fire.

[7] A fire ignited along the inner edge of a control line, to consume the fuel in the path of wildfire, is called a backburn.

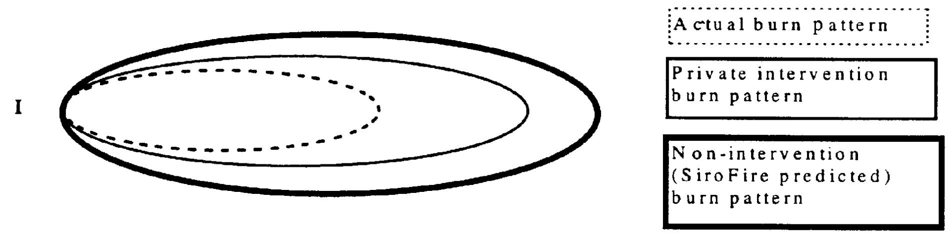

Figure 2 Predicted burn patterns

to the likely range of net benefits, as it assumes no response from private providers of fire management activities. Accordingly, in order to take into account that in the absence of the FMP, volunteer groups and private landholders may alter their fire suppression and fire prevention activities, a 'private intervention scenario' is introduced, which allows for privately provided fire management activities in the calculation of the net benefits of the FMP.[8]

5.1 Technical details of the tools used

SiroFire, a fire simulation model developed by the Division of Forestry and Forest Products of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), was chosen to generate the non-intervention scenario. SiroFire is a PC-based fire simulation model designed to predict the spread of unchecked wildfires (see Coleman and Sullivan 1995, 1996). It incorporates terrain, fuel and weather information to predict the spread of wildfires, and provides a visual representation of the fire as it spreads through time. A schematic representation of the inputs to, and the tools used for, the FMP evaluation is shown in figure 3.

DNRE Geographical Information System (GIS) data were used to generate a digitised topographical and vegetation map of Victoria, which was then imported into SiroFire. Fire spread is predicted by mathematical formulae based on the empirical algorithms developed by McArthur in the 1950s and 1960s (McArthur 1958, 1960). For this analysis the McArthur Mark 5 Forest Fire Danger model was used to predict the spread of forest

[8] The private intervention scenario allows private fire management efforts to occur in the absence of FMP intervention. Accordingly, sensitivity analyses are conducted (see Section 6.3) on the non-intervention scenario results (which assume no private intervention beyond that of the CFA in joint attack fires), to allow for a range of private responses in the absence of publicly provided fire management services.

