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A literature review on the economic, social and environmental impacts of severe bushfires in south-eastern Australia

Fire and adaptive management

report no. 87

State Government Victoria

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Photo: Front cover: Bushfire CRC

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Summary

Severe bushfires are capable of causing widespread economic, social and environmental impacts across spatial and temporal dimensions. This report explored a number of these impacts, primarily focusing on five major bushfires that have occurred in south-eastern Australia, being the 1983 Ash Wednesday Fires, 2003 Alpine and Canberra Fires, 2005–06 Grampians Fires, 2006–07 Great Divide Fires and 2009 Black Saturday Fires. As well as exploring the impacts of these fires, this literature review also examined and compared the literature in this area.

For the purposes of this review, economic impacts were those that were typically bought or sold and were grouped as being direct (e.g. loss of infrastructure or equipment) or indirect (e.g. business disruption). Social impacts were generally those that could not be bought or sold, and included such impacts as fatalities and injuries, health problems or the loss of cultural heritage assets. Environmental impacts related to the natural environment, such as the soil, water, air, flora and fauna, were, along with social impacts, classified as intangible.

In terms of important works that encapsulate many aspects of the economic, social and environmental impacts of severe bushfires, the reports of the Ministerial Taskforce on Bushfire Recovery after the 2003 Alpine Fires, 2005–06 Grampians Fires and 2006–07 Great Divide Fires contain loss data, information on many impacts across the three broader impact types (i.e. economic, social and environmental) and the range of grants and services made available to those affected. The Victorian Bushfire Reconstruction and Recovery Authority (2009) also produced a report covering the same areas after the 2009 Black Saturday Fires. Other documents that relate specifically to each broad impact type are highlighted under their respective categories.

Economic Impacts

Apart from the information provided in the reports of the Ministerial Taskforce on Bushfire Recovery, The Nous Group (2007) and Environment Protection Authority Victoria (EPA Victoria) (2003) provide detailed accounts of the impacts on infrastructure, namely from the disruption of power to thousands of Victorians and the impacts on the quality of potable water.

For impacts relating to economic production, Gangemi et al. (2003) and The Nous Group (2007) report on the losses sustained by the retail, commercial and industrial sectors. Tourism impacts can be found in Cioccio and Michael (2007), Gangemi et al. (2003) and Rural and Regional Committee (2007). For impacts sustained by the forestry industry, the best sources of information were found to be Department of Sustainability and Environment (DSE) and Parks Victoria (PV) reports, such as DSE (2005) and DSE and PV (2008). Information on agricultural and horticultural impacts was scattered throughout different documents, including Fleming et al. (2007), Gangemi et al. (2003) and in articles published on the Australian Wine Research Institute's website.

Property losses resulting from bushfires have been documented in numerous reports, with the most relevant to this research being found in Blanchi and Leonard (2005), the Country Fire Authority (CFA) (1983), Orchiston (2003) and Healey (1985). Insurance is another important flow-on effect resulting from property loss, with Clayer, Bookless-Pratz and McFarlane (1985) providing an insight into people's experiences when lodging claims.

For government services provided during and after severe bushfires, the reports of the Ministerial Taskforce on Bushfire Recovery provide the most useful information. For information relating to the functioning of the government centres responding to the event, Owen, Hickey and Douglas (2008) contains a detailed account.

Infrastructure

Critical infrastructure and services are damaged or destroyed when in contact with or close proximity to a severe fire. Transport networks are disrupted by the closure of roads, with roads that have been directly impacted by flames and heat remaining closed until the associated infrastructure can be replaced and the trees assessed. This is a high priority if these areas rely on tourism as the main source of income. Although rare, the loss of electricity to large towns or cities through the damage of power lines can cause widespread disruption, with the loss of communication equipment, household and business power or public transport services.

The threat of bushfires burning through catchments from which potable water is derived is always a large concern, with fire authorities doing everything possible to ensure that a severe bushfire does not reach these areas. In the event that a fire does enter an important catchment and cause these rivers or dams to be filled with large amounts of sediments, the requirement to either filter the water or find an alternative source can become expensive.

Economic Production

Those in the retail and tourism industries are particularly affected by bushfires, as tourists stay clear of the fire-affected and greater area, resulting in part from the media sensationalising the devastation caused. The disruption caused to local businesses during and after a severe fire can be extreme, with losses of 50–100% for an extended period being common. The forestry and agricultural industry can face ongoing costs in the event their products (e.g. timber, crops or livestock) are destroyed, as they have to regrow or replace what was lost. For horticultural enterprises, the threat of fire burning through their crops is minimal; however, the damage caused by smoke affecting the plant renders the fruit (e.g. wine grapes, berries) unusable, leading to the loss of a whole year's crop.

Property

Homes and other infrastructure have a high chance of being damaged or destroyed in the presence of severe bushfires, with the loss of iconic or important buildings being particularly upsetting to the wider public. The use of better building structures and products that greatly minimise the risk of ignition are important research areas that could minimise the loss of homes and other buildings in the future.

Insurance payouts assist those affected by bushfires to repair or replace what has been damaged or lost, although the behaviour of some insurance companies can further add to the stress felt by those affected by a severe bushfire.

Government Services

In the event of a severe bushfire, all levels of government work overtime to extinguish the fire in the shortest amount of time. Incident Control Centres are set up at the local level to handle the direct operational requirements. Coordination Centres are established at the local, regional and state level, and coordinate response actions (e.g. distributing resources to each fire) and feed information up and down the chain. Depending on the severity of a fire, these centres may be operational 24 hours a day, seven days a week.

The government initiates the recovery process as soon as the fire has passed through an area. Initiatives include the provision of counselling services for such problems as trauma, and financial and family relationship difficulties. Financial aid and relief packages are also provided to individuals, households, businesses and organisations to assist in repairing or replacing what was affected and promoting community spirit through organised events.

Social Impacts

There is a large amount of literature available regarding the impacts of bushfires on a community as a whole and on the firefighters and those close to them. Articles by Gordon (e.g. 1997, 2004) provided a good foundation for understanding the effects on a community's dynamics both during and after a fire. Articles by McFarlane (e.g. 1986, 1988) and Regehr, Hill and Glancy (2000) focused on the psychological impacts bushfires have on firefighters, while Regehr et al. (2003) undertook a comprehensive study that noted the experiences of the partners of firefighters.

The research available on health issues, both physical and psychological, arising from bushfires is widespread. Apart from fatalities or injuries sustained from direct contact with the flame, smoke is another major concern, with Aisbett et al. (2007), the Department of the Environment, Water, Heritage and the Arts (DEWHA) (2005) and EPA Victoria (2007) all contributing large amounts of information. The impact of bushfires on psychological health is explored in Camilleri et al. (2007), Clayer, Bookless-Pratz and McFarlane (1985) and Gordon (2006).

For impacts relating to Aboriginal cultural heritage values, Freslov (2004) provides a very detailed report on the condition of artefacts found after the 2003 Alpine Fires, while less detailed information on European early settlement cultural heritage values can be found in DSE and PV (2008).

Community

During the immediate threat, a proportion of community members will become isolated, whereas the community will come together once the threat has passed to undertake necessary activities. This does not last, as old divisions and divisions resulting from the bushfire cause a loss of cohesion among members. A temporary community structure is subsequently created to coordinate recovery efforts, before returning to a pre-fire community structure.

Those fighting the fire are commonly exposed to physical dangers, health risks and mental exhaustion while on duty. In some cases, the psychological stress associated with fighting a fire can manifest itself as varied levels of depression. However, a strong support network can assist these people in coping with their experiences and emotions. Those close to firefighters, such as their family, also feel high levels of stress during periods of severe fires, having to cope with household issues on their own while knowing that their partner or parent is possibly in danger.

Health

Smoke is the main product of bushfires that affects a person's health, with the level of impact being determined by factors such as the existing health condition of the individual, length of exposure and concentration of air pollutants. Smoke enters the respiratory system and eyes and causes a sore throat, runny nose and burning eyes. For healthy people, these symptoms generally disappear once the smoke has passed. For those with pre-existing medical problems, smoke can aggravate their conditions, with those suffering from asthma, other respiratory diseases and cardiovascular diseases at greater risk

The survival instincts of those threatened by a severe bushfire are greatly heightened. They generally carry out whatever work needs to be done to preserve their life, and if possible, other lives and personal property. Once the threat has passed, people will exhibit a number of reactions to deal with what has happened. In a majority of cases, those involved will resolve their responses to the experience within the next few months. For others, the trauma of living through such a threatening event can result in psychological problems, transpire into other issues (e.g. alcoholism) or adversely affect interpersonal relationships with family and friends.

Cultural Heritage

Cultural heritage assets are in danger of being damaged or destroyed during a severe fire. Aboriginal assets do, however, remain relatively undamaged by even the most intense fire, as a large number of the physical artefacts are made of stone, such as cooking and hunting instruments and paintings on stone walls. In some cases, the removal of vegetation and subsequent erosion has aided in locating many hundreds of artefacts and unearthing previously unknown cultural sites. Cultural heritage values from European settlements have a greater chance of being impacted by severe fires, with many structures being made out of timber and metal. Notably, 32 historic Alpine huts and several mining complexes have suffered some degree of damage.

Environmental Impacts

The literature on the environmental impacts resulting from bushfires is extensive and stretches back for many decades. Books that provide a good overall picture of fire's interaction with the natural environment include Bradstock, Williams and Gill (2002), Gill, Groves and Noble (1981) and the Victorian National Parks Service (1996).

For soil interactions, Attiwill and Leeper (1987), Raison (1979) and Walker, Raison and Khanna (1986) are good sources of information.

Notable research into the area of water runoff and erosion includes DeBano (2000) and Prosser and Williams (1998). For research relating to water sedimentation and water-flow impacts, EPA Victoria (2003, 2004), Lane, Sheridan and Noske (2006) and Leitch, Flinn and van de Graaff (1983) provide an in-depth analysis. Key research into hydrological processes includes Feikema, Lane and Sherwin (2008), Kuczera (1987) and Vertessy, Watson and O'Sullivan (2001).

The impacts on air are described through the movement of nutrients (i.e. in smoke) into the atmosphere and the influence of smoke on the enhanced greenhouse effect. Walker, Raison and Khanna (1986) explore the movement of nutrients into the atmosphere in depth, while reports by the Intergovernmental Panel on Climate Change (IPCC) (2007) and the National Association of Forest Industries (NAFI, 2007) highlight the contribution smoke makes to the enhanced greenhouse effect.

Many species of Australian flora either require fire to produce the next generation or have adaptive strategies that allow them to recover. For a general overview of fire-adaptive plant mechanisms, works by Attiwill and Leeper (1987) and Gill (1981, 1997) provide a good foundation. For information on fire regimes, Christensen, Recher and Hoare (1981), Gill (1975) and Gill and Allan (2008) offer ample reference material. Government agencies understand the delicate relationship between fire and its impacts on flora, and are undertaking a number of strategies to try and improve the floral diversity within the landscape through strategic burning techniques (e.g. Cawson and Muir 2008a).

As with flora, the impact of bushfires on fauna is well documented. Articles that study the responses of a range of terrestrial fauna during and after a fire include Friend (1993), Newsome and Catling (1983) and Whelan et al. (2002). For aquatic fauna, EPA Victoria (2006) provides numerous examples regarding the impacts on aquatic fauna.

Soil

Depending on the temperature of the fire, the effect on soil can occur at the biological, chemical or physical level. A proportion of soil nutrients and chemicals is removed from the site by the fire directly through the transfer of gases, particulate matter and ash to the atmosphere in the form of smoke. In addition, soil can be removed from a site once the fire has been extinguished through the erosive processes of wind or rain. In some cases, severe bushfires induce water repellency within the soil, making it even more susceptible to erosion.

Water

The hydrology of a landscape and the resultant quality of watercourses are significantly affected by severe bushfires. The removal of the vegetation encourages large-scale erosion that eventually flows into streams and rivers, causing sedimentation of these waterways and a deterioration in water quality. Even in areas where waterways have been severely impacted by large quantities of sediments, these sediments are typically flushed out over three to five years. On the catchment scale, the restoration of hydrological processes back to pre-fire conditions can take up to 150 years if a large proportion of the vegetation is removed, as growing trees require much more water than when they are mature.

Air

The smoke produced from severe bushfires contains a number of chemicals, including plant nutrients. Nitrogen in particular is highly susceptible to being lost to the atmosphere, but is eventually returned to the soil through a number of processes, such as nitrogen fixation. Greenhouse gases (e.g. carbon dioxide and nitrogen oxides) are also emitted to the atmosphere via bushfire smoke.

Biodiversity – Flora

Many Australian vegetative species have evolved to depend on fire for their ongoing survival, and therefore the persistence of whole ecological communities. In order to take full advantage of this element, plants have developed mechanisms that allow them to survive the initial fire front or reproduce once the fire has passed, which are: storing seed on the plant, storing seed in the soil, resprouting through lignotuberous buds (buds at the base of the tree), resprouting through epicormic buds (buds just under the bark) or spreading vegetatively through rhizomes (underground stems).

Fire can be seen as a positive element; however, if it is applied to the landscape outside its natural tolerances (e.g. too frequently or intense, not frequently or intense enough), then some species are in danger of becoming locally extinct. The ongoing health of natural ecosystems depends on how they are managed, with fire agencies needing to draw on a wide range of information sources to ensure that the natural landscape remains as healthy as possible.

Biodiversity – Fauna

Native fauna, both terrestrial and aquatic, is affected by severe fires as a result of the altered landscape, thereby influencing sheltering, feeding and breeding habits. When threatened with a fire, terrestrial fauna will burrow, avoid or make active use of it. Wombats and reptiles will generally try and burrow their way out of danger, while highly mobile animals, e.g. kangaroos and birds, will flee. Many raptor species have been observed taking advantage of the situation, feasting on those animals trying to escape. Once the fires have passed, until there is sufficient vegetative coverage, smaller animals such as reptiles and small mammals become easy prey for larger animals.

Aquatic animals are generally protected from fire by waterways; however, once the fire is extinguished, their survival is greatly dependant on the severity of the fire and the resultant erosive processes. Sedimentation can cause large short-term impacts, such as smothering stream beds with ash and silt, reducing oxygen levels, which causes aquatic life to suffocate, and increasing nutrient levels to toxic levels. Pre-fire conditions generally return within 5 to 20 years.

Severe bushfires have the potential to produce numerous economic, social and environmental impacts, which can range from short-term inconveniences to long-term life-changing impacts. While it is easy to observe the negative impacts typically found within the economic and social categories, the environment generally requires bushfires to remain healthy and support the rich diversity of flora and fauna. In the event bushfires enter a natural landscape outside its natural tolerances, however, the impacts could also be adverse and long-lasting.

Photo: Catherine Stephenson ▶

Fire and adaptive management

One: Introduction

Fire is an integral component in many Australian ecosystems. A majority of fires occurring in the natural landscape, whether they are ignited naturally through lightning, or artificially through fire-authority planned burning programs or by other human activities (e.g. campfires), are extinguished before they have any adverse impacts. However, when a bushfire[1] cannot be brought under control in time, the impacts can be very severe.

For the purposes of this report, the word 'severe' has been defined as '*causing very great pain, difficulty, worry, damage, etc.; very serious*' (Cambridge University Press 2010), and refers to the severity of the impacts, and not to the severity (e.g. intensity) of the actual bushfire. This is because a fire can be very intense, but burn in a remote area and not cause adverse physical or flow-on impacts. Conversely, a less intense fire may begin close to major infrastructure or economic sectors (e.g. tourism, agriculture) and cause widespread impacts. Therefore, it is the severity of the impacts that generally characterise a bushfire, and not its fundamental components.

The impacts of severe bushfires have been placed into three categories in this literature review: economic, social and environmental, which are known in the business sector as the triple bottom line. The triple bottom line approach is a philosophy that describes an organisation's processes, values and issues that must be managed with the aim of minimising harmful actions and maximising economic, social and environmental values (Spatial Vision 2006). The division of bushfire impacts into these categories was chosen for this review because this is how impacts are frequently categorised in natural disaster literature (Economic Commission for Latin America and the Caribbean (ECLAC) 2003; Benson and Clay 2004; McKenzie, Prasad and Kaloumarira 2005) and aligns with concepts used in government policies, such as the Sustainability Charter for Victoria's State forests (Victorian Government 2006).

Economic impacts are those that can be financially valued, and are typically grouped into either direct or indirect costs (Bureau of Transport Economics (BTE) 2001). Direct costs relate to the physical damage caused by the fire on capital assets, including private property, public buildings, commercial plantations and crops (van der Veen 2004). Indirect costs occur as a result of the impact of the fire (Handmer 2003), and incorporate such costs as disruption to business production in the event that power is cut during a fire. Direct economic costs are relatively easy to evaluate, whereas costing indirect impacts is an area of much contention. Rose and Lim (2002) identified a number of factors that make accounting for indirect costs complicated, including the difficulty of confirming these as easily as direct costs, the need to model these losses carefully, variability in the size of indirect effects and the possibility of manipulating these costs for political purposes.

Social impacts are generally those that are not normally bought or sold (BTE 2001), and include such impacts as emotional trauma from the death of a loved one or the loss of photos and other memorabilia. They are known in economic terms as intangible costs and are very difficult to measure financially. These impacts, however, are usually the most important, enduring long after the roads have reopened and buildings are rebuilt (Middelmann 2007).

Environmental impacts relate to the natural environment, such as soil, water, air, vegetation and fauna, and like social impacts, are classified as intangible impacts. Some economists believe that it is important to place monetary values on the environment (e.g. Costanza et al. 1997), thereby enabling natural environmental assets to be compared with man-made assets on equal terms (Pearce 1998).

On the surface, many impacts can be placed into one of the economic, social or environmental categories listed above; however, a more in-depth assessment reveals the complex nature of bushfire impacts (or any other disaster) and their inter-relationships, both within and between the categories. For example, the burning of an (eucalypt) ash forest allocated to be felled by a timber harvesting company can be seen as an economic and environmental impact. That is, the timber industry may lose millions of dollars from lost timber sales, whereas the forest may benefit from a severe fire, as it gives rise to the next generation of trees. This example highlights the difficulty in simply allocating certain impacts to one category or another. This literature review placed impacts into the most appropriate category; however, there will be instances where impacts can easily be placed into two or three of these categories simultaneously. For example, water has been placed in both the economic and environmental impact sections.

1 Regardless of how the fire started, bushfires are defined as '*a general term used to describe a fire in vegetation*' (Australasian Fire and Emergency Service Authorities Council)

This literature review examined the economic, social and environmental impacts of severe bushfires in Australia, focusing on five fires that occurred in south-eastern Australia: the 1983 Ash Wednesday Fires, 2003 Alpine Fires, 2005–06 Grampians Fires, 2006–07 Great Divide Fires and 2009 Black Saturday Fires. Background information on these fires and maps of the area burnt are included in Appendix 1. As well as exploring the actual impacts of severe bushfires, the other purpose of this report was to review and compare the literature in this area. Where relevant, this report highlighted significant pieces of work, impacts with much research dedicated to them and those impacts for which there was very little research. All dollar values described in this review are in Australian currency unless otherwise specified and are in the year of the referenced work.