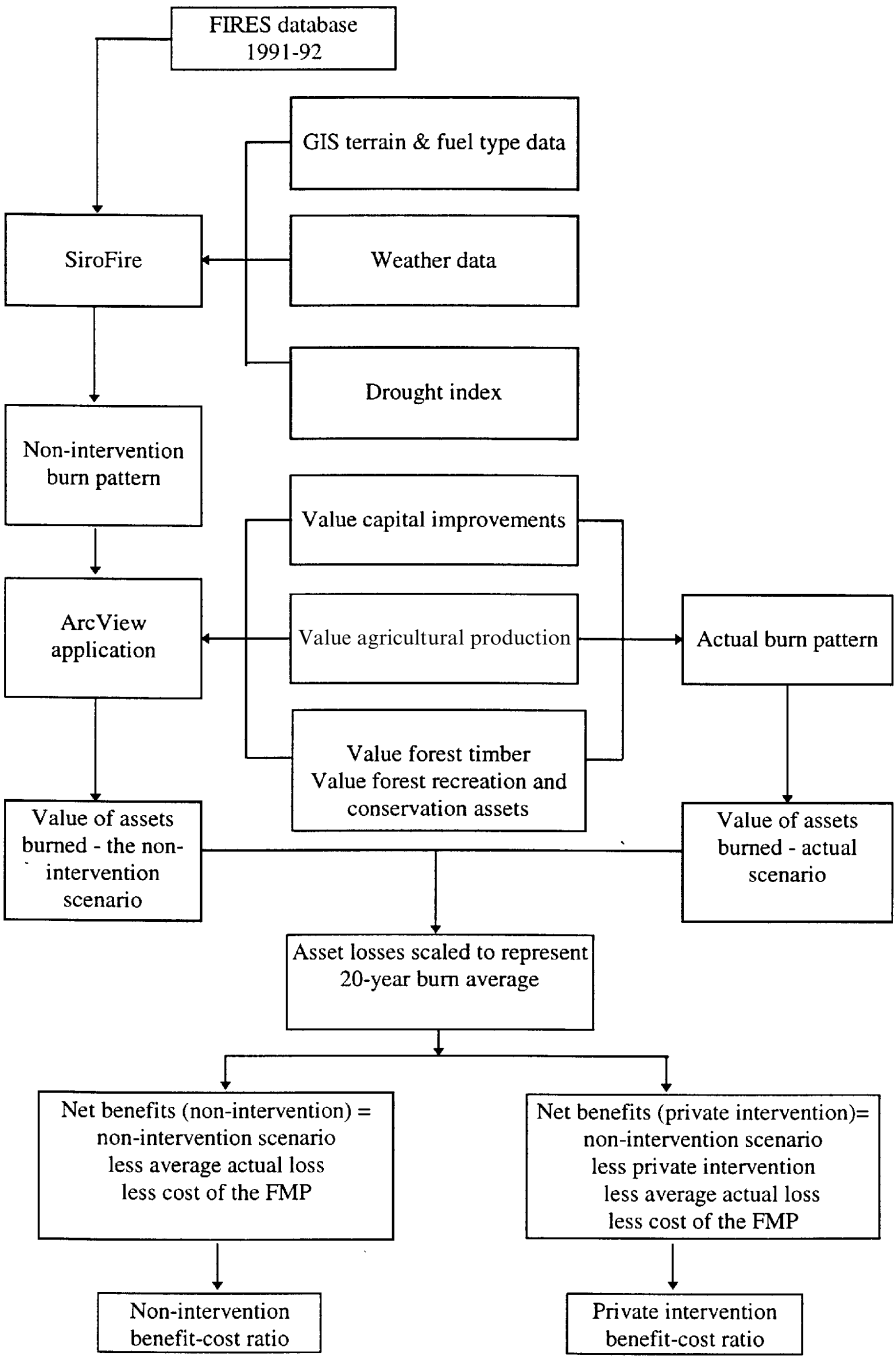

Figure 3 Schematic diagram of the benefit–cost analysis of the fire management program

Table 1 Statistics for the 1991–92 Victorian fire season

Fire statistics	1991–92
Number of fires	606
Area burned (hectares)	16 737
Cost of the FMP (A$m)	28.8
Fires attended by DNRE alone	276
Fires attended by DNRE and CFA	330

Source: Department of Natural Resources and Environment (1997a).

fires, and the CSIRO96 Grasslands model[9] was used for grass fires (SiroFire automatically switches between these algorithms depending on the fuel type that is being burned). Fuel type and terrain are set in the model according to the digitised GIS data. Before simulating fires the operator is required to input: hourly weather data (temperature, relative humidity, wind speed and wind direction); the Byram–Keetch Drought Index (BKDI);[10] the days since last rainfall; the rainfall to 0900 hours on that day; and the degree of fuel curing (a measure of the dryness of the fuel).

The 1991–92 fire season was chosen by Victoria's Chief Fire Officer as a representative fire year, as the number of fire ignitions in this year (606) was close to the 20-year average (1975–95) of 584 ignitions (see table 1).[11] All fires attended by DNRE firefighters during this season (including joint fires with CFA involvement) were simulated using SiroFire, to generate the non-intervention scenario. Actual fire locations, as listed in the FIRES database[12] for the 1991–92 fire season, were used in preference to random ignition points to reflect the differences in the distribution of wildfires across the State. Weather data were obtained from the Bureau of Meteorology for seven representative locations (Ballarat, Bendigo, Colac, Horsham, Melbourne, Orbost and Sale) across Victoria for the 1991–92 fire season, and the BKDIs for each of the 18 fire regions (outside of Melbourne) were

[9] The CSIRO96 Grasslands model is a modified version of the McArthur Mark 5 Grasslands Fire Danger model, and is described in detail in Coleman and Sullivan (1996).

[10] The BKDI is a measure of soil dryness, which is highly correlated with fuel flammability. The index ranges from 0 to 200 in increasing soil dryness.

[11] However, while the number of ignitions in 1991–92 was close to the 20-year average, the area burned (16 737 hectares) was far less than the 20-year average of 101 463 hectares. Section 6.1 amends the net benefits of the FMP to take account of this.

[12] The FIRES database is maintained by the FMP, and contains the location, probable cause, fire-fighting resources employed and assets damaged for all fires attended by DNRE staff.

supplied by the FMP. In 1991–92 the Bureau of Meteorology reported weather information every three hours at Ballarat, Bendigo, Melbourne and Sale, and every six hours at Colac, Horsham and Orbost. SiroFire requires hourly weather observations for simulating fires, and to accommodate this requirement linear interpolation was used to predict weather conditions between the observations reported by the Bureau. After consultation with senior FMP staff, the grassland and forest fuel were set at 6 tonnes per hectare and 15 tonnes per hectare, respectively, and the degree of grassland and forest fuel curing were set at 90 per cent and 50 per cent, respectively.

Fires for the 1991–92 season were simulated in chronological order, and then allowed to burn for 24 hours before being 'extinguished'.[13] At the end of each simulation the fuel hazard was set to zero for the burned area, and as a result subsequent fires that occurred within previously burned areas failed to ignite (which is consistent with observed fire behaviour). All towns and cities were designated 'unburnable', due to the modification of the native vegetation into an urban environment (involving the introduction of paving and concrete), which makes the incidence of wildfires in such an environment unlikely. All lakes, rivers, waterways and irrigated land were also designated as 'unburnable'. Finally, the burn patterns generated by SiroFire were imported into a customised ArcView application,[14] to determine the damage caused by unchecked wildfires.

5.2 Potential and measured damage caused by wildfires

Wildfires can cause damage to: forests, agricultural production, capital assets (such as private houses and community halls), conservation assets such as flora and fauna, infrastructure (such as roads, powerlines and communications equipment), water quality in catchments, tourism and recreational activities, and to humans through injury and loss of life. In this analysis, fire-induced damage to: forest timber, rateable capital improvements on privately owned rural land, agricultural production, and forest recreational use and

[13] The fire simulation time of 24 hours is a purely arbitrary value, and in actuality many fires would burn for periods of up to several days without active suppression. A period of 24 hours was chosen in consultation with Victoria's Chief Fire Officer, and is a conservative estimate of the time each fire would burn, and hence most likely represents an understatement of the damage that would be caused by unchecked wildfire.

[14] The ArcView application developed for the evaluation of the FMP allows the operator to visually overlay burn patterns, as generated by SiroFire, with assets such as forest type, and then to generate reports outlining the area destroyed and the dollar value of the loss.

conservation assets were quantified.[15] The potential damage to the other assets mentioned above has not been quantified, due to the subjective nature of the value judgments required, and/or a lack of robustness of the available economic methodologies for the valuation of such assets.[16] Extensive wildfires such as those experienced on Ash Wednesday 1983 can also lead to large government expenditure on emergency relief, which is discussed in DNRE (1997a).

Valuing forest timber

Forest timber was valued according to the method endorsed by the Victorian Department of Treasury and Finance (DNRE 1996b).[17] Using this method, the State-average value of Victoria's hardwood forests was calculated to be A$122 per hectare — of a total area of 6.7 million hectares of forested public land, the corresponding net available productive area[18] of Victorian native forests in 1995–96 was 1.2 million hectares, with a net present value of A$145.9 million (DNRE 1996b). In addition, the State-average value of softwood forests was calculated to be A$2177 per hectare — the net area of softwood plantations under the management of the Victorian Plantations Corporation at June 1996 totalled 106 000 hectares, with a forest value of A$230.9 million (VPC 1996).

Forest losses due to fire vary with the intensity of the fire, the forest type and the maturity of the stand; low-intensity fires may burn slowly through the undergrowth without causing any significant damage to mature trees, whereas high-intensity fires may totally destroy mature trees (Greaves, Innes and Dowse 1965; Nicholls and Cheney 1974). To determine the actual loss of forest timber under the non-intervention scenario, a model of fire intensity versus relative damage for each forest type and maturity would be needed.

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[15] The data used in the valuation of capital assets and agricultural production, based on Local Government Areas (LGAs), are detailed in DNRE (1997a).

[16] The valuation of these assets is discussed qualitatively in DNRE (1997a).

[17] The method values forest assets as the discounted flow of royalties that would accrue over a 100-year period, if the forest was logged in accordance with the maximum sustainable yield principle. Royalties are calculated annually by DNRE based on the quality of the harvested log, and are net of harvesting and transport costs.

[18] The net productive area is the net area of State forest available and suitable for sustainable sawlog production (DCNR 1995). It takes into account: the requirements of Victoria's Code of Forest Practices for Timber Production; the requirements of action statements (which identify the processes which threaten a species or community) under Victoria's Flora and Fauna Guarantee Act 1988; Forest Management Zones proposed in the Fire Management Plan; and includes only those areas capable of producing sawlogs (those mature trees which grow to heights greater than 24 metres).

However, precise information regarding the maturity of individual forests within the State is not available, and in the absence of these data it was assumed that all forest timber subjected to fire was totally destroyed.

Valuing capital improvements

The value of rateable capital improvements on privately owned rural land for each local government area (LGA) of Victoria was supplied by the Victorian Office of the Valuer General (for details see DNRE 1997a). Rateable capital improvements on private land include all works that increase the value of the property, such as houses, agricultural buildings and fences. For this analysis the total value of capital improvements for each LGA (valued in 1994 dollars) was divided by the area of private land in the LGA to determine the mean value of such assets in dollars per hectare. The number of hectares of privately owned rural land burned in each LGA was then multiplied by the per hectare mean value to determine the total loss, and summed across LGAs to derive the total State loss.

Valuing agricultural production

The loss of agricultural production, in dollars per hectare, was also determined by dividing the gross value of one year's production[19] (GVP) for each LGA by the area of agricultural land in the LGA. Agricultural production includes all commercial agricultural activities undertaken on private rural land, such as cropping, horticulture and livestock production. The total value of agricultural production for each LGA was taken from 1994 statistics collected by the Australian Bureau of Agricultural and Resource Economics (ABARE), and are detailed in DNRE (1997a). The number of hectares of agricultural land burned in each LGA was then multiplied by the per hectare mean value to determine the total loss, and summed across LGAs to derive the total State loss.

Grain crops grown in Victoria's Wimmera and Mallee regions make a significant contribution to regional GVP, with harvesting in these areas usually occurring between November and December. To take account of the fact that fires occurring after harvest would not have destroyed field crops (and therefore would not result in a total loss of one year's GVP), it was assumed that harvesting had been completed by 1 January 1992. For fires occurring in the Wimmera and Mallee after 1 January, damage losses (i.e. losses to GVP) were reduced by the proportional contribution made by grain

[19] It was conservatively assumed that, on average, fires on agricultural land would cause the equivalent of one year's lost production, and that output in subsequent years would return to pre-fire levels. If the true loss exceeds one year, then the current method underestimates the benefits of the FMP.

crops to the GVP of the SLA in which the fire occurred. The contribution of grains to each SLA was calculated using statistics collected by the ABS (1994), and are net of harvesting and transport costs as these costs would not be incurred when crops are destroyed by fire.[20]

Valuing recreational and non-use (conservation) attributes of fire-affected forests

To determine the total economic impact of the damage caused by wildfires, it is also necessary to determine the impact on use and non-use values of environmental amenities, particularly those attached to forests. Use values include direct productive values such as the commercial harvesting of a resource (for example, the timber and agricultural values given above) and on-site recreation values. Non-use values include the option value, existence value and bequest value of forests. Clearly, the evaluation of these values is complicated by the fact that environmental amenities do not typically operate through established markets and consequently, do not have observable prices (see Sappideen 1997; Bennett, Gillespie, Powell and Chalmers 1996).