When comparing the volume of literature on severe bushfires, there is a relatively small amount of information compared with other natural disasters. A scan through journal databases revealed that a large amount of information was available on catastrophes such as Cyclone Tracy (December 1974), the Boxing Day Tsunami (December 2004) and Hurricane Katrina (August 2005), including books, reports and journal articles. In relation to extreme bushfires, on the other hand, it was relatively difficult to find even small amounts of information, including for fires such as the August 2007 Greek and October 2007 Californian wildfires. Another scan through the literature showed that much of the publicly available information can predominantly be found in newspaper articles.

Following this introduction, the next three chapters (Chapters 2–4) cover a range of economic, social and environmental impacts. These chapters have been further divided into subheadings, with titles reflecting the asset class titles used by the (Victorian) Office of the Emergency Services Commissioner's (OESC) Wildfire Project (Spatial Vision 2006), with the exception of the 'Government Services' subheading under Economic Impacts, which was added by the author. Chapter 5 contains the conclusion, followed by the appendices in Chapter 6 and reference list in Chapter 7.

2

Two: Economic Impacts

As stated in the introduction, economic impacts can be financially valued and are classified as either direct or indirect costs (BTE 2001). In the field of economics, however, the word 'economics' also refers to the study of the economy as a whole and measures all losses and benefits to that economy, thereby presenting a holistic evaluation of the natural disaster being studied (Thompson and Handmer 1996). In this sense, all impacts, including environmental and social impacts, are included, regardless of whether they can be valued in monetary terms or not. In order to capture the impacts on a whole economy, economic loss assessments are commonly used (Handmer, Reed and Percovich 2002). Table 1 illustrates the types of impacts that may be measured in an economic loss assessment, using those impacts covered in the present literature review as examples. The terms **Eco**, **Soc** and **Env** denote the sections in which these impacts are located in the review.

Table 1: Types of loss and measurement (uncertainty in both identification and valuation increase from top left to lower right of the table)

Eco – Economic impact **Soc** – Social impact **Env** – Environmental impact

Can the loss be bought or sold?	Direct loss (Loss from direct contact with the natural event)		Indirect loss (No contact – loss as a consequence of the event)	
Yes – Tangible	• Electricity or power supplies	**Eco**	• Disruption to transport	**Eco**
	• Timber	**Eco**	• Water (for human consumption)	**Eco**
	• Agricultural products (e.g. livestock, crops)	**Eco**	• Disruption to commercial or retail businesses	**Eco**
	• Horticultural products (e.g. orchard fruit, grapes for wine production)	**Eco**	• Disruption to tourism	**Eco**
	• Buildings and contents	**Eco**		
No – Intangible	• Cultural heritage	**Soc**	• Loss of community	**Soc**
	• Ecological disturbance (i.e. to the land, water, air and biodiversity)	**Env**	• Physical health	**Soc**
			• Psychological health (of firefighters and others in the community)	**Soc**

Template source: Handmer 2003, p. 93

Fire and adaptive management

Several frameworks exist that undertake economic loss assessments of natural disasters. Notable works that measure the economic, social and environmental impacts of a natural disaster include:

- Disaster Loss Assessment Guidelines (Handmer, Reed and Percovich 2002)
- Handbook for Estimating the Socio-economic and Environmental Effects of Disasters (United Nations Economic Commission for Latin America and the Caribbean (ECLAC 2003))
- Rapid Appraisal Method (RAM) for Floodplain Management (Read, Sturgess and Associates 2000)
- The Development of a Socio-economic Impact Assessment Model for Emergencies (OESC 2008)

When undertaking an economic loss assessment, measuring the costs of economic impacts (i.e. as part of the triple bottom line) is relatively straightforward, such as the cost of rebuilding a home or replacing unserviceable machines in a factory. Estimating the cost of social and environmental impacts is not as easy; however, a monetary value has been placed on some of these impacts. The statistical values of a fatality and injury are the only social impacts for which a consistent dollar value has been developed (BTE 2001; Ashe, McAneney and Pitman 2007). Most recently, Abelson (2008) valued a statistical life at $3.5 million and an injury as a proportion of the value of a statistical life year ($151,000) (both in 2007 dollars), depending on the type of injury sustained. A statistical life was valued by measuring society's willingness to pay to reduce the average number of deaths by one. The proposed values have now been adopted by the Australian Government's Office of Best Practice Regulation (OBPR 2008). Another approach is the human capital or cost of illness method, which views people as a labour source and the '*value to society of preventing an injury is the saving in potential output or productive capacity*' (BTE 2001, p. 129). The BTE (2001) developed values for use in natural disaster cases, which are (in 1998 dollars): $1.3 million per fatality, $317,000 per serious injury and $10,600 per minor injury. Abelson (2008) highlights many limitations with the human capital approach, the most fundamental one being that it measures the amount lost post death (e.g. value of labour lost, medical expenses, legal costs). For society as a whole and more specifically from a policy-maker's point of view, the amount people are willing to pay to prolong their life is more constructive.

The natural environment can be valued in terms of its use or non-use values. Use values refer to the goods and services provided by the ecosystem and used by humans (Pagiola, von Ritter and Bishop 2004) for either consumptive (e.g. timber, medicine, water) or non-consumptive (e.g. recreation, cultural activities) purposes. Furthermore, these uses can either be enjoyed by visiting the ecosystem itself, or indirectly by those outside the ecosystem (e.g. carbon sequestration, water filtration). Non-use, or existence, values refer to the enjoyment people feel in the knowledge that the ecosystem is present (Nunes and van den Bergh 2001). A table summarising several methods for estimating environmental, or more specifically ecosystem service values is presented in Appendix 2.

While this section measures economic impacts in terms of the triple bottom line approach, economics does have a more holistic meaning when used in the term economic loss assessment, and this will be explored further in the report following this one[2], which analyses the impacts of five severe south-eastern Australian bushfires.

2.1 Infrastructure

A range of infrastructure is inevitably damaged or destroyed in the path of a severe bushfire. The costs associated with repairing or replacing these assets, particularly during a large-scale fire, can therefore become very expensive, with the economic impacts stretching out for months to years. The range of literature covering this topic is limited in relation to Australian bushfires. While many documents give basic losses or make general statements, the documents cited in the following subsections (i.e. transport networks, electricity and water) provide a much greater level of detail that includes costs and/or indirect impacts.

2.1.1 Road Networks

Repairing the state road network is an important step for initiating the economic recovery process for many affected communities, especially with respect to the tourism industry. The Ministerial Taskforce on Bushfire Recovery's 2003, 2006 and 2007 reports contain information on bushfire impacts on road infrastructure and the indirect short-term disruption effects on people's lives. Roads and their associated infrastructure (e.g. signposts, guardrails, bridges) are easily damaged or destroyed in the event of a severe fire, making

2 Report title: The Impacts, Losses and Benefits Sustained from Five Severe Bushfires in South-Eastern Australia

them unsafe and subsequently leading to road closure until repairs are made. The Ministerial Taskforce on Bushfire Recovery (2003) highlighted the stress this placed on those affected after the 2003 Alpine Fires, with communities finding it difficult to access supplies, counsellors not being able to reach traumatised people and farmers having trouble moving their stock to better feeding grounds. These problems generally added to the feeling of isolation. Understanding the implications of these flow-on effects, the Victorian Government acted quickly after the 2003 Alpine Fires to initiate the recovery process and repair the damaged roads and associated infrastructure. This was not an easy process, as 4435 km of roadway, including 870 km across 11 arterial roads, had been affected. Works across the 870 km alone included the replacement of 600 signs, 11,000 guideposts, 5.8 km of guardrails and 40 km of line-marking. Despite the enormous task of restoring the affected roads to pre-fire conditions, all roads were reopened in the first week of March 2003 (Ministerial Taskforce on Bushfire Recovery 2003).

As noted by the Ministerial Taskforce on Bushfire Recovery (2006), the damage caused by the 2005–06 Grampians Fires was significantly less than that from the 2003 Alpine Fires, with 240 km of roads being affected. These were quickly assessed and repaired; however, the 1200 km of forest roads damaged within the Grampians National Park required more time to thoroughly assess (e.g. checking for unstable ground, assessing overhanging trees) and reopen (Ministerial Taskforce on Bushfire Recovery 2006).

The severity and extent of the 2006–07 Great Divide Fires again had a significant impact on the Victorian road network. As a result of this fire being relatively closer to towns than the 2003 fires, a total of 110 roads were closed during this period, while others were restricted to local traffic. Although no numbers have been provided in the Ministerial Taskforce on Bushfire Recovery's (2007) report for the amount of roadside infrastructure needing to be replaced outside state forests and national parks, it can be assumed that they are at the very least equal to those of the 2003 Alpine Fire, given the similar size of the fires. Within state forests and national parks, data based on fire boundaries and the assets recorded within them showed that 7000 km of road and vehicle tracks, 680 km of walking trails, 344 road bridges, 800 road signs and hundreds of picnic tables, camping grounds, toilet blocks and shelters had been damaged or destroyed (Ministerial Taskforce on Bushfire Recovery 2007).

2.1.2 Electricity

A severe fire's impact on critical services such as electricity can be extremely costly, as it not only impacts on the area immediately surrounding the damage, but can have indirect implications for other parts of the state. Most likely owing to the rarity of such a large power disruption affecting extensive areas, very little information could be found on the impact of bushfires on this service. The Nous Group (2007), commissioned by the Victorian Department of Primary Industries, undertook an extensive review of the 2006–07 Great Divide Fires impact on powerlines on 16 January 2007, in which the Tatong–Watchbox Creek fire (north-east Victoria) cut off Victoria's main electricity link to the Snowy and to New South Wales at 4.03 pm on a Tuesday afternoon. This was the result of extreme weather conditions fanning the fire and pushing it towards the powerlines. Fire management agencies found it difficult to defend the lines, as their primary focus was saving hundreds of homes from burning. The impacts were immediate, with an estimated 700,000 Victorian electricity customers losing power. Even though supply began to be restored after 47 minutes, with full restoration taking 4.5 hours, damage had been done. The Nous Group (2007) listed a number of impacts, including homes losing the use of electronic services (i.e. communications, lighting and air conditioning), mobile phone coverage being lost in a 750 km² area and 1100 metropolitan lights shut down. Further compounding the frustration felt by all of those caught in the blackout was that it coincided with Melbourne's peak hour. During this period, 160 trains were cancelled and 616 trains delayed, affecting an estimated 175,000 passengers. The situation was made worse by the fact that 16 January 2007 was Melbourne's second hottest day during that summer (The Nous Group 2007).

2.1.3 Water

Water contamination is highly likely in the event of a severe bushfire. The degree of economic impact this has on those who use the water for drinking and agricultural purposes will depend on how much of the vegetation has been burnt by the fire, thereby leaving the area vulnerable to erosion, and if that watercourse feeds into town or city water supplies. While the physical processes of erosion and sedimentation of water bodies is discussed in *4.2 Water* under the *Environmental Impacts* section, the present section highlights the economic impacts on those directly using contaminated water and the long-term impact on water supplies if bushfires were to enter water catchments containing reservoirs and dams used for Greater Melbourne's water supply.

Following the 2003 Alpine Fires, EPA Victoria conducted numerous studies on the quality of streams and rivers directly affected by severe bushfires. One study in particular (EPA Victoria 2003) linked the presence of a severe bushfire to the economics of towns downstream and provides a good account of the overall impacts. Shortly after the 2003 Alpine Fires, flash floods caused a large volume of sediments exposed as a result of the fire to enter the Ovens River (EPA Victoria 2003). For several towns downstream of this flood, the impact on water supplies and irrigators was significant. Wangaratta, a major town of approximately 18,000 people, fully relies on the Ovens River for its water supplies (EPA Victoria 2003). Even though Wangaratta was approximately 170 km downstream from where the flood occurred, the council and businesses had to implement several strategies to ensure the town received acceptable potable water for some weeks after the event. EPA Victoria (2003) listed these impacts to be the introduction of Stage 4 water restrictions[3], extra treatment and filtration for Ovens River water in the treatment plants and the trucking in of water from other towns. Similarly, farms diverting water from the river had to struggle with large volumes of sediment, which reduced the effectiveness of their pumping and irrigation equipment and provided poor quality water for stock and domestic use (EPA Victoria 2003).

While the economic implications of having large amounts of ash and sediments enter a river used by towns can last for several weeks, the long-term impacts of a bushfire burning through Melbourne's major catchments can last for decades. Melbourne Water's website (**www.melbournewater.com.au**) provides many general facts regarding the city's water supply and the importance of managing fire within the catchments that supply Greater Melbourne's water, stating that Melbourne is one of only five cities in the world to receive its water from protected catchments (Melbourne Water 2006). This therefore makes the protection of the forests from extensive bushfires in these catchments a high priority, with Melbourne Water (2006) alone dedicating approximately $1 million a year to fire prevention and suppression activities. If, for example, fire was to remove all vegetation within the Thompson Catchment, which holds approximately 60% of Melbourne's water supplies (Melbourne Water 2005), Peel et al. (2000) predicted that annual water yields would sharply increase and then decline from a pre-disturbance yield of 692 to 30 mm within five to ten years, gradually increasing to pre-disturbance levels in approximately 150 years. This research was based on computer modelling using the complete logging of a Mountain Ash catchment as the basis for regeneration. Despite being a modelling study based on logging, it does demonstrate the ongoing economic and social implications of significantly reduced water supplies if fire (i.e. another method for clearing vegetation) was to enter the catchment. The reasons for the fluctuations in water level are explained in *4.2.3 Returning Hydrological Processes to Pre-fire Levels*.

The implications of these long-term hydrological processes were almost realised for Melbourne's water supply in the 2006–07 Great Divide Fire as the fire threatened to burn through the Thompson Catchment. Flinn, Wearing and Wadsley (2008) wrote in their narrative of this bushfire that as the front headed directly for the catchment surrounding the reservoir, possibly one of the longest and most difficult control lines in Victorian firefighting history was built along the western border of the catchment, stretching for 65 km. With the combined efforts of many firefighting resources (i.e. firefighters, fire trucks, water-dumping fixed-wing aircraft and helicopters, heavy excavation machinery), the fire was successfully kept out of the catchment.

2.2 Economic Production

Economic production, whether it is through the provision of goods or services, can be affected in several ways by the presence of bushfires. While the direct impacts are obvious to see, i.e. the destruction of trees allocated for timber, equipment or livestock, the indirect impacts can be much more devastating and long-lasting. This section provides examples of impacts to five economic sectors. The Ministerial Taskforce on Bushfire Recovery's 2003 and 2007 reports provide much of the information cited below and provide an overall picture of the impacts. More detailed descriptions of the impacts on specific sectors are shown through other documents; however, like for *2.1 Infrastructure*, the availability of relevant research was quite restricted.

3 Stage 4 restrictions include the following: water cannot be applied to residential, commercial or public gardens or lawns. Sporting grounds cannot be watered. A vehicle can only be washed for health and safety reasons. Residential or commercial pools and spas cannot be filled, added to or replaced with water (Our Water Our Future 2008).

2.2.1 Retail, Commercial and Industrial Sectors

Local businesses in the retail, commercial and industrial sectors are all unavoidably affected by a severe fire in their local area, potentially costing these businesses large amounts of lost revenue and lost customers. Those in the retail sector are particularly affected, with members of the local community either evacuating until the threat has passed, voluntarily staying on their property to defend it, or being forced to stay on their property owing to being physically cut off. The lack of tourists visiting fire-affected areas also causes widespread business disruption; the impacts of a severe fire on this aspect are discussed in *2.2.2 Tourism*.

While the threat is still present, regular business slows dramatically. The Ministerial Taskforce on Bushfire Recovery (2003) reported that businesses in the fire-affected areas of the 2003 Alpine Fires generally recounted a 50–70% downturn, with some experiencing losses of 100% during and immediately after the bushfires. There were, however, some instances where certain business experienced an upturn during fire suppression efforts, attributed to the need for firefighters and support personnel to use hotels when required and for provisions (i.e. food, water, equipment) (Gangemi et al. 2003). For those in the business of hosting events, however (conferences, receptions, etc.), the economic impact was severe, with the cancellation of many scheduled events resulting in non-recoverable losses (Ministerial Taskforce on Bushfire Recovery 2007).

In a study by Gangemi et al. (2003), it was found that the loss of retail and commercial income in four eastern Victorian shires over four months after the 2003 Alpine Fires totalled $48 million. This was only a proportion of the estimated $121.1 million lost across the four shires in total Gross Shire Product (Gangemi et al. 2003).

While the local community and its businesses are severely affected both during and after a bushfire event, the effect on businesses in towns and cities far away from the fire threat can also create significant disruption and financial losses. As well as describing the impact on households (*2.1.2 Electricity*), The Nous Group (2007) also described the impact on businesses when 70,000 metropolitan (mainly Melbourne and Geelong) businesses lost electricity for 4.5 hours during the 2006–07 Great Divide Fire power-cut. Unless the affected business had back-up power, they lost the use of all electronic equipment, including EFTPOS, phone, fax, internet services, lighting, refrigeration, air conditioning and ventilation systems (The Nous Group 2007). All aspects of these businesses were disrupted, with partially finished products worth millions of dollars being thrown away and production lines temporarily closing down. Ongoing disruptions included chemical and refinery processing plants shutting for up to a week until everything was back in order and affected business incurred penalties because they could not deliver products on time according to their contract (The Nous Group 2007). The direct impact on large businesses ranged from $50,000 to over $3 million, with ongoing impacts adding to these costs. In all, direct impacts across all customer types (i.e. households and businesses) totalled $235 million, while the indirect and flow-on costs resulted in an additional $265 million cost (The Nous Group 2007).

2.2.2 Tourism

Tourism in areas prone to bushfires is a risky business. While these environments are usually home to beautiful scenery and associated outdoor activities, they are inevitably burnt, leading to declines in local tourism for a period of time. Particularly in south-eastern Australia, where bushfires occur around the summer months, the drop in tourist numbers can dramatically impact on a community's immediate, short- and long-term economic future. The Ministerial Taskforce on Bushfire Recovery's 2003 and 2007 reports and the *Rebuilding Together* report following the 2009 Black Saturday Fires (Victorian Bushfire Reconstruction and Recovery Authority 2009) provide some overall information and loss estimates. Reports by Gangemi et al. (2003) and the Rural and Regional Committee (2008) present detailed information on the socio-economic impacts of severe bushfires, while Cioccio and Michael (2007) explored the realities of planning, preparing and recovering from the 2003 Alpine bushfires for small tourism operators in north-eastern Victoria.