Studies estimating unpriced values of environmental amenities are numerous (see Resource Assessment Commission 1992; Morrison, Groenhout and Moore 1995). However, there have been few Victorian-specific studies, which are necessary in the current context to enable an estimate of Victorian use and non-use values likely to be lost due to wildfires. One of the few exceptions has been Borrie (1989), who estimated the benefits derived from recreational use of National Parks in Victoria's La Trobe Valley, using a travel cost methodology to estimate the total willingness to pay (WTP) for access to parks. Later, Read, Sturgess and Associates (1994) used the same methodology to estimate the economic value of recreation in Victoria's Grampians National Park, while Lockwood, Loomis and DeLacy (1993) used a contingent valuation methodology to estimate the total WTP for the preservation of unprotected areas in south-east Gippsland.

The Resource Assessment Commission (1992) conducted an estimate (using the travel cost method) of the recreational value of 130,000 hectares of Natural Estate areas in south-eastern NSW and the east Gippsland (Victoria) forests, finding that visitors would be willing to pay A$8.50 each per year for use of the forests for recreational purposes. It also undertook a

[20] Harvesting and transport costs were netted from the LGA-based regional GVP data, which is listed in DNRE (1997a). In carrying out this adjustment, it was assumed that such costs represented about 30 per cent of total costs of grain production (taken from Hall 1996 and Kennelly 1997), and that grain industries represented about 25 per cent of the GVP from agricultural industries in the Wimmera and Mallee regions (ABS 1994).

contingent valuation study to evaluate the preservation values in these same forests — the median WTP to totally preserve these forests against logging was A$43.50 per household (A$22 per person) per year.[21] The Commission found that this approximate 3:1 ratio was a common outcome when both the contingent valuation and travel cost methods are applied simultaneously (ibid., p. E22), yet cautioned that it is not appropriate, due to the statistical form of the contingent valuation study, to extrapolate the sample mean WTP to the wider community's WTP for forest preservation (ibid., p. U16).

The usefulness of the above studies to this evaluation is limited for two important reasons. First, recreational use and non-use estimates of the value of a given area are inherently dependent upon the location of the asset being valued. The discrete areas considered by the available studies means that the values derived from them cannot be generalised on a Statewide basis, as is required for this study. Second, the values estimated in the literature are typically of the *total value* of the asset, whereas this study focuses on the *reduction in total value caused by wildfire-induced damage*, which may lessen the value of parks and forests for recreational users, and damage the conservation values of fire-affected areas. This information cannot be extracted through simple linear extrapolation of estimates of total use and non-use values contained in other studies. Moreover, while in some cases fire may completely eliminate the flora and fauna assets of any given area, typically the results will not be as drastic, and in many cases wildfires can have benefits by assisting in the rehabilitation of fire-dependent species (Loane and Gould 1986).

One notable exception to the abovementioned dearth of fire-specific studies is the work of Loane and Gould (1986). That study examined the effect of Victorian bushfires in reducing the value of parks to visitors for enjoyment or recreation, using a survey by Bennett (1984) of similar visitor losses in New South Wales parks. While the mean value of the estimated pre-fire willingness to pay to use each park was quite high (averaging A$5 (in 1983 prices) per group of three persons), individuals' estimates of loss due to fire were quite small, with many being zero. The average loss to recreation activities due to fires was found to range from 5 to 20 cents (1983 prices) on a per visitor day basis. Loane and Gould (1986) hypothesised that the above fire-induced losses to recreation activities were low as such use activities are not dependent on the state of vegetation in the park and can be readily substituted by another park or recreational activity. If we extrapolate these results on a Statewide basis for Victoria in 1995–96, this gives an upper

[21] Preservation values include visitor benefits and the enjoyment gained from non-visitors due to the preservation of the forests. The Resource Assessment Commission's figures are in current (1992) value terms.

bound of A\$4.5 million in current 1996 prices for such losses.[22] However, as mentioned above, this result was derived under the assumption that survey results for a limited number of particular park types, size and fire locations could be extrapolated across the whole State.[23]

Loane and Gould (1986) note that while it is extremely difficult if not impossible to place a value on the fire-induced damage to the value of the non-use attributes of forests, they provide a useful technique for valuing the per hectare non-use (conservation) values of flora and fauna affected by wildfires. The Loane–Gould conservation loss formula uses a base conservation value for each park, which represents the loss per hectare for small areas burnt. In the absence of data on the minimum value of losses per hectare due to small fires, we follow Loane and Gould in using the estimated value of native timber damage (A\$122 per hectare for hardwood losses) as the minimum value, on the grounds that if the conservation values of park areas have been deemed valuable enough for formal protection, then these conservation values would be at least as high as that of common forest reserved for timber. This base conservation value is then multiplied by an exponential function which increases with the proportion of any given park burnt — this factor accounts for the likelihood that the conservation losses from fire will rise rapidly with the proportion of the available reserves of any given park's flora and fauna species which are destroyed. The function for average conservation loss per hectare (CVL) is: $(\mathrm{CVL}) = S^{*}exp(5A - 3)$, where A is the proportion of any given park burnt, and S is the minimum loss per hectare (see Loane and Gould 1986, p.185 for further details). This function results in the average loss per hectare being 1.6 times the base conservation value (S) when half of any given park ($A = 0.5$) is destroyed by wildfire. Using the value of A\$122 per hectare (the value of hardwood) as the minimum loss per hectare results in an approximate average conservation loss of A\$134 per hectare, (1.095 times the minimum conservation value), given that 13 per cent ($A = 0.13$) of Victoria's forested public land is destroyed by the simulated wildfires. In turn, this gives a value of A\$113 million for the fire-induced conservation losses arising from the 846 000 hectares destroyed in Victoria by the simulated wildfires.