During and immediately after a severe fire, would-be visitors generally stay away from the areas directly affected and those areas within close proximity. The economic impacts of a lack of visitors are intensified in places such as north-eastern Victoria and east Gippsland where tourism is a key sector (Ministerial Taskforce on Bushfire Recovery 2003) worth over $1 billion per year (Ministerial Taskforce on Bushfire Recovery 2007). The Ministerial Taskforce on Bushfire Recovery (2003) noted that by April 2003 (only three months after the fires started), 1100 businesses had been affected, with at least 15 remaining closed. Then, during the process of recovery, the 2006–07 Great Divide Fires brought about more disruption to tourism businesses, resulting in an estimated loss of $200 million for the 12 months following the start of the fire (Ministerial Taskforce on Bushfire Recovery 2007). In Halls Gap, a tourist town located at the foothills of the Grampians National Park, an accommodation business recorded a loss of $150,000 in comparison with other years and a decrease of 1300 reservations in the summer of the 2006 Mount Lubra (Grampians) Fire (Rural and Regional Committee 2008). In addition, the Rural and Regional Committee (2008) noted that other towns felt the repercussions of this drop in business as a result of the 2005–06 Grampians Fires. Stawell is a major country town located 20 minutes out of Halls Gap. As a result of visitors not travelling through to Halls Gap as they normally would, the retail sector experienced a 30% drop in turnover. During the 2009 Black Saturday Fires, Lake Mountain Alpine Resort suffered extensive damage, with almost all buildings being destroyed and a majority of the forests being burnt (Victorian Bushfire Reconstruction and Recovery Authority 2009). This was not just a major loss to the resort, but the surrounding communities, as the resort was a key driver of Marysville's economy (it is the last town before reaching the mountain). The Victorian Bushfire Reconstruction and Recovery Authority (2009) allocated $9.2 million to rebuild the resort and promote its values both as a winter ski retreat and a summer bushwalking experience.

Many tourism operators felt that the way in which the mass media portrayed natural disasters greatly contributed to the immediate and ongoing lack of tourists, claiming that news was often sensationalist and sometimes inaccurate (Cioccio and Michael 2007). While the media are a useful tool for the communication of a natural disaster's progress and an effective method of warning people of dangers, they can also overdramatise a situation and turn people away in a time when tourism operators are most in need of business. Gangemi et al. (2003) documented that sensationalist reporting created a sense of panic among locals during the 2003 Alpine Fire. Many turned to their radio and TV for information on how the fire was progressing and as a result of the media coverage became highly stressed, even though they were not directly in danger. The only way this panic was counteracted was through local government meetings and briefings that gave townspeople the correct information. This also happened to many small towns scattered throughout the Great Dividing Range in Victoria during the 2006–07 Great Divide Fires. Places like Mansfield, Bright, Myrtleford and Beechworth were not directly under threat, but media reports portrayed them as being so, and this greatly reduced their bookings for that period (Rural and Regional Committee 2008).

Recovering from such a severe fire event may take tourism operators many years, as the 'product' being sold, i.e. the bush, can take that long to recover to a condition appealing to tourists. In the meantime, businesses can have great difficulty in convincing tourists to return and need to develop effective ways of persuading them back. In the months following the 2003, 2006 and 2006–07 fires, the state and local governments invested a lot of effort and money in promoting the affected areas, highlighting that there were still many sites and activities to enjoy and that experiencing a regenerating forest was a unique opportunity. The Ministerial Taskforce on Bushfire Recovery (2007) stated that 'brand marketing' campaigns became an essential component for restoring confidence in these areas after the fires, which focused on the core product strengths of the regions that could still be enjoyed. 'Blame it on the Alpine Air' (after the 2002–03 fires), 'Victorian Snowfields, Never Come Down' (launched in 2006) and 'Inspired by Gippsland' (launched in March 2007) were all brandings applied to different areas of Victoria (Ministerial Taskforce on Bushfire Recovery 2007). Following the 2006–07 Great Divide Fires, the Victorian Government stated that it would update these brands to reflect the current market conditions and incorporate areas affected by bushfires (Ministerial Taskforce on Bushfire Recovery 2007). These announcements may not have been effectively communicated to the local level of government, with one Alpine Shire Council tourism marketing officer stating that they were unaware of when the campaign was to run and any details surrounding it (Rural and Regional Committee 2007).

Even though the media had a negative impact on tourism in the short term, survey respondents in both Cioccio and Michael (2007) and Gangemi et al. (2003) stated that many operators conceded that the media greatly assisted in promoting the regeneration message out to the general public by means of advertisements and positive news stories through TV, radio, magazine and newspaper media. This message did reach the public, with operators in Bright, for example, being advised by some tourists that they intended to return every six months in order to document and photograph the natural regeneration of the bush (Gangemi et al. 2003).

2.2.3 Forestry

Whether timber comes from natural forests or plantations, the economic impact of a severe fire burning through stands will greatly affect a company's financial state during the season of the fire and for decades to come as new trees grow to logging age. Apart from information found in several government recovery documents, such as DSE (2005), DSE and PV (2008) and the Ministerial Taskforce on Bushfire Recovery's 2003 and 2007 reports, very little information exists in the public domain.

The impacts of severe fires on the forestry industry are best described using the highly valuable Alpine Ash (*Eucalyptus delegatensis*) and Mountain Ash (*E. regnans*) as examples. Following the 2003 Alpine and 2006–07 Great Divide Fires in the Great Dividing Range of eastern Victoria, thousands of hectares of these forest types marked for commercial timber purposes were burnt. As eucalypt Ashes are easily killed by fire and need to be salvaged within 18 months of the fire to minimise timber degradation, government bodies developed plans to salvage as much of the burnt timber as possible (Ministerial Taskforce on Bushfire Recovery 2003). By the end of 2004, approximately 200,000 m^3 of saw logs and 350,000 m^3 of residual logs had been removed. The DSE (2005) had projected a reduction in long-term yields of 18% as a result of the 2003 Alpine Fires, but with the 2006–07 Great Divide Fires also burning over some of the same area and other parts of the Great Dividing Range, this figure has undoubtedly increased. Over the short term, however, the removal of so many logs until 2004 created temporary employment for an additional 420 people involved in salvage operations (DSE 2005).

Regeneration was another vital component of post-fire forestry activities. Since Alpine and Mountain Ash eucalypts do not develop the capacity to produce seed until they are approximately 20 years old (DSE and PV 2008), manual seeding is required in areas in which immature Alpine and Mountain Ashes are killed to ensure continued sustainable harvesting. Two large-scale operations were conducted after both fires. More than five tonnes of Alpine Ash seed were harvested from grown trees following the 2003 Alpine Fires, and were aerially sown over 1600 hectares of immature fire-killed Alpine Ash regrowth during the first winter months following the fire (DSE 2005). An even bigger operation was undertaken after the 2006–07 Great Divide Fires, when almost 20% of the Mountain Ash burnt were immature, in part owing to the overlap in fire area from the 2003 Alpine Fires. As a result, the Victorian government pledged $5 million to regenerate 3500 hectares of fire-affected forests (Ministerial Taskforce on Bushfire Recovery 2007).

2.2.4 Agriculture

The extent of the impact on agricultural property depends on how much of the property and contents have been burnt and what suppression works have been undertaken. As with the *Forestry* section above, information was hard to find, with the DSE (2005) and the Ministerial Taskforce on Bushfire Recovery's 2003 and 2007 reports again providing a large amount of information. In relation to the 2006 Grampians Fires, the Friends of Grampians–Gariwerd (FOGGS) (Fleming et al. 2007) produced a book that contains a range of loss information relating to agriculture, as well as a timeline of events and stories from those who were affected by the fire. Some information was found in the Victorian Bushfire Reconstruction and Recovery Authority's 2009 report.

The amount of private property burnt in the 2003 Alpine Fires, 2005–06 Grampians Fires, 2006–07 Great Divide Fires and 2009 Black Saturday Fires was 60,000 ha (Ministerial Taskforce on Bushfire Recovery 2003), 51,000 ha (Fleming et al. 2007), 50,000 ha (Ministerial Taskforce on Bushfire Recovery 2007) and 120,000 ha (DSE 2009, Victoria February 2009 Fire Severity Area Statements, unpub.) respectively. Livestock losses amounted to 13,000 in the 2003 Alpine Fires (DSE 2005), 65,300 in the 2005–06 Grampians Fire (Fleming et al. 2007), a relatively small 1700 during the 2006–07 Great Divide Fires (Ministerial Taskforce on Bushfire Recovery 2007) and 11,000 during the 2009 Black Saturday Fires (Victorian Bushfire Reconstruction and Recovery Authority 2009). In comparison, substantially higher livestock deaths resulted from the 1983 Ash Wednesday fires, with Healey (1985) stating that 26,000 perished in the Victorian fires and 257,350 (246,900 were sheep) died in South Australia.

Restocking livestock is difficult when a farmer loses a substantial number, being made more difficult if prime breeding stock is also killed. Since breeding stock can take many generations to reach the desired level, the time required to produce this quality of livestock again may be many years (Australian Bankers' Association 2002). The market price of breeding stock is also higher. Therefore, in the event stock is killed, market demands will inevitably drive the prices of the remaining stock up.

For livestock that do survive the fire, the risk of death through starvation is a real threat. Farmers who lose their already stretched supply of fodder as a result of the recent prolonged drought conditions are not able to keep their animals alive without the assistance of outside donations. The quantity of fodder being incinerated amounted to approximately 167,800 square bales during the 2003 Alpine Fires (DSE 2005), 10,400 tonnes of hay during the 2005–06 Grampians Fires (Fleming et al. 2007) and 1050 tonnes of hay during the 2006–07 Great Divide Fires (Ministerial Taskforce on Bushfire Recovery 2007). Among other initiatives assisting farmers to get back on their feet, the State Government, charity organisations and other local and interstate farmers donated large amounts of feed to struggling farmers (DSE 2005).

Another impact associated with livestock is the destruction of fences. While they serve the purpose of keeping livestock in, they also aid in keeping wild dogs and foxes out (especially electric fences). In all, approximately 1500 km of fences bordering Crown land were burnt during the 2003 Alpine Fires (Ministerial Taskforce on Bushfire Recovery 2003), a total of 2300 km of fencing was destroyed during the 2005–06 Grampians Fires (Fleming et al. 2007) and 2000 km of fencing was destroyed in the 2006–07 Great Divide Fires (Ministerial Taskforce on Bushfire Recovery 2007). Owing to the 1983 Ash Wednesday and 2009 Black Saturday Fires burning through relatively more densely populated areas, fencing losses were an estimated 5900 km in Victoria and 10,000 km in South Australia (Healey 1985) for Ash Wednesday and over 8200 km during the 2009 Black Saturday Fires (Victorian Bushfire Reconstruction and Recovery Authority 2009). Even though fences adjoining Crown land are legally the responsibility of the private land-holder, the Victorian Government announced a fencing relief package for both the 2003 and 2006–07 fires (Ministerial Taskforce on Bushfire Recovery 2003; Ministerial Taskforce on Bushfire Recovery 2007). In addition, volunteers organised through local municipal recovery committees were assigned to help farmers clean up their property. DSE (2005) documented the extent of this help after the 2003 Alpine Fires, with 850 volunteer days being spent removing and replacing burnt-out fences, as well as removing hazardous debris and performing revegetation activities for 55 land-holders in north-eastern Victorian. Furthermore, approximately 500 volunteer days were spent clearing 1000 km of fences on 93 Gippsland properties (DSE 2005).

Fire is not the only force to potentially impact on farms. When required, fire authority bulldozers establish control lines by scraping the soil to mineral earth as a means to prevent the fire travelling further. The resultant threat of soil erosion and on-farm and catchment water-quality pollution means that rehabilitation works have to be undertaken quickly to minimise the damage. In the 2003 Alpine Fires, where 1400 km of control lines were established on private property, rehabilitation works could not be done quickly enough (DSE 2005). Shortly after the fires, the affected regions experienced major flooding, causing widespread erosion and water pollution. The DSE (2005) reported that government staff worked with farmers over the following two years to rehabilitate the land, including such activities as soil erosion control, resowing perennial pasture, revegetating with native plants and water quality restoration. In all, almost 240 erosion sites were treated for a variety of issues.

2.2.5 Horticulture

Horticulture-related businesses, such as those growing fruit, vegetables, flowers and shrub products are vulnerable to fires passing through them like any other asset, however a large amount of damage is caused by smoke permeating through the skin of the fruit and leaves (smoke taint) from fires occurring up to many kilometres away. This can have severe economic implications for the operator, or in the most extreme cases, force them to close down completely. Some examples of this can be found in Gangemi et al. (2003) and the Ministerial Taskforce on Bushfire Recovery (2007).

In the last few years, the problem of smoke taint in food products (mainly in grapes for wine-making) has generated large amounts of research. Two websites provide detailed information on all aspects of smoke taint: the Victorian Department of Primary Industries (**www.dpi.vic.gov.au**) and The Australian Wine Research Institute (**www.arwi.com.au**). In addition, numerous journal articles have been published on the effects of smoke on grapes. A study by Kennison et al. (2007) in Western Australia, for example, identified a number of additional chemical compounds in wine whose grapes were exposed to smoke, with taste testers describing these wines as exhibiting smoky, burnt and earthy flavours. The Victorian government supported this field of research, providing $84,000 after the 2006–07 Great Divide Fires (Ministerial Taskforce on Bushfire Recovery 2007).

Since smoke travels well beyond the perimeters of a severe fire, the impacts on horticultural businesses can be far-reaching. In the Alpine Shire, Gangemi et al. (2003) noted that smoke taint from the 2003 Alpine Fires rendered grapes useless. This cost wine-growers between $10,000 and $1 million dollars each, with a combined estimated loss ranging from $5 to 8 million. Following the 2006–07 Great Divide Fires, Whiting and Krstic (2007) noted that the value of smoke-tainted grapes in north-eastern Victoria was estimated at $15–20 million, which amounted to a $75–90 million loss in wine sales.

Other business types are also impacted by smoke taint. Gangemi et al. (2003) reports that a berry farmer in the Indigo Shire (north-eastern Victoria) had to put his once-thriving business up for sale as a result of smoke taint after the 2003 Alpine Fires. As well as losing the income from selling the berries, the farmer lost the tourist dollars associated with 'pick your own' visits.

2.3 Property

Bushfires are generally confined to the bush; however, severe fires have the power to overwhelm fire authority agencies and burn through public buildings and private properties alike, affecting homes, outbuildings and other infrastructure. Reports that highlight the impacts of bushfires on property are very limited. Reports and inquiries that contain a large amount of detail regarding losses referred to in the present review include the CFA (1983) and Healey (1985) (both for the 1983 Ash Wednesday Fires) and Blanchi and Leonard (2005) (2003 Canberra Fire).

Insurance is an issue faced by everyone affected by a severe bushfire, in terms of those who do have it, those who are not adequately covered and those who do not have it at all. Very little research could be found on this topic, with small sections within reports addressing this issue. This information can be found in several documents referred to in the *2.3.2 Insurance* section.

2.3.1 The Destruction of Property and Research into its Minimisation

The 1983 Ash Wednesday Fires were a series of large, individual fires burning through forest and grasslands in Victoria and South Australia (CFA 1983). Thousands of homes and other buildings were destroyed or damaged, including 385 in South Australia (predominantly in the Adelaide Hills) (Healey 1985) and many thousands in Victoria. The Bushfire Review Committee (1984) stated the loss as being 2080 in Victoria, while the CFA (1983) reported 2897 as the total. This discrepancy may have been from the CFA (1983) highlighting estimated losses. By the time the Bushfire Review Committee's (1984) report was published, a more thorough investigation may have reduced this estimate to the final total of 2080. Blanchi and Leonard (2005) stated that urban house losses from the 2003 Canberra Fire totalled approximately 516, and describe in detail the degree of damage sustained and the causes of these fires in terms of housing designs and materials used. As with the 1983 Ash Wednesday Fires, the 2009 Black Saturday Fires resulted in high residential losses, with approximately 2300 homes being destroyed (Teague, McLeod and Pascoe 2009). This was particularly devastating for small towns. The town of Callignee, just south of Traralgon, lost 57 of 61 homes (McGourty 2009).

A particularly important area severely damaged by the 2003 Canberra Fire was the Mount Stromlo Observatory. In addition to gutting many of the buildings on site, the fire destroyed six historically significant telescopes and refractors. These had been acquired during the early 1900s, with the oldest dating back to 1911 (Orchiston 2003). The Australian National University (2003) preliminarily estimated the value of the losses at $20 million; however, the social and cultural impacts of losing one of Australia's scientific icons in terms of the objects and history undoubtedly stretch far beyond this value.

Constructing or improving homes to better protect them against bushfires is necessary if the owner or occupant wants a higher possibility of saving it. Significant research has been undertaken by the Bushfire CRC (www.bushfirecrc.com) into the performance of residential properties in the presence of bushfires as part of Program D1: Protection of People and Property – Building and Occupant Protection. Their aim is to use this research to better inform architects, builders, government policy-makers and the general public of how certain products and construction techniques perform in the presence of a bushfire, thereby highlighting how building design can be improved. This research has included such infrastructure as timber decking (Macindoe, Leonard and Bowditch 2007), water tanks (Blanchi et al. 2007) and windows (Bowditch et al. 2006). The cost of implementing recommendations from these reports and other reports (such as inquiries) that refer to better building methods and structural designs for protection from bushfires and their embers could become very expensive. All of those involved in the building industry, from suppliers who invest in research to create more fire-resistant products, to the architects who spend more time in designing homes able to withstand large bushfires, add their costs to their products, which in the end get passed on to the consumer.

2.3.2 Insurance

Insurance provides a certain level of security in the event a severe fire does impact on a family's home, a business or other infrastructure. Indeed, the inquiry by Esplin, Gill and Enright (2003) after the 2003 Alpine Fires stated that insurance was necessary for those living in rural areas as a good preparedness measure. This is particularly true for tourism operators, who indicated various commercial insurance policy types as their main approach to risk management in a survey conducted after the 2003 Alpine Fires (Cioccio and Michael 2007).

While the total value of insurance claims for the more recent bushfire events could not be sourced, Healey (1985) showed that the 4,540 claims made (860 in South Australia and 3,680 in Victoria) after the 1983 Ash Wednesday Fires totalled $193 million ($60 million in South Australia and $133 million in Victoria). In a (relatively) similar estimate, Crompton and McAneney (2008) estimated that the insurance paid out originally amounted to $176 million. This figure, along with those from nine other natural disasters that occurred in Australia, were normalised to reflect the amount of insurance paid out if these disasters were to happen in 2006. As a result, the 1983 Ash Wednesday Fires across Victoria and South Australia produced a normalised insurance loss of $1,630 million. This rated as the fifth highest-costing Australian natural disaster between 1967 and 2006, with Cyclone Tracy topping the list ($3,650 million in 2006 dollars).

People generally receive insurance payouts if they are properly insured; however, the impact of unfair insurance company practices or inadequate insurance cover can be very upsetting for those trying to recover from a severe fire event. Insurance assessors that undervalued people's assets were commented on widely in the report by Clayer, Bookless-Pratz and McFarlane (1985, p. iii) following the 1983 Ash Wednesday fires, with many survey responses stating similar problems to this:

> *'… it looks to me as if the insurance company is running some kind of racket, because the money I was insured for I never received. I had to accept what they offered me because I am financially broke due to the fire.'*

In addition, several respondents highlighted the practice, unreasonable to many, undertaken by insurance companies that those making claims had to sign a disclaimer that stated that no further claims could be made. Understandably, many were in a distressed state of mind and neglected to include simple things like fences to keep livestock in, and were therefore denied when trying to amend their claims. Attention was given to this practice in the first year after the fires, when a representative of the insurance companies held a press conference to state that they were prepared to review inadequate claims despite people signing disclaimers. Stories like these led to Clayer, Bookless-Pratz and McFarlane (1985, p. 66) concluding that '*insensitive and inadequate behaviour by some insurance companies led to long-term problems*'.