When compared with the wildfire-induced losses to agricultural production (A\$432 million) and capital improvements (A\$1.09 billion), both the use

[22] In 1995–96 there were 12.96 million visitor days recorded in Victoria's parks and reserves (Department of Natural Resources and Environment 1997b). The implicit price deflator (GDP(E)) used here moved from 62.5 to 110.1 between 1983 and 1996 (Reserve Bank of Australia 1996).

[23] See Brookshire and Neill (1992) for an analysis of the efficacy of the concept of benefit transfers in natural resource management.

Table 2 Summary of data used in calculating the benefit–cost ratio of the FMP in the non-intervention scenario

Value of fire-induced loss	Non-intervention scenario 1991–92 (A$m)	Actual fire damage 1991–92 (A$m)	'Average' non-intervention loss (A$m)	'Average' actual loss (A$m)
Capital improvements[a]	1 090	1.4	1 050	8.48
Agricultural production[b]	432	0.90	416	5.45
Hardwood[c]	38	0.67	37	4.06
Softwood[d]	30	0.03	29	0.18
Recreation and conservation[e]	118	–	114	–
Total loss	1 708	3.0	1 646	18.2
DNRE benefits[f]	1 522		1 467	
Net benefits[g]	1 490		1 435	
Ratio of benefits to costs (BCR)	52		50	

Notes:
[a] The value of capital improvements on privately owned rural land includes all works that increase the value of the property, such as houses, agricultural buildings and fences.
[b] The value of agricultural production includes all commercial agricultural activities undertaken on private rural land, such as cropping, horticulture and livestock production.
[c] Native hardwood timber includes ash species (such as alpine and mountain ash) and high elevation mixed species (such as messmate and peppermint gums).
[d] Softwood timber is predominantly *Pinus radiata.*
[e] Recreation and conservation (flora and fauna) losses which are induced by wildfires, assuming that 13 per cent of the area of Victorian forested public land is burnt.
[f] Net of CFA contribution (calculation of net benefits is described in section 5.3).
[g] Net Benefits = DNRE Benefits less Actual Damage less Cost of the FMP (A$28.8 million).

(timber (A$68 million) and recreation (A$4.5 million)) and non-use (A$113 million) losses caused by wildfires are relatively small (see table 2).[24] However, the relative magnitude of these results is consistent with those of the Resource Assessment Commission (1992), which found that the existence and other non-use values of forests typically exceed, by a considerable margin, the direct use values of forests.

[24] The values calculated for the wildfire-induced losses to agricultural production, rateable capital assets on privately owned land, forest timber, and forest recreation and conservation values have been expressed in 1996 Australian dollars. The GDP deflator (GDP(E)) was used to convert the value of agricultural production, capital assets and forest recreation from 1994 Australian dollars to 1996 Australian dollars (Reserve Bank of Australia 1996; Australian Bureau of Statistics 1996). The value of forest timber and conservation assets has already been expressed in 1996 dollars.

5.3 Calculation of net benefits of the FMP for the non-intervention and private intervention scenarios

The total fire damage under the non-intervention scenario was calculated by summing the losses of agricultural production, capital assets on privately owned land, forest timber and forest recreation and conservation assets. In fires that were fought jointly by DNRE and CFA personnel, 80 per cent of the benefits of assets saved due to fire-fighting were allocated to the FMP;[25] all the benefits were attributed to the FMP in sole attacks by DNRE personnel.

The net benefits of actions taken under the FMP are given by the difference in value between the hypothetical asset losses generated by the non-intervention scenario and the actual asset losses suffered with DNRE intervention, less the cost of the FMP. To determine the actual losses that occurred in the 1991–92 fire season, the value of lost agricultural production, rateable capital assets on privately owned land, and forest use and non-use assets were calculated under the same assumptions used to generate the non-intervention scenario. This figure was then adjusted to reflect the mean annual amount of land burned over the last 20 years, by multiplying the 1991–92 loss by the ratio of the mean number of hectares burned over the last 20 years to the actual number of hectares burned in 1991–92.

The non-intervention scenario assumes that there is no adjustment to private fire suppression and prevention efforts (through both private landholders and volunteer groups) in the absence of intervention under the DNRE's FMP. Clearly, it is likely that an increase in private efforts would occur, and so sensitivity analyses are conducted on the non-intervention scenario results, to allow for a range of private responses to the absence of publicly provided fire management services, and are denoted as the private intervention scenario (see section 6.2). The sensitivity analyses allow for private fire management efforts to range between 100 per cent as effective as DNRE's FMP (in which case the area burned would be close to the 1991–92 actual burn) and zero per cent as effective as DNRE's FMP (the non-intervention scenario result), highlighting the cases where private efforts are 25, 50 and 75 per cent as effective as the FMP. These scenarios are estimated in conjunction with a variation in the estimated contribution of the CFA to joint-attack fires fought with DNRE's FMP.

[25] Through consultation with DNRE's Chief Fire Officer it was decided to allocate 80 per cent of the benefits of fire suppression activities on fires attended jointly by CFA and DNRE personnel to the FMP. This reduction in benefit was made in recognition of the valuable contribution that the CFA personnel make to first attack on DNRE fires, as part of the Multi-Agency Incident Management Agreement.

6. Quantitative estimates of the net benefits to Victoria from the FMP

Quantitative estimates of the ratio of the social returns to the FMP in relation to its costs are presented in this section. The net benefits of the FMP are first calculated under the non-intervention scenario, which provides an upper bound to the range of likely benefits, as it does not allow for any response from private landholders and volunteer groups in the absence of publicly provided fire management activities. Sensitivity analyses are then conducted which allow for a range of private fire management responses (denoted as the private intervention scenario).

6.1 Calculation of the net benefits of the FMP under the non-intervention scenario

The non-intervention scenario, as generated by SiroFire, resulted in 2.14 million hectares (or 9.4 per cent) of the land mass of Victoria being burned by wildfires (see figure 4). This burn area is very close to that of the disastrous Black Friday fires of 1939, which destroyed 2.03 million hectares. In the non-intervention scenario 1.27 million hectares of private agricultural land was subjected to fire, resulting in the loss of A$432 million of agricultural production (9.0 per cent of the total gross value of production (GVP) for Victoria) and A$1.090 billion of Victoria's capital assets (10.1 per cent of the State's total value of rateable capital assets on privately owned rural land).[26] In addition, some 846,000 hectares of forested land was burned (312 000 hectares of hardwood, 14 000 hectares of softwood and 520 000 hectares of non-commercial woodlands), resulting in the loss of A$30 million of softwood trees, A$38 million of hardwood trees and A$118 million in forest recreation and conservation assets. Accordingly, the value of the total loss suffered under the non-intervention scenario was A$1.708 billion (see table 2). This figure represents the gross benefits of fire-fighting to Victoria from fires attended by DNRE personnel alone and joint attacks with the CFA, assuming no intervention by private providers of fire management services. The benefits attributable to the FMP under the non-intervention scenario, after removing the CFA contribution to joint attack fires, were calculated (as described in section 5.3) to be A$1.522 billion.

[26] The majority of agricultural losses in the Wimmera and Mallee regions in the non-intervention scenario occurred before the assumed harvest date of January 1 (see section 5.2 for details). These findings seem intuitively correct for two reasons. First, fires in the Wimmera and Mallee regions are more prominent before harvest, as crops provide substantially more fuel for fires than post-harvest stubble or fallow. Second, crops are a major contributor to agricultural GVP of these two regions, therefore wildfire-induced losses incurred after harvest are likely to be small relative to those incurred prior to harvest.

Figure 4 Non-intervention burn patterns generated in SiroFire

For the 1991–92 fire season the actual amount of land burned was 16 737 hectares, which was valued at A$3.0 million (see table 2, column 2). The cost of the FMP in 1995–96 was A$28.8 million (DNRE 1996a). The net benefits of the FMP, which are given by the total value of the (forest, agricultural, capital and conservation) assets lost under the non-intervention scenario, less both the value of the actual losses and the cost of the FMP, was calculated to be A$1.490 billion. This represents a benefit–cost ratio (BCR) of 52 (see table 2, column 1). That is, for every A$1 of public funds allocated to the FMP, the State of Victoria benefits by A$52 in the reduction of agricultural, capital, forest and conservation assets which would otherwise be lost to wildfires.[27]

The 1991–92 fire season was selected for the evaluation as the number of fire ignitions in that year (606) was close to the 20-year average value of 584, however the actual area burned was only 16737 hectares compared with the 20-year average burn of 101 463 hectares (see table 1). To reflect the 20-year average, both the wildfire losses generated by the non-intervention scenario and the actual wildfire-induced losses were scaled to represent 584 fires and 101 463 hectares, respectively. The losses generated under the non-intervention scenario were multiplied by the ratio of the 20-year average number of fires (584) to the actual number of fires in 1991–92 (606), to generate the 'average' non-intervention loss. This gives a value of A$1.646

[27] An alternative way of calculating the returns to Victoria from fire-fighting is to note that to break-even with the costs of the program (A$28.8m), the per hectare value of the total area unburned (2.1m hectares) due to intervention by the FMP would have to be approximately A$14.

billion for the average non-intervention loss, while the benefits of actions carried out under the FMP, after removing the CFA contribution to joint attack fires, are A$1.467 billion (see table 2, column 3). The loss calculated for the actual amount of land burned in 1991–92 (A$3.0 million) was multiplied by the ratio of the 20-year average burn (101 463 hectares) to the actual burn in 1991–92 (16 737 hectares), to generate the ‘average’ actual loss. This gave a value of A$18.2 million for the average actual loss (see table 2, column 4). Under these assumptions the net benefits of actions taken under the FMP decreased to A$1.435 billion, and the BCR was 50 (see table 2, column 3). That is, for every A$1 of public funds allocated to the FMP, the State of Victoria benefits by A$50 in the reduction of agricultural, capital and forest assets which would otherwise be lost to wildfires.

The actual number of fires attended by DNRE personnel in the 1991–92 fire season was 606, with 469 (77 per cent) extinguished before burning more than 5 hectares of land, and only 19 fires (3.1 per cent) burned more than 100 hectares. Under the non-intervention scenario only 22 fires (3.6 per cent) burned less than 5 hectares, and 386 fires (64 per cent) burned in excess of 100 hectares. This highlights the importance of the timely response of actions taken under the FMP in minimising the damage caused by wildfires.