The Australian viticulture (grape-growing for wine production) industry has had to look into insurance cover in recent years with respect to smoke taint (see *2.2.5 Horticulture*), as, for example, many thousands of dollars' worth of grapes were not covered by insurance after the 2003 Alpine Fires (Gangemi et al. 2003). Even though many wine-makers did not have insurance for smoke damage during these fires, many did, however, have insurance against contaminants, and in the Australian Wine Research Institute's view, guaiacol, one of the main compounds entering grapes from bushfire smoke, is a contaminant (Godden et al. 2003). It is crucial that these differences in terminology and their impact on subsequent insurance policies be resolved, as the occurrence of more bushfires impacting on vineyards is inevitable.

2.4 Government Services

Both state and federal governments are actively involved in emergency management at all stages of the prevention, preparedness, response and recovery cycle. When a bushfire does occur, their commitment to the response and recovery components are clearly evident, as they combat the fire and provide assistance to impacted communities. Research into this area is relatively restricted; however, a report by Owen, Hickey and Douglas (2008) provides a detailed account of the operational structure and information flow between different government agencies when fighting a fire. The Ministerial Taskforce on Bushfire Recovery's 2003, 2006 and 2007 reports and Victorian Bushfire Reconstruction and Recovery Authority's 2009 report provide an overall account of the recovery measures put in place.

2.4.1 Firefighting Arrangement

All levels of government work overtime to attend to a severe fire, with many working 'behind the scenes' to ensure that a bushfire is brought under control in the safest and quickest time possible. Owen, Hickey and Douglas (2008) have written a very detailed report describing the flow of information throughout the response stage of a bushfire, with an accompanying illustrative model highlighting the complexity of the system. Their report describes how emergency coordination centres (ECCs) are established at the local (Municipal ECC, MECC), regional (Regional ECC, RECC) and state (State ECC, SECC) levels to coordinate response actions and allow information to flow up and down the chain. Connected to this chain at the ground level are the Incident Control Centres (ICCs), which handle direct operational requirements, such as deploying firefighters to the fire line and setting up base camps to house firefighters and support staff. If the fire becomes too big, Integrated Fire Agency Coordination Centres (IFACCs) are required to oversee a number of ICCs (up to five) to ensure that information is synthesised before it moves up the chain (Owen, Hickey and Douglas 2008). Given the complexity of this arrangement, the requirement for all of these centres to be operational 24 hours a day, seven days a week while the fire is at its height is demanding. Many government resources are required to staff these centres and the fact that these people can work in excess of 60 hours a week for prolonged periods (approximately 10 weeks during the 2006–07 Great Divide Fires) demonstrates the amount of stress placed on government resources during these times and highlights the financial costs associated with keeping such a large operation running.

2.4.2 Recovering from a Bushfire

Once the immediate fire threat has passed, the government initiates the recovery process. In Victoria, the Department of Human Services is responsible for the coordination of this stage (Minister for Police and Emergency Services 2008), and assist those requiring help through a number of strategies. The Ministerial Taskforce on Bushfire Recovery (2007) lists these as being, among other things, the provision of counselling services for such problems as trauma, financial and family relationship difficulties, disseminating information and working with local governments to arrange community meetings.

Another service governments in all states provide is the allocation of financial aid and relief packages. This is a difficult task, as the financial damage to all affected people cannot be covered by the finite amount of money provided by the government. As a result, ministerial taskforces were established towards the end of the 2003, 2005–06 and 2006–07 fires to assess the impacts of the fires and generate a range of recovery measures (Ministerial Taskforce on Bushfire Recovery 2007) through the provision of financial relief grants and packages. In total, the Victorian government provided $86 million to support community recovery, the rebuilding of infrastructure and the recovery of state and national parks after the 2003 Alpine Fires (Ministerial Taskforce on Bushfire Recovery 2003) and $10.8 million after the 2005–06 Grampians Fires (Ministerial Taskforce on Bushfire Recovery 2006). This amount then grew to $138 million after the 2006–07 Great Divide Fires (Ministerial Taskforce on Bushfire Recovery 2007) and then $517 million following the 2009 Black Saturday Fires (Victorian Bushfire Reconstruction and Recovery Authority 2009).

At the local level, councils are the key to ensuring a steady and positive recovery process. The Ministerial Taskforce on Bushfire Recovery (2007) explained that the council's desire to promote community spirit and support rebuilding activities were important to boosting community morale, and their continued interaction with government and non-government organisations was vital when tackling the resultant economic and social challenges. On a practical level, the local government's position as the initial 'go-to' point for those seeking assistance was an efficient way of referring them on to the most appropriate local service provider. This arrangement proved very useful for recovery purposes during the 2003 Canberra Fire, with the creation of the Recovery Centre. The Bushfire Recovery Taskforce (2003) acknowledged its success, writing that it was publicised in many forms of media and quickly became known as the place to go for information or as the initial contact point for any form of recovery for community members affected by the fire. Similarly, during the 2009 Black Saturday Fires, 10 Community Service Hubs were established in the areas most affected by the fires. The purpose of these was to provide people with a 'one-stop shop' for information regarding all the Government services available to them. They also became a place where people would drop in to share their experiences and develop support networks (Victorian Bushfire Reconstruction and Recovery Authority 2009).

Three: Social Impacts

Social impacts cover a wide range of community-orientated, health (both physical and psychological) and cultural heritage impacts. Relative to the other impacts, community-orientated and psychological impacts are harder to recover from, as they can develop quickly or over a long period of time, and require potentially long periods of support and/or counselling to come to terms with. In order to minimise adverse social consequences, Lindell and Prater (2003) advocate that a more holistic understanding of a natural disaster's social impacts can be used in the development of contingency plans to counteract or lessen the predicted outcomes. One way of doing this is through the use of Social Impact Assessments (SIAs), which are generally used to analyse, monitor and manage the social consequences of planned programmes, projects or policies (Twigg 2007). Vanclay (2003) advocates that the techniques used by SIAs can be used when considering the social impacts resulting from natural disasters and other types of unplanned events.

The literature available relating to the social impacts resulting from bushfires is extensive. Three broad areas were discussed in this review: community, health and cultural heritage. Given that each of these areas contained a large amount of research in their own right, relevant research has been discussed at the beginning of each of the sections.

3.1 Community

Communities are a collection of open-ended groups, constantly changing through time and space (Masolo 2002). This section explores the social impacts of severe bushfires on two forms of communities, firstly on the dynamics of the community as a whole and secondly on those who are directly or indirectly involved in fighting the fire. The Australian Bureau of Statistics (ABS 2001) defines communities (among other definitions) as those who share a set of interests or activities, and in this context, the second point above includes firefighters, support personnel and their families, who all share a common interest, the fire.

The effects of natural disasters on community dynamics has been researched extensively for many decades. In relation to bushfires, Gordon (e.g. 1997, 2004) and McFarlane (e.g. 1986, 1988) are notable researchers who have produced numerous papers on the impacts of bushfires, with Gordon creating a framework from his observations and McFarlane concentrating on the psychological impacts bushfires have on firefighters. Emergency Management Australia (EMA) is referenced throughout the *Social Impacts* section (i.e. EMA 2002), but the information within this reference was written by Gordon.

3.1.1 Effect on the Community as a Whole

The relative position of community groups within a space can be mapped in terms of their social closeness and strength of connection through such elements as locality, culture, religion or political preferences (EMA 2002). Figure 1a depicts a community framework, illustrating the complex 'social bonds' that exist between clusters of various groups. The four remaining images step through the stages of a community's disaster response and recovery process. Gordon (2004) highlights that this model has been taught at Australian Emergency Management Institute recovery courses since the mid 1990s, and has been validated by numerous emergency and social workers in a broad range of emergency types, including the 1996 Port Arthur shootings and the 2002–03 Victorian drought.

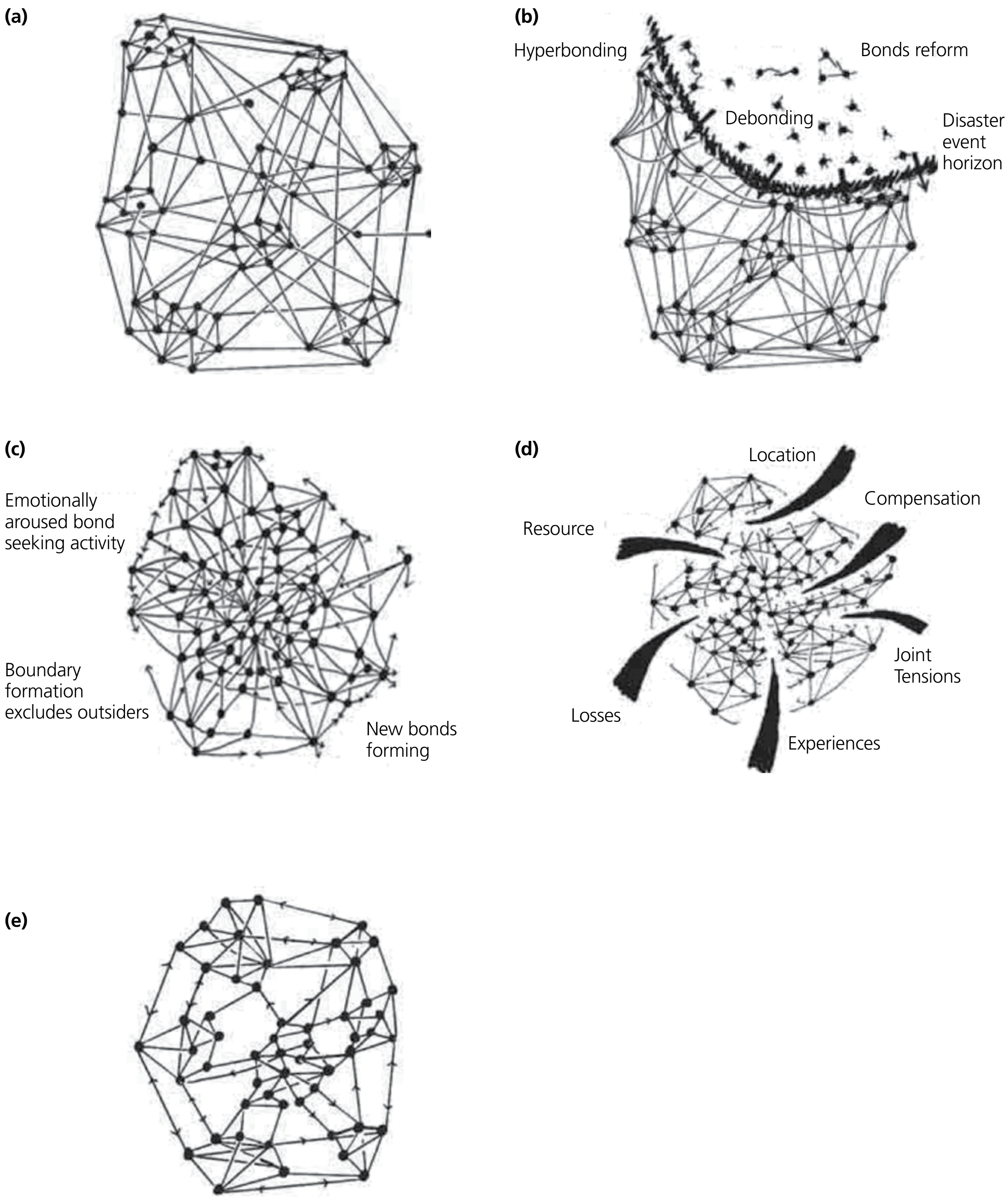


Figure 1: Phases of a community's response and recovery process during and after an emergency. (a) The community as a structure of social units bonded to each other with differing closeness on a variety of dimensions. (b) Disaster impact: the disaster event ('event horizon') moves across the community, severing communicational bonds at impact and forcing people to confront the survival threat individually, i.e. debonding. (c) The fused community: following impact, debonded community members join in intense indiscriminate social bonds based on the common experience of the disaster and the tasks required. (d) Cleavage planes develop in the fused community on the basis of divisions between groups affected differently by the disaster or recovery factors. (e) Constructive differentiation through coordinated development of interest groups and building active communicational relationships between them and the coordinating body, leading to the establishment of new social bonds. (Figures brought together from five separate diagrams in EMA (2002), text from Gordon (2004))

At impact, people become highly aroused, typically suppressing emotional responses to carry out necessary rational actions. As those in the face of danger are generally only concerned with their own and loved ones' survival, the community temporarily becomes irrelevant. This determination, coupled with the loss of communication with the 'outside world', means that they become detached from the crystalline framework in a process Gordon calls 'debonding' (2004) (Fig. 1b). As a result, the framework is severely altered. If debonded people are cut off from others, mentally or physically, over a prolonged period of time or their bushfire experience was too much to handle, their health and wellbeing can be critically undermined (Kaniasty and Norris 1999). During the 2003 Alpine Fires, residents directly affected by the fire were physically cut off from the outside world for weeks. Gangemi et al. (2003) noted that people in the caring professions (e.g. nurses, priests) were denied access to these areas because they were not seen as accredited professionals by police. One priest stated that it took three weeks for him to gain access to a severely affected community, and by this time, many felt pained and angered by their isolation. Since 'psychological first aid' in the form of social contact and support at an early stage is a very important step in the course of a healthy recovery (Gordon 1997), allowing these services to access the community sooner may have allowed people to communicate their emotions and relieve some of the anger that had built up.

Once the threat has passed, EMA (2002) identifies a driving need for community members to become reconnected and establish new networks as quickly as possible. In order to begin the recovery process, previous social groups and clusters are set aside in favour of an indiscriminate structure (Fig. 1c), wherein bonds are typically formed around task-focused, present-orientated activities.

Once the emergency and its aftermath subside, pre-existing divisions begin to present themselves again. Further adding to this, differences resulting from the emergency also cause a breakdown of the fused community. Examples of these include those who lost their house vs. those who did not, those who were eligible for certain types of compensation vs. those who were not, those who fought the fire vs. those who left well before the fire passed through. These are known as 'cleavage planes' (Fig. 1d), and create varied levels of competition, conflicts and resentment within the community (EMA 2002). A wide range of cleavage planes were experienced by many in the 1983 Ash Wednesday Fires, with two excerpts from Clayer, Bookless-Pratz and McFarlane (1985, p. 33 and 41) highlighting the pain and frustration felt by affected residents:

> *'I feel more help could have been given to the people who lost everything except their home – the feelings of guilt because your neighbour and best friends lost everything and you still had your home and then trying to stretch yourself to help all those people. Then watching all the help come in to them and nobody ever thinking of you, who had fought the fire for five hours straight while others had not even lived through the horror of that time.'*

> *'Bushfire relief workers were always very helpful. Our biggest problem is jealously from other people because we have built a nicer home than we had before, but they forget we had to pay for it, and it wasn't a nice way to get it, plus it still doesn't feel like home…'*

The isolation usually associated with this phase can be very stressful and depressing, with psychological problems often resulting from this stage (Gordon 2004). If this stage is approached in a planned and coordinated response and the needs of the community can be managed, Gordon (2004) states that there is a greater likelihood of better emotional support and limited conflict in the transition to the final stage. This was documented by McGourty (2009, p. 253) during the 2009 Black Saturday Fires when a paramedic described the support framework set up for those distressed by their experiences:

> *'I've been up there [in the fire areas] twice and we have some paramedics who live in the area or have relatives in the area and with some of them there is a sense of survivor guilt. Some are more affected than others. We call them first and we also have face-to-face meetings. It's a well-organised procedure, which we first developed more than 20 years ago.'*

The last stage of the recovery process before a community returns to the structure presented in Fig. 1a is described by Thompson and Hawkes (1962) as the establishment of a 'synthetic community'. A central coordinating group (shown in Fig. 1e as a denser cluster of dots) made up of community members and service providers is typical formed, facilitating communication requirements throughout the network. Examples of this arrangement were described in *3.4.2 Recovering from a Bushfire*. This structure gradually loses its function with the restoration of a more complex pre-emergency crystalline arrangement (EMA 2002).

Bushfires are an inevitable part of the Australian landscape that many people will have some interaction with during their lifetime, whether personally or through the experiences of a loved one. It is therefore important that Australian communities accept this element and adapt to it. A major national inquiry into bushfire mitigation and management issues was conducted after the 2002–03 season by Ellis, Kanowski and Whelan (2004), with one of the sections of this report dedicated to how communities can learn to live with fire. It proposed a number of options, such as school and community education programs, which would then enable people to understand the nature of fire and be better prepared for it in the event they are faced with the threat. This is further advocated by Tibbits et al. (2008, p. 69), who reasoned that shifting a person's mindset from a bushfire being '*terrifying and life-threatening' to 'dangerous but survivable*' may help lessen the trauma associated with the event.

3.1.2 Effects on the Firefighters, Support Personnel and their Families

Firefighters and their associated support personnel (e.g. incident control centre staff, base camp support, catering services) are an essential component in many Australian communities. The inherently dangerous activities undertaken by paid staff and volunteers alike while fighting a fire place them under significant physical and psychological stress, which can adversely impact them, other members of the family and close friends. These stresses can be further exacerbated in the event of a severe bushfire, as the work being undertaken may become more demanding and urgent, the shifts longer and the time away from home greater.

Little research is available on the effects of fighting a bushfire on the interpersonal relationships of Australian firefighters, support personnel and their families (Cowlishaw and McLennan 2006). McFarlane (1988) studied the impact of the 1983 Ash Wednesday Fires on firefighters, while research from Canada offered perspectives of firefighter-related experiences from the firefighters' (Regehr et al. 2003) and families' (Regehr et al. 2005) point of view.

Moran and Colless (1995) found that even though firefighters generally rate their job as more stressful than other occupations, they also rate their personal chances of being negatively affected as slightly less than fellow firefighters. This resembles the 'unrealistic optimism' phenomenon, whereby most people perceive their chances of being hurt as below average (Weinstein 1980). In the study by Moran and Colless (1995), psychological work stress was rated highest amongst all stress types. This is understandable, since the firefighters' exposure to psychological trauma in the form of fatalities, devastated families who have lost everything or people who worry about their own family or property during a bushfire threat while away working, all impact on a person's mental health. This was particularly evident in the 1983 Ash Wednesday Fires when McFarlane (1988) interviewed 50 paid and volunteer South Australian firefighters eight months after the fire who were considered to be at high risk of developing post-traumatic stress disorder (PTSD). This condition includes symptoms such as intrusive thoughts and feelings, nightmares and trouble concentrating (Salzer and Bickman 1999). Of the 50 firefighters, 11 had developed acute[4], delayed or chronic[5] PTSD. As part of the interview process, McFarlane (1988) discovered that 31 of the 50 had been injured, 20 had lost a loved one and 19 had sustained property loss, which often leads to a loss of livelihood for volunteers.

The degree of trauma sustained by those fighting a fire may be greatly dependent on the support networks around them. Regehr, Hill and Glancy (2000), for example, surveyed 164 Victorian metropolitan and rural firefighters, with 78% of those surveyed being previously exposed to a critical incident (e.g. death, rescue of a severely injured person). The perceived support given to those who had been involved in a critical incident was approximately 80%, indicating that many felt they were receiving sufficient support in dealing with trauma and emotional stress. In contrast, the survey demonstrated that those firefighters who did not perceive that they were receiving support from their employer, union, family and friends had scores indicative of depression (Regehr, Hill and Glancy 2000). In a similar study focusing on the level of social support and the associated trauma symptoms between new recruits and experienced firefighters in Toronto, Canada, Regehr et al. (2003) found that experienced firefighters had significantly lower levels of perceived support from their employer and family and also lower overall social support than their less-experienced comrades. Regehr et al. (2003) attributed this to shift

4 A rapid onset and/or over a short period or time
5 Over a long period of time

work possibly undermining the strong social bonds that were previously formed, the initial excitement or 'honeymoon' phase wearing off or increased competition for senior positions as people moved up the ranks. Possibly as a result of an inferior social support network, depression and trauma symptoms were found to be significantly higher in more experienced firefighters than their less-experienced counterparts.

It is reasonable to assume that family members and friends of those away at a fire are also affected by certain stressors. In the event of a severe, long-running bushfire, the requirement for firefighters and support staff to be on standby and away from home for week-long periods can place significant stresses and strains on interpersonal relationships, the general working of a household and childcare arrangements. A comprehensive study by Regehr et al. (2005) interviewed the partners of career firefighters in Toronto, Canada. While the opportunity was offered to male and female partners, only female partners expressed an interest is sharing their experiences. Although this research was not carried out for Australian conditions, the results could easily transfer to the emotions and thoughts of those in Australian fire situations. Regehr et al. (2005) found that many female partners experienced trouble with their children. Concerns included that the combination of shift work and child-caring responsibilities could limit the time spent between couples, that prolonged periods of time without their father caused stress to children and that some women felt like single parents. When the family lived a relatively long distance from the fire station, women felt that they did not receive support from others in the service, culminating in feelings of being disconnected and isolated (Regehr et al. 2005).

3.2 Health

The impacts of bushfires on individuals can be divided into two categories, physical and mental health. A common physical health problem is the impact of smoke, which can travel great distances from the fire itself. A wide variety of research exists in this area, including examples on high smoke days during bushfires (e.g. EPA Victoria 2007), the impact of smoke on asthma sufferers (e.g. Johnston et al. 2002) and the impact on firefighters (e.g. Aisbett et al. 2007). The Bushfire CRC has also dedicated a large amount of time and resources to this issue, providing an extensive and diverse range of information. Three research areas in particular focus on smoke and its social implications: Project B2.2 – Smoke Composition from Prescribed and Wildfires and Health, Project D2.2 – Air Toxics Exposure and Management, and Project D4 – Respiratory Health of Firefighters.

In terms of the mental health aspect, problems can arise in individuals who have been in immediate danger and those close to them. While Gordon (e.g. 2006) and McFarlane (e.g. 1986) both contribute significantly to this research, other authors also provide a comprehensive account of the impacts of natural disasters on the psychology of individuals. An article by Salzer and Bickman (1999) provides a thorough exploration of the short- and long-term impacts of natural disasters, while the report by Clayer, Bookless-Pratz and McFarlane (1985) undertaken after the 1983 Ash Wednesday Fires provides a detailed account of the actual impacts on people's mental health, as well as the flow-on effects to their physical well-being.

3.2.1 Physical Health Problems Arising from Bushfire Smoke

The effects of smoke on air quality and consequently human health depend greatly on factors such as the existing health condition of individuals, length of exposure, and concentration and size of air pollutants. The standard method for assessing the impact of smoke on human health is to measure the amount of particulate matter (PM) (aerosols[6]) in the air, which is measured according to its diameter: coarse particles are between 2.5 and 10 μm (micrometers) (PM_{10}) and fine particles are between 1 and 2.5 μm ($PM_{2.5}$) (Tham and Bell 2008). $PM_{2.5}$ are so small that approximately 30 particles would be able to fit across the width of a human hair (Kaiser 2005). DEWHA (2005) describes how PM_{10} can be absorbed into the body, typically entering a person's respiratory system and eyes, causing a sore throat, runny nose and burning eyes, which usually disappear in healthy people once the smoke has cleared. Those with pre-existing medical conditions, however, may find that their conditions are exacerbated during these periods. People with a greater risk of being impacted by bushfire smoke include those with asthma, other respiratory diseases and cardiovascular diseases (DEWHA 2005). $PM_{2.5}$ are of particular concern, as they are small enough to pass through the lungs and enter the bloodstream, sending harmful toxins to other parts of the body (Tham and Bell 2008).

6 Solid (e.g. black carbon, dust) or liquid (e.g. water) particles diffused as a suspension in gas, in this case the atmosphere. There are millions of tonnes of these particles present in the atmosphere at any one time (Highwood and Kinnersley 2006)

During a severe fire, the amount of PM_{10} in the atmosphere can reach very high levels, considered dangerous to human health. The Australian National Environmental Protection Measure for Ambient Air Quality target for maximum mean PM_{10} over a 24-hour period is 50 µg/m³ (Luhar, Galbally and Keywood 2006). During the 2003 Alpine Fires and 2006–07 Great Divide Fires, several days exceeded 50 µg/m³, with all air-quality monitoring stations around Victoria showing more days with readings above 50 µg/m³ during the 2006–07 Great Divide Fires (EPA Victoria 2007) (Table 2).

Furthermore, the highest 24-hour PM_{10} reading across both fires was 276 µg/m³ in north-eastern Victoria during the 2003 Alpine Fires (EPA Victoria 2007) (Table 3). In another example, Pio et al. (2008) measured PM_{10} concentrations during the northern hemisphere summer of 2003, in which almost 400,000 ha of forest burnt in Portugal. PM_{10} concentrations averaged over an hour frequently reached 100 µg/m³, with monitoring stations recording 300 µg/m³ during more severe fire periods.

Table 2: Comparison of the number of days that PM_{10} did not meet the air quality objective of 50 µg/m3 during the 2003 Alpine and 2006–07 Great Divide Fires at various locations around Victoria

	Number of days of PM_{10} above 50 µg/m³	
Region	**2003 Alpine Fires**	**2006–07 Great Divide Fires**
Melbourne	10	15
Geelong	6	11
Latrobe Valley	10	16
NE Victoria (Wangaratta)	16	17
East Gippsland (Bairnsdale)	Not monitored	9
SW Victoria (Warrnambool)	Not monitored	3

Source: EPA Victoria 2007, p. 9

Table 3: Comparison of the highest PM_{10} levels recorded in each location during the 2003 Alpine and 2006–07 Great Divide Fires for various locations around Victoria

	Highest 24-hour average PM_{10} (µg/m³)	
Region	**2003 Alpine Fires**	**2006–07 Great Divide Fires**
Melbourne	125	220
Geelong	112	116
Latrobe Valley	178	254
NE Victoria (Wangaratta)	276	213
East Gippsland (Bairnsdale)	Not monitored	194
SW Victoria (Warrnambool)	Not monitored	67

Source: EPA Victoria 2007, p. 10

The excessive levels of particulate matter in the atmosphere during severe bushfires and their impact on human health have shown mixed results. When looking at asthma by measuring the number of hospital admissions during and after a bushfire, two studies found a direct link between bushfire smoke and asthma (Churches and Corbett 1991; Johnston et al. 2002), while another two did not (Cooper et al. 1994; Smith et al. 1996). Johnston et al. (2002) argued that the other three studies measured incidences based on post-hoc comparisons after an unexpected fire event, leading to bias in unmeasurable confounding factors. The study undertaken by Johnston et al. (2002), on the other hand, measured hospital asthma presentations throughout the 2000 fire season, thereby allowing for periods of low and high bushfire activity.

While members of the public may choose to temporarily relocate if smoke becomes a health issue, bushfire suppression workers cannot avoid it while on the fire line. According to Aisbett et al. (2007), prolonged expose during intense work can severely effect a firefighter's health in two ways: firstly, by preventing oxygen from being released into the working muscles through the inhalation of carbon monoxide, leading to a reduced work output and increased heart rate, and secondly, by increasing a firefighter's exposure to particulate matter, which can weaken lung function. This, in turn, decreases the volume of air that can be inhaled or exhaled, restricting productivity.

3.2.2 Mental Health Problems of Individuals

The American Psychiatric Association (2000) states that a traumatic event is one perceived by a person as threatening their or a close associate's life, and includes learning about the death, injury or avoided injury of a family member or another close associate. During the event, a person's survival instincts are greatly heightened, with most people acting rationally (Salzer and Bickman 1999). Depending on the person's level of knowledge and experience, Gordon (2006) explained that they generally help others around them and cooperate to get the necessary work done. Gordon (2006) further explained that once the immediate danger has passed, people will display a number of reactions, including shock, distress or anxiety, go into automatic-pilot mode or become so involved in recovery activities that they do not think of or feel their own losses. A person's ongoing recovery from such an event is influenced by their personality, individual experiences at the time (i.e. a family may experience a significant threat together, but their recollection of the event and its impact on their recovery are likely to be unique; EMA 2002) and access to support networks.

In many cases, those involved in the emergency gradually resolve their responses to the experience over the next few months; however, some proportion of those severely exposed are likely to endure a diagnosable psychological injury, such as anxiety states, depression or post-traumatic stress disorder (PTSD) for a number of years (North et al. 1999; Bushfire Recovery Taskforce 2003). A comprehensive study by Clayer, Bookless-Pratz and McFarlane (1985) was undertaken one year after the 1983 Ash Wednesday Fires, in which the results of a questionnaire sent out to those living in the burnt areas were analysed. Their research demonstrated a 283% increase in mental illness after the fire. In addition, the number of respondents who suffered from multiple problems one year after the fire rose considerably. For example, those suffering headaches, sleep problems and nervous problems increased by 161% (70 to 183), while those who suffered these symptoms and palpitations increased by 400% (from 8 to 40) (Clayer, Bookless-Pratz and McFarlane 1985). McFarlane (1986) also described the impact of fires on 36 psychiatric patients whose problems could wholly or partially be attributed to the 1983 Ash Wednesday Fires. He found that few people asked for mental health-related help in the first few days following the fire, those who did seek help generally dated their first symptoms to two months after the fire and that cases were still presenting themselves two years later (McFarlane 1986).

The psychological and emotional impacts of living through a severe fire can be very strong, affecting other parts of a person's life. The report by Clayer, Bookless-Pratz and McFarlane (1985), for example, recorded large increases in substance abuse in the year following the 1983 Ash Wednesday Fires, with a 96% increase in alcoholism and 118% increase in drug problems. Gangemi et al. (2003) also observed this situation after the 2003 Alpine Fires in an area severely impacted by the fire. In addition to this, Gangemi et al. (2003) also noted excessive smoking, irrational behaviour and eating disorders, which the researchers feared might lead to domestic violence, suicide and family breakdown.

Another flow-on impact is the relationship with other family members who have lived through the experience. This was evident after the 1983 Ash Wednesday Fires, with the Clayer, Bookless-Pratz and McFarlane report (1985) counting 142 cases of marital problems directly after the fire. This increased to 190 cases during the year, before decreasing back to 92 cases at the time of the survey one year later. Survey respondents associated these problems with the stress of the fire, increased alcohol consumption and a despondent partner. In contrast, Camilleri et al. (2007) conducted interviews with people who were directly affected by the 2003 Canberra bushfires approximately three years after the fire and found that many partners felt that their bond had strengthened over that time. Reasons for this stronger bond included a mutual respect for each other's ability to deal with stress and going through a common experience. If the 1983 Ash Wednesday survey had been conducted over a longer time period, similar comments to those of Camilleri et al. (2007) may have been found.

Psychological trauma not only impacts on those directly involved in the threat, but can be just as significant for those away from the emergency who have loved ones directly involved; this is known as 'informational trauma' (Gordon 2006). Not knowing a loved one's situation or fate heightens their sense of arousal (i.e. a state of heightened psychological activity), sometimes leading to problems even after reunion. Firstly, Gordon (2006) reasons that people away from the event make decisions and adjustments before the fate of their loved one is known that may then persist in the long run. For example, detachment from a partner on their return to a farm property may exist if they believe their partner was killed when the farm house burnt down. Secondly, informational trauma may lead to problems with not knowing what their loved one went through and having to imagine it. If the loved one died, they are typically consumed by this thought process and want to know how they died and if they suffered. Conversely, if the loved one lived and both people were reunited, the one with informational trauma typically pushes their problems aside to focus on the one who faced the threat. If their experiences are not validated, or their needs are unmet, they will also find it difficult to cope, leading to misunderstandings and possibly undermining the relationship (Gordon 2006). During the 2003 Alpine Fire, children were sent away from their properties to relatives' homes outside the fire zone for up to six weeks. Gangemi et al. (2003) noted that some children were adversely affected by this separation, exhibiting attention-seeking behaviour on their return.

3.3 Cultural Heritage

From the little information that could be sourced on the topic of cultural heritage, the impact of severe fires on certain aspects of cultural heritage can be extensive. The International Council on Monuments and Sites (ICOMOS) provides good background information on cultural heritage. Freslov (2004) gives readers an appreciation of the impacts of bushfires on Aboriginal values, while reports by the Ministerial Taskforce on Bushfire Recovery (2003) and DSE and PV (2008) detail the loss of European settler structures from the 2003 Alpine Fires and 2006–07 Great Divide Fires respectively.

ICOMOS (2002) states that culture refers to all features that characterise a social group, community or society, and in reference to Australia, encompasses Aboriginal, early European and later groups of people. More specifically, cultural heritage is defined by ICOMOS (2002, p. 21) as:

> *'…an expression of the ways of living developed by a community and passed on from generation to generation, including customs, practices, places, objects, artistic expression and values. Cultural Heritage is often expressed as either Intangible or Tangible Cultural Heritage'*

In the event of a severe bushfire, tangible forms of cultural heritage are impacted, and for those linked to Aboriginal culture, the level of damage can vary. Some destructive impacts include the complete burning of scar trees, sooty covering and blackening of artefacts, movement of small artefacts down a slope through erosive processes and loss of rock art as a result of exfoliation of granite rock that has been subjected to intense heat (Australian Alps Liaison Committee 2003). Following the 2003 Alpine Fires, the DSE and PV commissioned Freslov (2004) to conduct an archaeological survey of 14 fire-affected sites in search of Aboriginal cultural heritage values. The survey located a total of 325 sites with Aboriginal significance, ranging from areas burnt by high-intensity fires to areas left untouched by the fire. The report found that severe fires aided in locating sites, firstly by defoliating vegetation to enable better line of sight and exposing the soil, and secondly by triggering erosion, which in some cases washed the overlying soil away (Freslov 2004). In other cases, the complete defoliation enabled the researchers to discover and record artefacts and sites not previously known.
In terms of severe fire impacts on physical objects, Freslov (2004) found very minimal damage to artefact

scatters, grinding grooves, rock shelters and quarry sites, citing sooty deposits as the main impact.

Early European cultural resources have been affected during the recent Victorian fires. In the 2003 Alpine Fires, the Ministerial Taskforce on Bushfire Recovery (2003) conveyed that approximately 270 known non-indigenous archaeological sites were located within the fire boundary, including old mining sites, early European settlement areas and pastoral properties. Some sites were saved; however, 32 historic Alpine huts and several mining complexes suffered some degree of damage (Ministerial Taskforce on Bushfire Recovery 2003). Furthermore, 245 historic places were recorded within the 2006–07 Great Divide Fires boundary according to DSE and PV (2008), with eight huts being burnt during this fire. One very significant cultural icon destroyed during the fire was Craig's Hut, which was constructed for the set of the iconic film *The Man from Snowy River*. These sites, especially those in relatively accessible locations, are significant tourism and recreational attractions. Therefore, damage to or destruction of these sites have large ongoing economic and social implications for tourism operators and the wider community, especially since the fire-affected areas rely heavily on tourism for their economic stability (DSE and PV 2008).

4

Four: Environmental Impacts

The natural environment is affected by any natural disaster, with bushfires being no exception. Their impact on the landscape goes well beyond the obvious signs of blackened forests and grasslands, directly and indirectly affecting all components of the ecosystem, including the soil, water bodies, hydrological processes, air, and animals. Depending on the severity of bushfires, this may be for a period of days to decades.

While much of the Australian environment has evolved to live with fire over tens of thousands of years (Attiwill and Leeper 1987), changes to the 'natural cycle' of fire and the clearing of land for residential, industrial and agricultural purposes have placed greater pressure on the remaining forests and grasslands to stay healthy and support wildlife. Even though natural ecosystems have an intrinsic value in their own right, their full value to humans has only been explored in the past 40 years through the concept of ecological economics (Patterson 2006). As well as valuing methodologies used in economic assessments, as described in Appendix 2, economists can also place a dollar value on each good (water, food, medicines) or service (regulation of the water cycle, waste management, carbon sequestration) provided by these natural environments.

The impact of bushfires on all aspects of the environment has been studied extensively for many ecosystems throughout the world. In relation to ecosystem types of south-eastern Australia, significant literature that provides a good overall picture of fire's interaction with the natural environment and its parts includes books by Bradstock, Williams and Gill (2002), Gill, Groves and Noble (1981) and the Victorian National Parks Service (1996). Literature that focuses on each ecosystem component is referred to in the relevant sections below.

4.1 Soil

Soil is a combination of organic matter, mineral matter, air and water that has been shaped by numerous biological, chemical and physical processes occurring concurrently over long periods of time (DeBano, Neary and Ffolliott 1998). The effect of fire upon it has been widely studied, with papers by Attiwill and Leeper (1987, chapter 12), Raison (1979) and Walker, Raison and Khanna (1986, chapter 8) all providing thorough details of the interactions. DeBano (2000) also provides a thorough review of soil hydrophobicity (water repellency), which can occur as a result of fire.

Soil is the foundation for a healthy ecosystem. It carries out a number of functions that enable all other components of the ecosystem to live, including storing nutrients and water for use by plants and the transportation of water through the soil profile to underground aquifers. Fire has the potential to impose long-term physical, chemical and biological changes on soil. The severity of these impacts on soil processes is determined by the soil temperature produced by the fire (Table 4), with temperature becoming less influential with increasing depth (Figure 2).