6.2 The private intervention scenario and sensitivity analyses

The non-intervention scenario assumes that the fire management practices of private groups (such as private landholders and volunteer fire-fighting groups) would remain the same with or without intervention by DNRE’s FMP in the management of wildfires on or threatening public land.

A sensitivity analysis was performed to take into account that in the absence of the FMP, volunteer groups and private landholders may alter their fire suppression and fire prevention activities, thereby making the non-intervention scenario in this analysis unlikely. This intervention by volunteer groups and private landholders is denoted as the ‘private intervention scenario’.

The sensitivity analysis of the private intervention scenario is calculated on the assumption that private intervention (fire-fighting) on fires that threaten public land could be 25 per cent, 50 per cent and 75 per cent as effective as DNRE’s FMP[28] (see table 3). This results in the value of losses

[28] This means that volunteer groups and private landholders would be able to contain the fire with either 25 per cent, 50 per cent, or 75 per cent of the effectiveness of DNRE’s FMP in all cases where wildfires threatened public land, that is wildfires whose ignition point is in, or threatens, all national parks, State forests and protected public land as defined by Section 3 of Victoria’s Forests Act 1958.

Table 3 Summary of data used in the sensitivity analyses of the benefit–cost ratio for the private intervention scenario

	Effectiveness of private intervention relative to the FMP				
Value of fire-induced loss	0% effectiveness (A$m)	25% effectiveness (A$m)	50% effectiveness (A$m)	75% effectiveness (A$m)	100% effectiveness (A$m)
Capital improvements[a]	1 050	787.5	525	262.5	40
Agricultural production[b]	416	312	208	104	16
Hardwood[c]	37	28	18.5	9.25	1
Softwood[d]	29	21.75	14.5	7.25	1
Recreation and conservation[e]	114	86	57	29	4
Total loss	1 646	1 235	823	412	62
DNRE benefits[f]	1 467	1 101	733	367	55
Net Benefits[g]	1 435	1 054	686	320	8
Ratio of benefits to costs (BCR)	50[h]	37	24	11	0.28[i]

Notes:
[a] The value of capital improvements on privately owned rural land includes all works that increase the value of the property, such as houses, agricultural buildings and fences.
[b] The value of agricultural production includes all commercial agricultural activities undertaken on private rural land, such as cropping, horticulture and livestock production.
[c] Native hardwood timber includes ash species (such as alpine and mountain ash) and high elevation mixed species (such as messmate and peppermint gums).
[d] Softwood timber is predominantly *Pinus radiata.*
[e] Recreation and conservation (flora and fauna) losses which are induced by wildfires, assuming that 13 per cent of the area of Victorian forested public land is burnt.
[f] Net of CFA contribution (the derivation is described in section 5.3). These scenarios continue to assume that 20 per cent of the benefits of fire management activities on public land for joint attack (DNRE/CFA) fires can be attributed to the CFA.
[g] Net Benefits = DNRE Benefits less Actual Damage less Cost of the FMP (A$28.8 million). Apart from the zero per cent effectiveness column all other figures represent gross benefits, as they do not take into account the costs of privately provided fire management activities.
[h] This column replicates column 3 of table 2, as the non-intervention scenario assumes there is no public or private provision of fire management activities.
[i] This column assumes that, in the absence of the FMP, private fire management activities would be equally as effective as those of DNRE's FMP in suppressing and preventing the extent of damage caused by wildfires.

calculated under the non-intervention scenario being reduced by 25, 50 and 75 per cent, respectively. In the private intervention scenario the net benefits of the FMP were estimated to be A$686 million (see table 3). This figure represents the benefits to Victoria after accounting for private intervention being 50 per cent (half) as effective as the activities of the FMP, which

Table 4 Sensitivity analyses: benefit–cost ratios of the FMP allowing for variation in the effectiveness of private intervention and in the contribution to joint attack fires by the CFA

	CFA contribution to CFA/DNRE joint attack fires		
	10%	20%[a]	40%
Benefit–cost ratio with 0% effectiveness of private intervention[b]	53	50	44
Benefit–cost ratio with 25% effectiveness of private intervention	39	37	32
Benefit–cost ratio with 50% effectiveness of private intervention	26	24	21
Benefit–cost ratio with 75% effectiveness of private intervention	12	11	10
Benefit–cost ratio with 100% effectiveness of private intervention	0.42	0.28	0.05

Notes:
[a] This scenario replicates the assumption made under the non-intervention scenario of 20 per cent of the benefits of fire management activities on public land for joint attack (DNRE/CFA) fires being attributed to the CFA; see the results given in the final row of table 3.
[b] In analysing these scenarios, 'effectiveness' refers to the ability of privately provided fire management activities (carried out by private landholders and volunteer groups) to substitute for the publicly provided fire management services of DNRE's FMP. Zero per cent effectiveness implies that private fire management services are not able to be substituted for public fire management services; 100 per cent implies that the former are perfect substitutes for the latter. It should also be noted that (as with table 3), apart from the zero per cent effectiveness row, the figures in all rows represent gross benefits, as they do not take into account the costs of privately provided fire management activities.

reduces the value of the losses calculated in the non-intervention scenario accordingly. However, the costs associated with such intervention have not been included in the analysis, resulting in an underestimation of the returns to the FMP under the private intervention scenario.