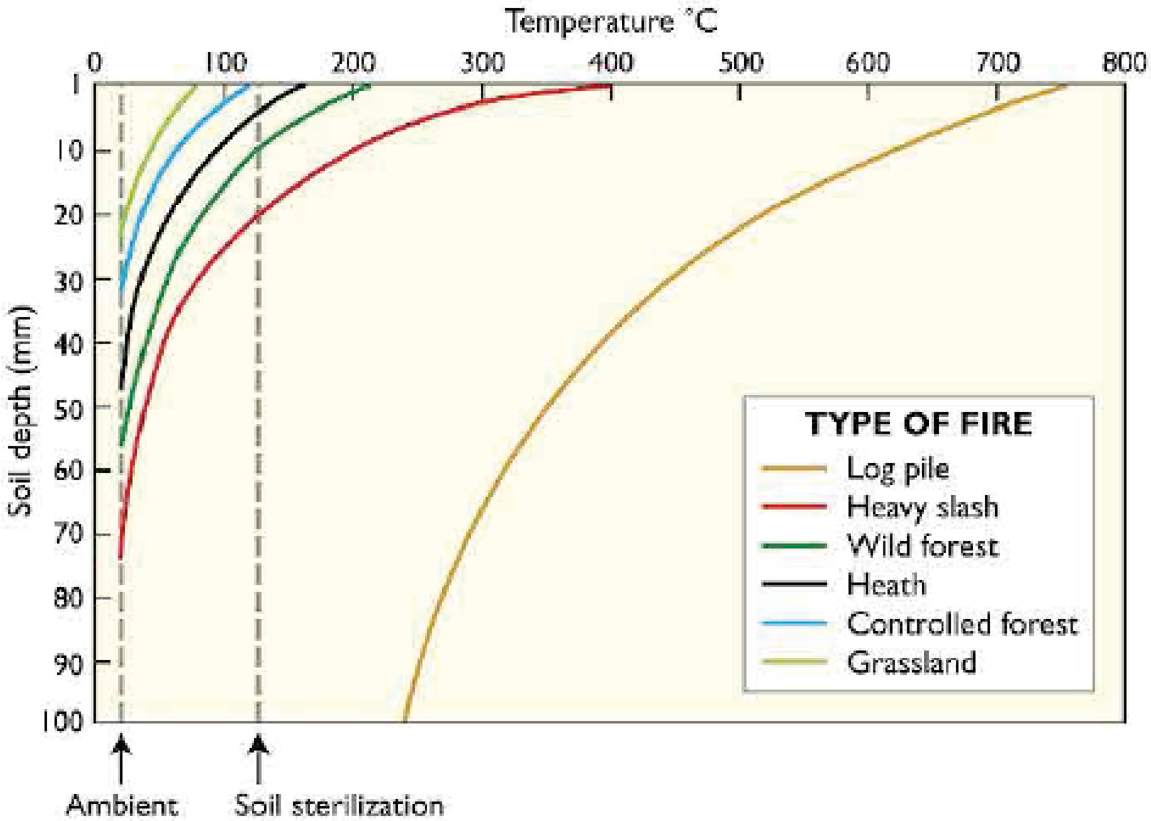
The changes described in Table 4 were compiled by Walker, Raison and Khanna (1986) from several studies, while the diagram in Figure 2 was first presented in table form by Humphreys and Craig (1981) and later shown graphically by Attiwill and Leeper (1987), Walker, Raison and Khanna (1986) and McKenzie (2003).

Table 4: Changes in soil, plant and animal material following heating at different temperatures

Dominant type of change	Temp. (°C)	Change
Physical	950	Clay minerals converted to different phase
	600	Maximum loss of potassium and phosphorus
	600	Fine ash and haematite produced
	540	Little residual nitrogen or carbon left
	420	Water lost from within clay minerals, causing change in type
	400	Organic matter carbonised
Chemical	300	Maximum amino acid nitrogen released
	300	Loss of sulphur and phosphorus begins
	300	Organic matter charred
	200	Loss of nitrogen commences
	200	Hydrophobicity caused by distillation of volatiles
	125	Soil sterilisation (i.e. death of soil organisms)
	110	Soil water lost
	100	Soil ammonium production starts
	70	High nitrate mineralisation
Biological	50	Mild sterilization owing to water loss
	37	Maximum stimulation of soil micro-organisms
	<25	Usual soil temperatures

Source: Walker, Raison and Khanna 1986, p. 194

Figure 2: Soil temperature profiles for different types of fire (image: McKenzie 2003, p. 7; original research: Humphreys and Craig 1981, p. 180)



Fire leads to substantial losses of plant nutrients and other chemicals from soil *in situ*. Walker, Raison and Khanna (1986) explain that direct losses of nutrients and chemicals occur through the volatilisation[7] and convective transfer of gases, particulate matter and ash to the atmosphere in the form of smoke. Once the fire has passed, soil and ash can be removed through the erosive actions of wind and water (Raison 1979). These processes subsequently impact on other parts of the ecosystem, which will be explained further in the relevant impact type section.

Soil hydrophobicity is an important impact that is closely linked to erosion (DeBano 2000). When bushfires pass through a landscape, heat from the fire is able to vaporise organic compounds, which subsequently condense to form a hydrophobic film at or just below the soil surface (Humphreys and Craig 1981). This in turn enables water runoff to increase considerably in localised areas; however, Prosser and Williams (1998) demonstrated that this water may be intercepted by areas downslope that are not hydrophobic before it reaches a stream, river or lake. Hydrophobicity can remain in the soil anywhere from a few months following low-intensity fires to several years after a severe fire (DeBano 2000). Even though hydrophobicity can be a product of fires in a range of soils, Rustomji and Hairsine (2006) demonstrated that many naturally contain this property without the presence of fire. This is true of soils under eucalypt-dominated forests, which can show either an enhancement (Shakesby et al. 2007) or large reduction (Doerr et al. 2006) in existing soil hydrophobicity, depending on a number of site conditions.

4.2 Water

Fires have the potential to significantly change the hydrology of a landscape and the quality of streams, rivers and lakes within it. Severe fires reduce vegetation and litter to ash and create or enhance hydrophobic properties within some soils, leading to greater water runoff, erosion and sedimentation of water bodies throughout the catchment. The window of opportunity for accelerated runoff and erosion greatly depends on how much is burnt. Regrowing vegetation gradually reduces the amount of runoff and potential for erosion until the hydrology of a landscape returns to pre-fire levels (Prosser and Williams 1998).

7 The conversion of a solid or liquid into a gaseous state. Also known as vaporisation.

Notable research into the area of runoff and erosion includes DeBano (2000) and Prosser and Williams (1998). For research relating to water sedimentation and water-flow impacts during the 1983 Ash Wednesday Fires, Leitch, Flinn and van de Graaff (1983) demonstrate the full impacts, whereas for the 2003 Alpine Fires, EPA Victoria (2003; 2004) and Lane, Sheridan and Noske (2006) provide an in-depth analysis. Key research into the impacts of bushfires on hydrological processes includes Feikema, Lane and Sherwin (2008), Kuczera (1987) and Vertessy, Watson and O'Sullivan (2001).

4.2.1 Erosion

The scale of runoff and erosion depends on a number of factors; however, storms after a fire have the potential to cause a large amount of damage. In a severe fire, every component of the landscape is burnt, including the plants that normally intercept raindrops and the littler that covers the soil. As a result, rain falls directly onto the ash and soil. The extent of surface runoff and erosion will depend on the storm's intensity, nature of the soils and steepness of the slope (Chandler et al. 1983), with these factors also influencing the amount of nutrients and seeds lost from the site, the latter being critical for trees that solely rely on seeds for regeneration (e.g. eucalypt Ashes).

Sheet erosion is a process whereby water runoff transports ash, soil and sometimes other debris down a slope. Leitch, Flinn and van de Graaff (1983) studied this process after the 1983 Ash Wednesday Fires in Warburton (Victorian Central Highlands). The study revealed that a hydrophobic layer of soil had formed below the ash layer, and when an intense thunderstorm of short duration took place just six days after the fire, the intensity of the raindrops quickly saturated the ash layer and caused it to 'slide' down the slope over the water-repellent soil layer below. The steepness of the slope assisted the rapid movement of the ash, to the point that it became a raging torrent, picking up large rocks, logs and tree stumps. The larger debris were dumped on the Warburton Highway, while the finer sediment was flushed into the Yarra River. Leitch, Flinn and van de Graaff (1983) estimated that 770 tonnes of ash and loose soil were removed from the 35-ha study site (approximately 22 t/ha). They further estimated that of this, 2880 kg was nitrogen and 220 kg was phosphorus. Even in large rivers, these levels of nutrients represent a considerable contribution to the deterioration of water quality (Leitch, Flinn and van de Graaff 1983).

A similar situation was experienced in Licola, a small Victorian town at the base of the Great Dividing Range, during the 2006–07 Great Divide Fires. The Ministerial Taskforce on Bushfire Recovery's report (2007) described how intense bushfires completely surrounded the town, killing livestock, burning fences, incinerating fodder and leaving the already drought-affected soil scorched and in a highly erosive state. Only weeks after the fires had been extinguished, moderately intense thunderstorms descended over the area at the end of February 2007. As a result, flooding, landslides and large mud-flows significantly impacted on the environment, moving large boulders, trees and other debris down the mountain slopes and pouring large volumes of sediment into the river (Ministerial Taskforce on Bushfire Recovery2007). These storms also severely impacted on the town's people, with their main road in and out of town being covered by boulders and mud and the steep embankments either side becoming unstable.

4.2.2 Sedimentation and Water Quality

There will always be some proportion of soil and ash that reaches a watercourse after any fire suitably intense to bare mineral soil (Chandler et al. 1983). Sedimentation occurs when particles, such as ash, soil and silt, are washed into waterways. Some impacts of this development include the smothering of river beds with sediments, changes to water chemistry, and the death of aquatic fauna (the last two are discussed in *4.5 Biodiversity – Fauna*).

In 2004, EPA Victoria conducted extensive studies on stream health and sediment loads after the 2003 Alpine Fires in north-east Victoria. They found that the number of sites in good condition fell from 65% prior to the fire to 40% one year after the fire. Conversely, the sites rated as poor rose from 16 to 30% in the same timeframe. Sediment 'slugs' (i.e. bodies of water containing a relatively large volume of sediments) were a major contributor to this deterioration in water quality. The Ovens River, a major river in the Victorian Great Dividing Range, was particularly impacted by a sediment slug following flash flooding shortly after the fire, posing a serious threat to aquatic life (EPA Victoria 2003). Suspended solid levels rose dramatically in a short amount of time, from an average of 6 to 33,000 mg/L in its peak flow. The ecological impact of these sediment slugs were not consistent, however, with some EPA Victoria (2004) testing sites showing no decline in stream condition after large sediment slugs had passed.

In terms of the volume of solids that entered the water following the 2003 Alpine Fires, Lane, Sheridan and Noske (2006) measured both the sediment load and annual water flow within a moderate to severely burnt East Kiewa catchment and a predominately light to moderately burnt West Kiewa catchment over two years. These catchments lie in north-eastern Victoria and are dominated by Alpine Ash. Their study revealed that total suspended sediment loads increased nine-fold in the East Kiewa catchment (0.23 to 2.05 t/ha/yr) after the first year, dropping back to 0.39 t/ha/yr by then end of the second year (Lane, Sheridan and Noske 2006). Two storm events were responsible for 79% of the total sediment load measurement in the first year after the fire. The West Kiewa streams received substantially less suspended sediment loads, with the authors (2006) reasoning that the less intense fires over a smaller area of the catchment and less damage to riparian[8] vegetation that traps sediments were major contributors to this result.

The results found in the study by Lane, Sheridan and Noske (2006) support the research conducted by EPA Victoria (2006). In a three-year study of fire-affected streams, EPA Victoria (2006) stated that there was no direct link between fire severity and changes to stream health, with subsequent rainfall events, fire patchiness and the existence of unaffected streams within the network as a source of recolonisation determining the true impact of a fire on stream health.

4.2.3 Returning Hydrological Processes to Pre-fire Levels

Returning hydrological processes back to pre-fire levels can be viewed either in the short or long term. In the short term, the time required to return erosion rates, nutrient loads and water sediment loads back to pre-fire levels depends on the ecosystem components (e.g. soil hydrophobicity, soil structure, return of vegetative cover, rate of litter accumulation) and fire conditions (e.g. intensity, patchiness, scale (discussed later in *4.4.2 Fire Regimes*)). In severely burnt Australian landscapes dominated by eucalypt species, water sediment loads were shown to return to pre-fire levels within three (EPA Victoria 2006) to five (Brown 1972) years. Wilkinson et al. (2006) deduced that this was the result of recovering hillslope vegetation reducing the possibility of erosion over the first two years, followed by the flushing of sediment from the waterways over three to five years.

Another way of measuring the impact of a severe fire on long-term hydrological processes is through the fluctuation in catchment (stream) water yields as a forest regenerates. Langford (1976) was the first to identify this link by comparing water yields (stream flow) before the 1939 Black Friday Fires to the flows afterwards in four affected Victorian mountainous catchments, with water yields being recorded up until 1970. Kuczera (1985) extending this research with an additional 11 years of data and additional four catchments to produce what is commonly known as the 'Kuczera Curve' (Figure 3). These catchments were dominated by Mountain Ash and other drier mixed-species eucalypts. There was a marked decrease in water yields three to five years after the fire across a majority of the study sites, reaching a maximum reduction of approximately 50% 25 years after the fires. With the additional data, Kuczera (1987) predicted a very slow increase in water yields, returning to pre-fire levels once the Ash forests had reached maturity in approximately 100–150 years.

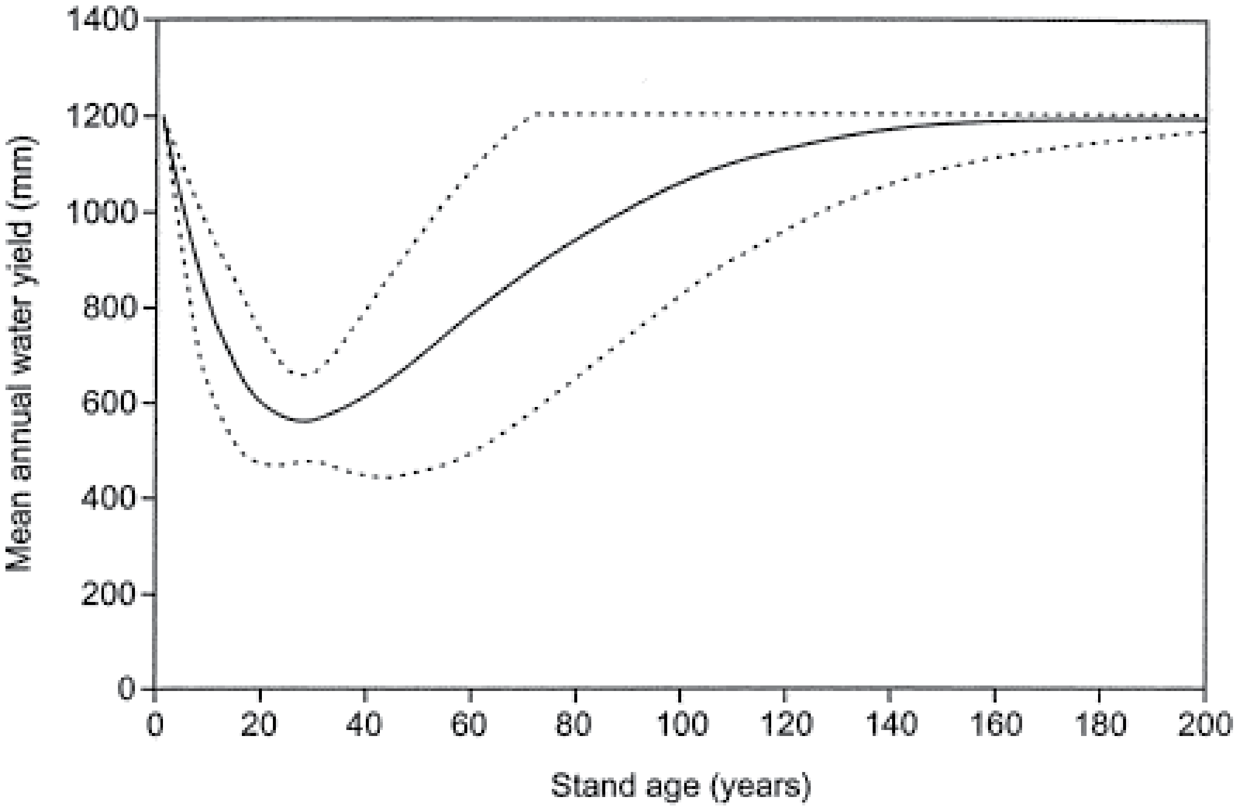
The reason for this relatively sharp reduction and then slow rise is the result of evapotranspiration[9]. As an Ash forest regenerates after a severe fire, thousands of seedlings grow rapidly per hectare during the first 10 years, competing for light and dominance. Consequently, the demand for water is very high, resulting in high transpiration rates (Vertessy, Watson and O'Sullivan 2001). Thinning of the weaker ash seedlings begins at an early age and 15 years post fire, the remaining gaps have been replaced by growing understorey species (e.g. wattles). The requirement for water still results in declining average water yields; however, as the growing Ash continue to thin out, their requirement for water decreases and the amount of rain reaching the streams gradually increases (Vertessy, Watson and O'Sullivan 2001).

While there is general agreement regarding stream flow rates decreasing beyond three to five years after a severe fire, the initial rates of water yield immediately after a fire and in the next three to five years have been an area of inconsistency. Both Langford (1976) and Kuczera (1987) found no difference in stream flow rates from immediately after the 1939 fire to three to five years after it. Langford (1976) suggested that enough vegetation may have been left intact to intercept the water in the catchments being studied and that mixed eucalypt species forest (as opposed the pure Ash forests) grow rapidly after a fire and would

8 The area adjacent to a watercourse, such as the banks of a stream, river or lake or area around a wetland.

9 Evapotranspiration is the combined water loss of evaporation from soil, rocks and water surfaces and the transpiration of water from leaf surfaces, which primarily entered the plant through its roots.

Figure 3: Relationship between mean annual water yield and regenerating stand age for Mountain Ash forest catchments after bushfire (image: Vertessy, Watson and O'Sullivan 2001, p. 15; original research: Kuczera 1987)



have reduced surface runoff. Kuczera (1987) referred to the variability in the data and that it may have 'hidden' any increase or decrease in water yields.

Conversely, numerous other studies have found a significant increase in water yields straight after a bushfire or logging operation that persisted for two to eight years before declining below pre-disturbance levels (Cornish 2003; Feikema, Lane and Sherwin 2008; Lane, Sheridan and Noske 2006; Vertessy, Watson, and O'Sullivan 2001; Watson et al. 1999), possibly as the result of relatively higher fire intensity, larger area burnt (or timber removed) or more data. Watson et al. (1999) remodelled the Kuczera Curve in relation to water yield data from a clearfelling logging coupe, as both bushfires and logging operations remove vegetation that then has to regenerate. They predicted a sharp increase in water yields in the first five years above pre-fire yields, before a decline below this benchmark. Watson et al. (1999) found this to be an improvement on the Kuczera Curve, with knowledge of the average yearly water yields after a fire or logging having large implications for town water supplies (discussed in *2.1.3 Water*), irrigation needs and the timing of timber harvest rotations.

Feikema, Lane and Sherwin (2008) modelled the impact of bushfires on the hydrology of three Melbourne catchments, using several variables (e.g. percentage coverage of fire, time between successive fires) to produce a detailed account of the reduction in stream flows and years required to restore the flows back to their pre-fire levels. The study highlighted that the reduction in stream flow rates and the time taken to recover were highly dependent on the type and percentage of trees burnt within the catchment. For example, catchments with a greater proportion of Ash-type eucalypt forests (e.g. Alpine Ash, Mountain Ash) tended to result in less stream flow following a bushfire than mixed-type eucalypt forests. This is because Ash-type eucalypts have a greater ability to take up water before it reaches a stream than other eucalypt types.

4.3 Air

During a severe fire, the air is quickly filled with large plumes of smoke. Smoke is a mixture of gases, particulate matter and ash that is removed from a site by volatilisation and convective transfer processes (DEWHA 2005). The final composition of smoke depends on the type of vegetation being burnt, the temperature of the fire and the wind conditions present. Some important chemicals contained within smoke include elements required for plant growth (e.g. nitrogen and phosphorus), while others contribute to greenhouse gases (e.g. carbon dioxide and nitrogen oxides) (DEWHA 2005).

The impact of smoke on air has always been of interest to scientists, with the relatively contemporary issue of climate change directing a large amount of research into this area. While key documents will be referred to in each section below, the Bushfire CRC are undertaking two projects that look at the environmental impacts of smoke: Project B2.1 – Behaviour of Smoke Plumes and Hazes from Rural or Urban Fires, and Project B2.2 – Smoke Composition from Prescribed and Wildfires and Health.

4.3.1 Soil and Plant Nutrients up in Smoke

Since nutrients are found in all components of a natural ecosystem, and predominantly in the soil, the literature recommended under *4.1 Soil* also provides a thorough picture of the impact of fires on nutrient loss to the atmosphere from soils. In addition, Raison, Khanna and Woods (1985) specifically examined the mechanisms of nutrient transfer to the atmosphere using seven nutrients in their experiment.

Raison, Khanna and Woods (1985) identified that fire intensity directly influences the volume of plant nutrients leaving a site, as it influences both the temperature of the fire and the amount of ash removed in the convection column. Carbon, nitrogen and sulphur are volatilised (to some degree) at low temperatures, meaning that any vegetation fire will remove some proportion of these elements, whereas phosphorus requires temperatures above 600°C for volatilisation (Walker, Raison and Khanna 1986). More examples of nutrient losses in response to fire temperatures are listed in Table 4.

Nitrogen is an important element limiting the productivity of most Australian ecosystems and is also the element most susceptible to loss during and after a fire (Attiwill and Leeper 1987). The amount of nitrogen lost to the atmosphere is relatively easy to measure, with Raison, Khanna and Woods (1985) demonstrating a significant positive linear relationship between the percentage of fuel burnt at a site (weight lost) and the percentage of nitrogen lost. In temperate grasslands, for example, an estimated 21 kg/ha of nitrogen was lost to the atmosphere, while in tall closed eucalypt forests, approximately 330 kg/ha was lost (Walker, Raison and Khanna 1986). Nutrients are returned to the cycle through the weathering of parent rock, rainfall, litterfall, decomposing roots and atmospheric nitrogen fixation by leguminous understorey plants (Keith 1997). Nitrogen fixation by wattle species can greatly contribute to the return of nitrogen back into the cycle, with Adams and Attiwill (1984) estimating that wattles associated with high-rainfall Mountain Ash forests fixed 50 kg/ha over three years.

4.3.2 Smoke and the Enhanced Greenhouse Effect

The impact of smoke from biomass burning on the global climate has received a lot of attention in recent years, with a wide range of literature exploring many aspects of this issue. Little information could be found on gas emissions from smoke as a result of Australian bushfires, however, with Flinn, Wareing and Wadsley (2008) and Berners-Lee (2010) offering some degree of scale as to the large impact smoke from severe bushfires has on the climate. In addition, Cary (2004) reviewed the impacts of bushfires on air quality.

A report by the IPCC (2007) stated that it is extremely likely that global atmospheric concentrations of carbon dioxide, nitrous oxide and methane have significantly increased owing to human activity since 1750. These chemicals occur naturally in the atmosphere as greenhouse gases and along with aerosols, absorb a proportion of solar radiation, with approximately 50% reaching the earth's surface (DSE 2004). The earth is therefore warmed to a temperature that sustains life. In exchange, infrared radiation is emitted from the earth's surface and either travels through the atmosphere to space, or is absorbed by greenhouse gases, only to be re-emitted in all directions. This process is known as the greenhouse effect. The presence of much higher concentrations of these gases and aerosols in the atmosphere has led to an increase in the amount of solar and infrared radiation being absorbed in the atmosphere or 'trapped' around earth, thereby leading to an increase in global surface temperatures (DSE 2004).

Given that head fires (i.e. the main fire front) may release up to 1% of the available fuel and particulate matter into the atmosphere (Cary 2004), the amount of greenhouse gases being released would also be immense. On a global scale, using fire to clear tropical and sub-tropical forests for agricultural expansion, especially in the Amazon and south-eastern Asia, is a large contributor to the total biomass burned (Oglesby, Marshall and Taylor 1999). In relation to severe fires in south-eastern Australia, the amount of greenhouse gases released from one fire is very large. In the 2006–07 Great Divide Fires, Flinn, Wareing and Wadsley (2008) estimated that 20 to 40 million tonnes of carbon dioxide were released from one million hectares of forest, with NAFI (2007) stating that the highest value in this estimate is comparable with the annual emissions of eight million cars. Furthermore, NAFI (2007) found that 130 million tonnes of carbon dioxide had been emitted to the atmosphere during the 2002–03 bushfire season. An estimated 165 million tonnes of carbon dioxide was produced by the 2009 Black Saturday Fires – equivalent to approximately one third of Australia's annual carbon footprint (Berners-Lee 2010).

In response to the growing threat of the enhanced greenhouse effect and climate change, the Kyoto Protocol (adopted on 11 December 1997) (United Nations 1998) was developed to try and curb the amount of greenhouse gases being produced by industries and biomass burning, including the burning of fossil fuels. The (Australian) Department of Climate Change (2008) provided an overview of the Kyoto Protocol and its implications, explaining that carbon has been given a financial value and can thus be traded. As a result, governments and businesses can either buy or sell carbon 'credits' in order to meet their emission targets.

In the absence of fires or other large disturbances (e.g. insect attacks), forests and grasslands are generally carbon sinks (i.e. they remove more of these gases from the atmosphere than they emit in a given time) (Canadian Forest Service 2007). In the presence of severe bushfires, however, they become a major source of these gases. As a result, forests and grasslands are the focus of much attention when it comes to trading the carbon held within them. Several markets exist around the world that encourage companies to revegetate or afforest landscapes, thereby offsetting their carbon emissions, including the New South Wales (NSW) Greenhouse Gas Reduction Scheme (NSW Government 2008) and the New Zealand Emissions Trading Scheme (Ministry for the Environment 2007).

For fire management authorities, the evolution of carbon trading and the monetary value placed on the carbon released from burning vegetation places another level of complexity in their fire management duties, both for (uncontrolled) bushfires and (controlled) prescribed fires. That is, while fire is an important ingredient for the regeneration of many Australian vegetative species, the gases released in the process contribute to the greenhouse effect and to total emissions. The Northern Territory State Government, Aboriginal communities in West Arnhem and the Darwin Liquefied Natural Gas (DLNG) plant, however, used the development of carbon trading to their advantage in 2006, making their arrangement the first of its kind in the world (Horstman 2006). Burning the northern Australian savanna early in the dry season while the landscape is still relatively moist has been a traditional practice among Aboriginal people for millennia. This allows the fire to be controlled relatively easily, with fire-breaks being created to prevent large uncontrolled fires burning towards the end of the dry season. With Aborigines moving to towns over the last few decades, however, this is exactly what has been happening (Horstman 2006). Under the arrangement, DLNG provides the Northern Territory Government $1 million per annum for 17 years to fund burning programs early in the dry season when fires are manageable (Barnsley 2009). As a result, Aboriginal people have the funding to conduct burns early in the dry season, which encourages economic and social stimulus in their local communities, and DLNG are able to offset a proportion of the greenhouse gases being emitted by the plant because they are greatly reducing the amount of greenhouse gases being released from uncontrolled fires later in the season (Barnsley 2009).

4.4 Biodiversity – Flora

Bushfires have been a significant factor influencing the distribution and development of much of Australia's vegetation for tens of thousands of years (Attiwill and Leeper 1987). Many Australian species have, in turn, developed a number of mechanisms that not only allow them to survive these events, but may mean the difference between successive generations and the death of a whole community type. The impact of fire itself is very positive; however, there is the potential for adverse long-term impacts if bushfires are introduced to a landscape outside its natural fire regime (see *4.4.2 Fire Regimes)*. Given all the variables that need to be considered when managing a natural landscape and fire within it (whether wild or prescribed), the use of indicator species, scientific research and local knowledge all aid in ensuring that fire is present within a landscape in the most responsible way to ensure maximum overall biodiversity.

Fire's influence on floral species has been studied extensively in all community types around the world. Apart from the numerous articles published in the books recommended in the *Environmental Impacts* section, other papers are highlighted in the sections below. Furthermore, the Bushfire CRC Project B3.1 – Impacts of Fire on Ecological Processes and Biodiversity and a special issue by the International Journal of Wildland Fire, entitled Large Fires and their Ecological Consequences (Volume 17, Issue 6 2008), offer a diverse range of papers that explore a fire's impact on ecological processes.

4.4.1 Fire-Adaptive Plant Mechanisms

The survival and reproduction mechanisms of many vascular Australian plants when exposed to fire can broadly be identified through five techniques: storing seed on the plant, storing seed in the soil, resprouting through lignotuberous buds, resprouting through epicormic buds, or spreading vegetatively through rhizomes. Plant that exhibit the first two are typically classified as seeders and the last three as sprouters. Gill (1981) is a good source of information for full descriptions on these mechanisms, providing numerous examples of Australian plants that fall into each category.

For many species that store their seeds on the plant, severe bushfires are necessary for the opening of their woody fruit and the subsequent release of seeds onto the nutrient-rich ash below. This includes species from such genera as the eucalypts (predominantly from higher-rainfall areas), banksias, hakeas and she-oaks (Attiwill and Leeper 1987). In Alpine Ash and Mountain Ash, for example, crown fires kill the parent tree, but produce an abundance of seedfall onto the ash bed below. The resulting seedlings grow into a dense stand (tens of thousands per hectare), before thinning out over time to produce the next even-aged forest. As a result of this process, Attiwill and Leeper (1987) stated that ash forests are generally referred to by the year of their creation, i.e. the 1939 Ash (after Black Friday) or the 1983 Ash (after Ash Wednesday). This long-standing theory, however, has been questioned by Lindenmayer et al. (2000), who observed multi-aged cohorts of Ash species in an old-growth forest in the Central Highlands of Victoria. Their research demonstrated that fires within these ecosystems could produce enough heat to initiate the regeneration process, but not enough to become a crown fire and kill the older stand (Lindenmayer et al. 2000).

Species may also store their seeds in the soil in a hard seed coat. The heat generated from bushfire softens the seed coat and stimulates germination (Gill 1981). This is a feature of many leguminous pea species (Family Fabaceae), such as the wattles, parrot peas and bush peas (Auld 1996). Seeds are able to lie dormant in the soil for many years before a fire passes over them to stimulate germination.

A common fire-adaptive trait among many Australian tree and shrub species is lignotubers located at the base of the tree just below or above the soil surface. Gill (1981) explains that as well as storing carbohydrates and nutrients, these structures contain numerous buds that resprout in the event that a severe fire kills the above ground vegetation. Common species that possess lignotubers are Mallee eucalypts (Gill 1997), Snow Gums (*E. pauciflora*) and members of the banksia genus.

Epicormic, or dormant, buds are another strategy that allows plants to recover quickly after a severe fire. These buds are located just under the bark and are stimulated in the event fire kills the apical (leading) stem (Attiwill and Leeper 1987), generating a profusion of small branches. Like the dense stand of eucalypt Ash seedlings, these branches thin out over time. The use of epicormic buds is widespread among Stringybark and Box Eucalypts in particular.

The final method of surviving fire is by the use of a rhizome, or underground stem, which sends up new shoots in the event of a fire. This technique is rare among southern species of eucalypts, with Gill (1997) stating that it is mainly used by eucalypts in tropical savanna woodlands. Even though species with resprouting capabilities use these as a means to recover from fire, they generally require the distribution of seeds for the ongoing survival of their species (Gill 1997).

4.4.2 Fire Regimes

Many Australian plants have evolved to respond to varying cycles of fire in the landscape. Gill (1975) proposed the term 'fire regime' to describe the four variables of fire that influence a plant's response, being the fire frequency, intensity, season in which it occurs and type (i.e. ground (including subsurface), surface, crown). The extent (or patchiness) of the fire has also been incorporated into the fire regime (NSW Department of Environment and Climate Change (DECC) 2008). The natural fire regime has changed since the arrival of humans on the Australian landscape, first by Aboriginals and then by European and later settlers, thereby altering the abundance, diversity and structure of vegetation. This section focuses on the impact of fire frequency and intensity on subsequent plant responses. For an overall perspective on the influence of fire regimes, recommended texts include Gill (1975) and the

International Journal of Wildland Fire's special edition (2008, Volume 17, Issue 6). For studies that focus on one aspect of the fire regime, the articles referenced in the following text provide good examples.

The frequency of a bushfire has the power to change whole ecosystem types. For example, Ellis and Pennington (1992) noted that the absence of fire in Alpine Ash forests in the highlands of Tasmania resulted in the death of the eucalypt community and gradual succession to a rainforest in their place, a process taking approximately 90 to 150 years. Conversely, too frequent fires are also successful at changing part or all of an ecosystem type. Ashton and Attiwill (1994) highlighted that fires occurring before some plants reach maturity and are able to set seed are in danger of being eliminated from a site if this is the only means of regeneration for that species (i.e. seeders). This situation was realised for a large area of Alpine Ash and Mountain Ash forests in Victoria's eastern mountainous regions. Fire burnt through approximately 230,000 ha, or 49%, of Victoria's native stands in both the 2003 Alpine Fires and 2006–07 Great Divide Fires (DSE and PV 2008). Since these trees require approximately 20 years to reach reproductive maturity (DSE and PV 2008), the possibility of local extinction in these areas would have been very likely without the reseeding program undertaken by forestry operations (refer to *2.2.3 Forestry*). Even with manual regeneration, the loss of these trees in some areas has far-reaching implications for the resultant ecological values, including for the fauna that rely on these forest types for food, shelter and breeding sites.

Fire line intensity can be described as the rate of heat output per metre (kW/m)[10] and can have a large impact on the relative abundance of plants regenerating from seeds or resprouting from existing plants (Chatto and Tolhurst 2004). Cheney (1981) and Christensen, Recher and Hoare (1981) have described the expected fire behaviour and vegetative responses associated with different fire intensities (Table 5).

Table 5: Expected effects on eucalypt forests of fire of different intensities

Fire intensity (kW/m)	Remarks from Cheney (1981)	Remarks from Christensen, Recher and Hoare (1981) based on a community dominated by leguminous species
<500	Low – maximum flame height of 1.5 m Upper limit recommended for fuel reduction burning	Little tree canopy scorch, but understorey species may be partially or wholly damaged; can expect vegetative regeneration, but little or no seed regeneration
500–1700	Moderate – maximum flame height of 6 m Scorch of complete crown in most forests	Defoliation and death of most understorey species; damage to branchlets of overstorey and some fire scarring on boles of overstorey may occur. Would expect regeneration by both vegetative and seed means
1700–3500	Moderate/High – flame height between 6 and 15 m Scorch of complete crown in most forests, with crown fire in low forest types (<15 m high)	Significant physical damage to bole and crown of trees. Epicormic shoots generally stimulated
3500–7000	High – maximum flame height of 15 m Crown fires in low forests (<15 m high)	Tree canopies defoliated over large areas; understorey woody stems destroyed and mineral soil exposed. Vegetative regeneration may not occur owing to outright death of plants
7000–70,000	Very high – flame heights of greater than 15 m Crown fire in most forest types, with firestorm conditions at the upper fire intensities	Death of almost all above-ground foliage of most species; can cause uprooting and fracturing of trees. Upper reaches of this range are more characteristic of Eucalypt Ash forests

Source: Chatto and Tolhurst 2004, p. 6

10 Fire line intensity (kW/m) $I = H \times w \times R$, where: H = heat yield of the fuel consumed (kJ/kg), w = amount of fuel consumed (kg/m²), R = fire forward rate of spread (m/s) (Chatto and Tolhurst 2004).

The effects of a fire on soil-stored seed germination do not exclusively depend on its intensity, with Christensen, Recher and Hoare (1981) arguing the degree to which seeds are exposed to heat is more influential. During a high-intensity fire, many seeds directly exposed to the heat and flames would die. Members of the pea family that store their seeds in the soil have developed a clever strategy to ensure seed survival by developing a fruit-like appendage (aril) at the base of the seed that is very attractive to ants (and birds). When the seed falls to the ground, ants carry it to their nests to feed on the aril, thereby protecting the discarded seed from the intense heat and allowing it to wait for fire to break its dormancy (Auld 1996). The success of this strategy ultimately depends on the ants, with the depth of the ants' nest and its constituents e.g. soil, within a fallen or standing tree trunk determining the germination potential of each seed (Drake 1981).

4.4.3 Managing Fire in Relation to Maintaining Vegetative Diversity

When Europeans first settled in Australia relatively recently, fire was seen as a destructive force that needed to be prevented or extinguished as fast as possible. Only in the last few decades has there been a greater understanding of the integral relationship between fire and the vegetative (and faunal) diversity of many Australian ecosystems (Gill 1975).

Understanding and restoring natural fire regimes has been recognised as a major component of maintaining healthy environmental ecosystems. State and federal fire authorities carry out many strategies that promote this diversity, such as undertaking planned burns at certain times of the year and monitoring what plants are present before and after a burn (e.g. Cawson and Muir 2008a; Cawson and Muir 2008b), and working closely with scientific institutions (e.g. Bushfire CRC, CSIRO) and with Aboriginal people, who have an intimate understanding of the natural environment.

Managing the impact of fire does not end when it has been extinguished, particularly in the case of severe fires. The complete removal of vegetation, creation of a nutrient-rich ash bed and ample light create a perfect location for weeds to thrive and threaten the regenerating native vegetation. The Victorian Government recognised this risk after the 2003 Alpine Fires (DSE 2005) and 2006–07 Great Divide Fires (DSE and PV 2008) and action was taken to remove infestations as quickly as possible, particularly of blackberries (*Rubus fruticosus* agg.), English Broom (*Cytisus scoparius*) and willows (*Salix* spp.).

No matter how fire is managed in the landscape, the possibility of local or absolute plant extinction is high without government intervention. One plant species that would have become extinct if not for collaborative contingency planning between government agencies and other organisations was the Shiny Nematolepis (*Nematolepis wilsonii*). The only known wild population of this plant, consisting of 500 plants, was totally wiped out in the Yarra Ranges National Park during the 2009 Black Saturday Fires. In 2008, cuttings were taken and cultivated at the Melbourne Royal Botanic Gardens and replanted into the park after these fires (Victorian Bushfire Reconstruction and Recovery Authority 2009). The only other population is found at Melbourne Museum's Forest Gallery (Melbourne Museum 2009).