The degree of contribution made by the CFA on fires fought jointly by DNRE and CFA personnel (see table 1), is also taken into account in the sensitivity analysis. Under the non-intervention scenario, of the fires the CFA and the FMP fight jointly, it is estimated that the CFA contributes 20 per cent to the fire-fighting efforts expended on those fires (see note 25). Further sensitivity analyses were also conducted, by varying the CFA contribution to joint attack fires from 20 per cent to 10 per cent and 40 per cent (see table 4).

6.3 Results of the sensitivity analyses

The sensitivity analysis under the private intervention scenario, assuming that private fire management activities are half (50 per cent) as effective as the activities provided by DNRE's FMP, results in a reduction in the benefit–cost ratio (BCR) from 50 (under the average non-intervention scenario) to 24 (private intervention scenario). A BCR of 24 still represents a very high return to Victoria from public monies invested in fire-fighting on public land (see column 3 of table 3 and column 2 of table 4). The assumption that privately provided fire management activities are half as effective as the FMP was chosen as the most likely outcome of the sensitivity analysis, as it lies directly between the two unlikely scenarios for private intervention, those being:

- zero per cent as effective as public intervention under the FMP (this is the non-intervention scenario, which reflects no change in the fire management activities of private landholders and volunteer groups in the absence of the FMP, see tables 2, 3 and row 1 of table 4); and
- equally (100 per cent) as effective as the FMP in suppressing and preventing the extent of damage caused by wildfires (this corresponds with the actual result for the 1991–92 fire season, see tables 2, 3 and row 5 of table 4).

For example, row 3 of table 4 demonstrates that in the absence of the FMP, if privately provided fire management activities are half as effective as the FMP's fire management activities, then the benefit–cost ratio for the FMP ranges from a high of 26 (assuming 10 per cent of the benefits from CFA/DNRE joint attack fires are attributed to the CFA) to a low of 21 (assuming 40 per cent of the benefits from CFA/DNRE joint attack fires are attributed to the CFA).

6.4 Why the results are likely to underestimate the net benefits of the FMP

The net benefits of the FMP, as calculated in this report, will tend to understate the true value because the potential fire losses in urban areas have been excluded, and potential fire losses to public infrastructure, water quality and quantity, human life, agricultural production (exceeding the equivalent of one year's worth of production) and the cost of emergency relief have also not been quantified. In addition, while SiroFire is widely acknowledged to be the most accurate model of wildfire, it has a tendency to underpredict the spread of wildfires in the non-intervention scenario (Coleman and Sullivan 1996).[29] This underprediction arises because the model does not take into account factors such as: acceleration; fire spread at high wind speed (that is,

[29] The extent to which SiroFire underpredicts fire spread is difficult to precisely estimate, due to a lack of data and the difficulty of conducting actual field trials. In trials of SiroFire's grassfire component, Cheney, Gould and Catchpole (1998) compare the predictions of SiroFire in grassland areas with experimental grassland fires. The results indicated that 95 per cent of the actual wildfire perimeters fell within the predicted boundaries generated by SiroFire.

greater than 40 kilometres per hour); fuel moisture content time-lag; spotting over topography and breaks; lee-slope fire spread; and wind speed variation within terrain.[30] Fires were also only simulated in the non-intervention scenario for 24 hours, when in reality unchecked wildfires may burn for extended periods of time. Finally, under the private intervention scenario the costs associated with private provision of fire management activities have not been included.

Offsetting this slightly will be the overstating of FMP benefits given the assumption of zero salvage value for timber in fire-affected forests in the non-intervention scenario. However, on balance it is likely that the estimated net benefit calculation is an understatement of the actual net benefit to the State from the FMP. Given these limitations, the true value of the net benefits of the FMP will most likely be considerably greater than the A$686 million stated here, and represents a very high return to the State on the expenditure required to fund the fire management program.

7. Summary and conclusions

The risk of major economic and social losses to Victoria arising from wildfires is ever present, particularly as its climatic conditions, vegetation and topography combine to make it one of the world's most fire-prone regions. Following Royal Commissions into the devastating wildfires of 1939 and extensive grassland fires of 1944, fire suppression and prevention on public land have been an activity of government. The value of publicly provided fire suppression and prevention activities is a function of the potential damage avoided, and is determined by such variables as: the location, timing and likely spread of bushfires; the nature and value of assets potentially damaged by bushfires; and the extent to which alternative providers of fire management activities will reduce the damage caused by unchecked bushfires.

This evaluation of Victoria's fire management program has found the ratio of benefits to costs in the average fire year is about 24 to one. That is, for every A$1 of public resources allocated to the Department's fire management program, the State benefits by A$24 in terms of assets not destroyed by wildfire. This result was obtained using conservative valuations of both the

[30] In addition to the limitations of the fire spread models used in SiroFire, there are limitations in applying these models in a software package. These are: any estimates of fire made beyond the scale or accuracy of the geographic data may be erroneous (this problem is particularly obvious when simulating small fires running on large grid terrain and fuel maps under high winds); and the precision or time step levels in SiroFire mean that in high winds, fire predictions are likely to 'jump over' changes in fuel type or terrain (Coleman and Sullivan 1996).

assets burned and the number of asset classes (capital improvements, agricultural production, forest timber, forest recreation and conservation (flora and fauna) assets) included in the valuation, a simulation model which underpredicts likely burn patterns, and assuming that the fire management activities of private landholders and volunteer groups are half as effective as those provided by the Department's fire management program. Overall, Victoria has received high benefits from its allocation of resources to the fire management program to carry out its important fire suppression and fire prevention activities.

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