4.5 Biodiversity – Fauna

As with Australian plants, severe fires can affect animal species both directly and indirectly, through direct contact with fire (i.e. flames, heat, smoke, anoxia) or the indirect effects of increased predation and forced emigration. More importantly, fires are able to change favourable habitat characteristics (e.g. structure, age, density) and the animal's accessibility to shelter, food and breeding sites, both in the short and long term. The response of individuals, populations and whole species to the immediate threat of fire and long-term survival is very complex and relies on numerous factors (Whelan et al. 2002), and as a result, studies have highlighted the difficulty of accurately determining the impact of fire on animal dynamics (Schlesinger, Noble and Weir 1997; Keith, McCaw and Whelan 2002; Whelan et al. 2002).

A vast amount of research has been conducted in this area. Studies that provide a detailed account of the influence of fire on terrestrial fauna dynamics include those by Newsome and Catling (1983) (for kangaroos, wombats, dingos, foxes and cats) and Friend (1993) (for small mammals, reptiles and amphibians in the Mallee region). A study by EPA Victoria (2003) after the 2003 Alpine Fires presents a good summary of the impacts on aquatic fauna. The report by Brown et al. (1998) explores fire's impact on both terrestrial and aquatic fauna in the Australian Alps.

4.5.1 Terrestrial Fauna

Animals use three main strategies to survive a fire: burrowing, avoidance or active use. In the presence of severe fires, these strategies are less likely to work, and the number of animal mortalities can greatly increase. For ground- and litter-dwelling invertebrates, an intense fire that penetrates the soil a few centimetres will have a large impact on immediate losses. For other animals that retreat to burrows, such as wombats (*Vombatus ursinus*), some small mammals, snakes, skinks, lizards and some frogs, Friend (1993) found that the initial survival rate was generally high. Fire severity greatly influences the survival of less mobile animals, such as Ring-tail Possums (*Pseudocheirus peregrinus*) and Koalas (*Phascolarctos cinereus*), which are unable to escape highly intense canopy fires as easily as other animals. In contrast, Whelan et al. (2002) described that for highly mobile animals, such as kangaroos (*Macropus* spp.) and most bird species, even the most intense fire presents little threat to their safety. Some animals are even attracted to the fire by the smoke's odour (smoke flies (*Microsania* spp.)), residual heat (fire beetles), or the presence of other fleeing animals (some mammals and birds) (Shaffer and Laudenslayer 2006). Raptors in particular have been observed in large numbers feasting on the fleeing animals all over the world, these including eagles, kites, vultures and falcons (*Falco* spp.) (Chandler et al. 1983).

The short-term impact of an intense fire greatly depends on its extent, or patchiness, and the animal's mobility, thereby determining the availability of food sources and amount of shelter remaining to conceal animals from predators. Generally, for small reptiles and mammals surviving in areas with very little cover from predators and little food, Friend (1993) stated that short-term post-fire deaths are high, forcing some predators to find alternative sources. Newsome and Catling (1983), for example, found that Dingos (*Canis lupus dingo*) in a reserve on the New South Wales southern coast maintained their pre-fire population by changing their diets from a high proportion of small mammals before the fire to mainly macropods in the 6 to 18 months after the fire. Conversely, the abundance of European Foxes (*Vulpes vulpes*) and European (domestic) Cats (*Felis catus*) abated quickly for approximately one year after the fire, as they continued to prey on small mammals (Newsome and Catling 1983).

The long-term impact of severe fires on terrestrial fauna is greatly dependent on all aspects of the fire regime, i.e. the frequency, intensity, season, type and extent. As discussed in *4.4 Biodiversity – Flora*, these have serious ramifications for the resultant vegetative structure and composition and therefore the diversity of animals within it. For example, arboreal mammals and birds are likely to be severely impacted in the presence of intense and extensive bushfires (Brown et al. 1998), as trees containing suitable hollows for nesting sites are likely to be engulfed in flame, leaving them blackened and unusable. For territorial species such as the Yellow-Bellied Glider (*Petaurus australis*), the move to a new hollow in another area may be difficult if the integrity of trees in their territory is lost (Brown et al. 1998). Alternatively, fires are an important catalyst in the formation of future tree hollows, particularly in wetter forest types. Fire creates wounds in the trunk, which allow decay-causing organisms to enter and begin the hollow-making process (Koch et al. 2008).

The close frequency of the 2003 Alpine Fires and 2006–07 Great Divide Fires caused the local extinction of large areas of Alpine Ash, and may also have contributed to the local extinction of some threatened fauna. DSE and PV (2008) noted that local populations of the Spotted Tree Frog (*Litoria spenceri*) and Long-footed Potoroo (*Potorous longipes*) may not have had adequate time to recover before the next fire. For the Spotted Tree Frog, this threat was further compounded by the season in which the fires occurred. Brown et al. (1998) stated that these frogs are likely to be most vulnerable to intense bushfires during summer if rain follows shortly after, leading to increased sedimentation and nutrient accumulation within the waterways. This transpired in both years, leading to some clear and swift-flowing upland streams (DEWHA 2003) being transformed into muddy, debris-filled sediment slugs.

The existence of Leadbeater's Possum has been put in jeopardy after the 2009 Black Saturday Fires, as their habitat, small pockets of Mountain Ash forests in central Victoria, sustained heavy damage during the fires (Victorian Bushfire Reconstruction and Recovery Authority 2009).

4.5.2 Aquatic Fauna

Unlike terrestrial fauna, aquatic fauna is generally protected during a severe fire by the water. However, its ongoing survival is totally dependent on the environmental circumstances following the fire and the levels of sediments, nutrients and other debris entering through erosive processes, as already discussed.

The increase of sediments entering the water can have multiple effects on stream biota. The initial impact is the rapid reduction in dissolved oxygen levels, which is 'consumed' by bacteria in the stream beds working to break down the sudden influx of ash and organic material (Nelson and Milligan 2003). In addition, fine particles become lodged in the gills of aquatic species and reduce their ability to take in oxygen (EPA Victoria 2006). During the 2003 Alpine Fires, EPA Victoria (2004) recorded dissolved oxygen concentrations of almost zero during the peak of a large sediment slug over a day, resulting in numerous fish deaths and even driving crayfish to escape from the water. In another 2003 fires study, EPA Victoria (2003) measured the effect of a large sediment slug on macroinvertebrate (e.g. insects, worms and snails) populations. The short-term impacts were considerable, with the number of macroinvertebrate families dropping from approximately 24 in autumn 2002 to 6 one month after the fire. This was attributed to low oxygen levels, the smothering of rock and gravel crevices and the scouring of stream beds associated with moderate to fast currents (EPA Victoria 2003).

Increased nutrient levels (eutrophication) also have the potential to alter stream diversity and abundance. The higher levels of nitrogen and phosphorus combined with greater light penetration can lead to excessive algal and plant growth. While growing, some species of blue-green algae are a risk to all animals (including humans) owing to the toxins they produce, with Whittington (1999) noting that this could possibly lead to damage of the liver and neurological system, and in severe cases death. The subsequent overgrowth of algae can then lead to the algae's demise, as the available sunlight is reduced. Decomposing algal blooms are often associated with fish deaths, as they require large amounts of oxygen to decompose. If the problem persists, there may be a simplification in the ecosystem from the loss of biodiversity (EPA Western Australia 2007).

The medium- to long-term effect of fires are not generally damaging, with waterway conditions returning to pre-fire levels within 5 to 20 years depending on the fire's severity (Nelson and Milligan 2003). The time needed for recovery was shown to be shorter than five years for a number of stream and rivers studied after the 2003 Alpine Fires by EPA Victoria (2006), with only one of 13 sites continuing to be impacted three years after the fires. Freudenberger and Norris (2005) demonstrated that one important positive outcome of a severe fire was the addition of structural complexity. The accumulation of rocks and falling of trees over the water provides important breeding habitat for a range of aquatic fauna and living spaces for macroinvertebrates once the sediment has been flushed out of the water.

As with plants, both terrestrial and aquatic fauna have evolved to live with fire. Severe fires themselves should not been seen as a catastrophic force in terms of short-term animal mortality, but as a long-term opportunity to increase vegetative diversity and promote habitat diversity. It is when unfavourable fire regimes burn through a landscape that animal diversity and abundance are threatened to the point of local or absolute extinction.

Five: Conclusion

Severe bushfires are an inevitable event in many parts of Australia's landscape, producing countless economic, social and environmental impacts. The Ministerial Taskforce on Bushfire Recovery's 2003, 2006 and 2007 reports and the Victorian Bushfire Reconstruction and Recovery Authority 2009 report contained much information about economic impacts. Direct impacts on the economy include the loss of agricultural products and equipment and the loss of timber from plantations and natural forests. Even when bushfires are for the most part contained within the bush (e.g. 2003 Alpine Fire, 2006 Mount Lubra (Grampians) Fire, 2006–07 Great Divide Fire) the research presented in this review highlights the large economic impacts experienced by those towns close to but physically unaffected by fire (tourists staying away, loss in retail business, transport disruptions). Furthermore, towns and cities well outside the immediate bushfire zone were also subjected to downturns in their economy, whether it be, for example, from flames or smoke cutting off the power supply to Melbourne and causing large-scale disruptions or smoke taint in grapes.

Available research into the social impacts of a severe bushfire is thorough. Studies by EMA (2002) and Gordon (2004) show that when directly threatened with a bushfire, the community goes through a series of defined stages throughout the response and recovery phases that see people 'debond' and then be brought back together. Experiments by McFarlane (1988) and Regehr et al. (2003) have demonstrated that firefighters are not immune from the experiences they face, with McFarlane (1988) in particular describing the psychological disorders some firefighters developed after the 1983 Ash Wednesday Fires. An individual's health, whether physical or mental, is an important aspect to consider. The levels of smoke in the air during a fire and its consequences on people's health (especially asthma) are represented in research relating the number of extra hospital admissions due to high levels of smoke (e.g. Johnston et al. (2002). The psychological and emotional impacts on people defending their home from a fire, escaping it or knowing that a loved one is in direct danger can have significant short and long terms outcomes. A large amount of literature on this issue is available relating to the 1983 Ash Wednesday Fires, with McFarlane (1986) and Clayer, Bookless-Pratz and McFarlane (1985) providing detailed accounts of people's adverse reactions to this event. The last social impact reviewed, Cultural Heritage, had very little literature dedicated to it. ICOMOS (2002) offers a solid foundation for understanding the meaning and ideas behind cultural heritage, and Freslov (2004) gave a detailed account of Aboriginal cultural heritage destroyed during the 2003 Alpine Fires, which Freslov (2004) concluded to be very little. Freslov (2004) also noted that there were some positive outcomes, with the fire allowing new artefacts and sites to be discovered and recorded. Destruction of European cultural heritage assets proved to be much more extensive, with the Ministerial Taskforce on Bushfire Recovery (2003) reporting on the damage after the 2003 Alpine Fires and DSE and PV (2008) after the 2006–07 Great Divide Fires.

The environmental impacts of severe bushfires are an area in which there is a great deal of knowledge, with several books describing the impact of Australian bushfires on a wide range of ecological components (e.g. Bradstock, Williams and Gill 2002; Gill, Groves and Noble 1981; Victorian National Parks Service 1996). Fire impacts on soil in two ways, firstly by changing the soil's biological, chemical and physical properties (Walker, Raison and Khanna 1986) and sending soil nutrients into the atmosphere, and secondly by leaving the bare soil vulnerable to erosive processes of water and wind. If rain falls shortly after a bushfire, then ash, sediment and larger debris are likely to be washed into streams, rivers or lakes. The impact on water bodies depends on other factors, however, such as a soil's hydrophobic properties, steepness of slope and the intensity of rainfall on burnt ground, as demonstrated by Prosser and Williams in their experiment (1998), after the 1983 Ash Wednesday Fires (Leitch, Flinn and van de Graaff 1983) and after the 2006–07 Great Divide Fires (Ministerial Taskforce on Bushfire Recovery 2007). In the event a severe bushfire burns through most of a catchment, Kuczera (1987) predicted that its water yield may be greatly reduced for up to 150 years, with Feikema, Lane and Sherwin (2008) using computer modelling to predict losses in water yield under a variety of bushfire conditions. Air contamination by nutrients, gases and particles from both soil and vegetation burning is an area receiving much attention owing to its links to the enhanced greenhouse effect, with government schemes being put in place to try and reduce the amount of greenhouse gases being produced.

Reviewing the impact of fire on vegetative species has demonstrated that many Australian plants require fire for regeneration and have developed a range of adaptive mechanisms that take advantage of it; the study by Gill (1981) provides detailed information on this subject. Although many plants require fire for ongoing survival, inappropriate fire regimes can risk this, as demonstrated by DSE and PV (2008) and Ellis and Pennington (1992). The impact of severe bushfires on fauna is diverse, with the capacity of animals to escape the fire generally determining their fate. For small (e.g. reptiles, small mammals) or highly mobile (e.g. kangaroos, birds) animals, Friend (1993) and Whelan et al. (2002) found that survival rates were generally high immediately after a fire. These then varied in the months following a fire, with Newsome and Catling (1983) demonstrating that smaller mammals were heavily preyed upon by larger ones. EPA Victoria (2003, 2004, 2006) conducted a range of experiments on aquatic fauna after the 2003 Alpine Fires and concluded that while mortalities were low during the fire, storms shortly after the fire made the water uninhabitable for fish and other aquatic species. The medium- to long-term effects on aquatic animals are not generally damaging, with EPA Victoria (2006) finding that stream health had returned to pre-fire levels within three years of the fire.

The information presented in this review offers readers an idea of the range of economic, social and environmental impacts a severe bushfire can have. While not exhaustive, the range of impacts described here can have both short- and long-term implications and these are likely to be felt well beyond the boundaries of the fire. Even though bushfires have the potential to be destructive, the actions we take to mitigate, prepare and respond to severe bushfires will ultimately determine the level of severity and the degree of recovery from all three impact types.

Six: Appendices

Appendix 1: Brief Overview of Each Fire

The five fires studied were chosen because they are significant in south-eastern Australia's fire history. They caused widespread destruction, leading to numerous economic, social and environmental impacts.

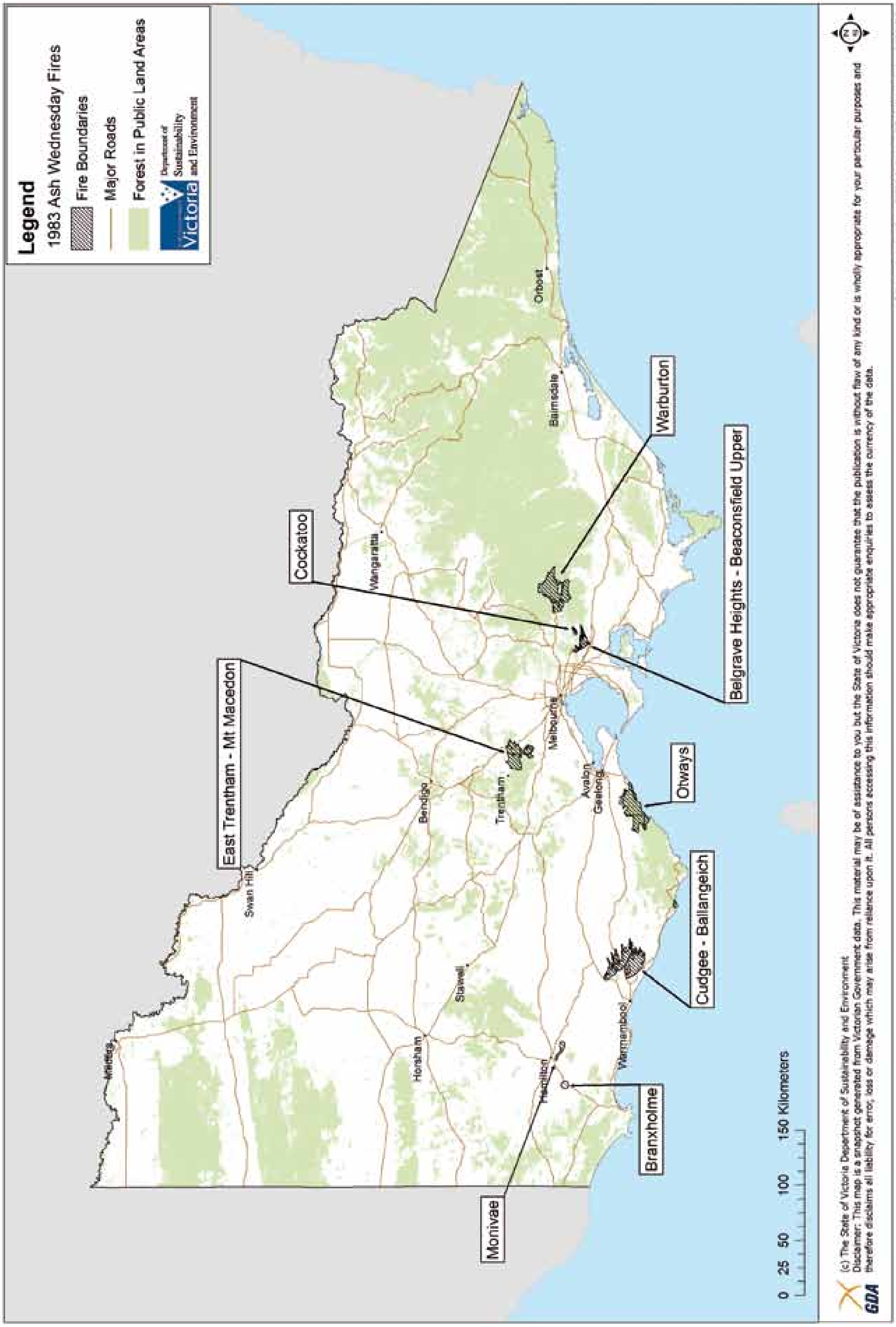
1983 Ash Wednesday Fires

Prolonged drought, less than 60% average rainfall in the six months leading up to February 1983 and three days of 40°C and over in February 1983 meant that the land was extremely susceptible to fire during the 1982–83 season (Rawson, Billing and Duncan 1983). On 16 February, which came to be known as Ash Wednesday, the conditions were just as severe. Temperatures were over 40°C for much of Victoria, the relative humidity was very low (below 10% at Melbourne Airport) and winds were strong (Oliver, Britton and James 1984).

A total of 180 fires were attended by the CFA on this day alone, with a CFA report (1983) highlighting eight as being of major significance. The CFA (1983) could not identify the cause for half of the fires, and suspected sparks from power lines for ignition of the other half. Once a fire had begun, it was very hard to bring under control. In total, approximately 180,000 ha were burnt from fires beginning on Ash Wednesday, with 47 Victorians (including 12 CFA volunteers and 1 casual firefighter) losing their lives (CFA 1983). Other impacts include the loss of around 2,100 homes, 20,000 sheep, 9,000 cattle and 2,300 ha of soft- and hardwood plantations (CFA 2003).

A map illustrating the locations of the Ash Wednesday Fires, as well as other large bushfires from the 1982–83 season, is shown in Figure 4. Those fires labelled with a box are the eight fires described in the CFA (1983) report.

Figure 4: Area burnt by the1983 Ash Wednesday Fires (DSE 2010)



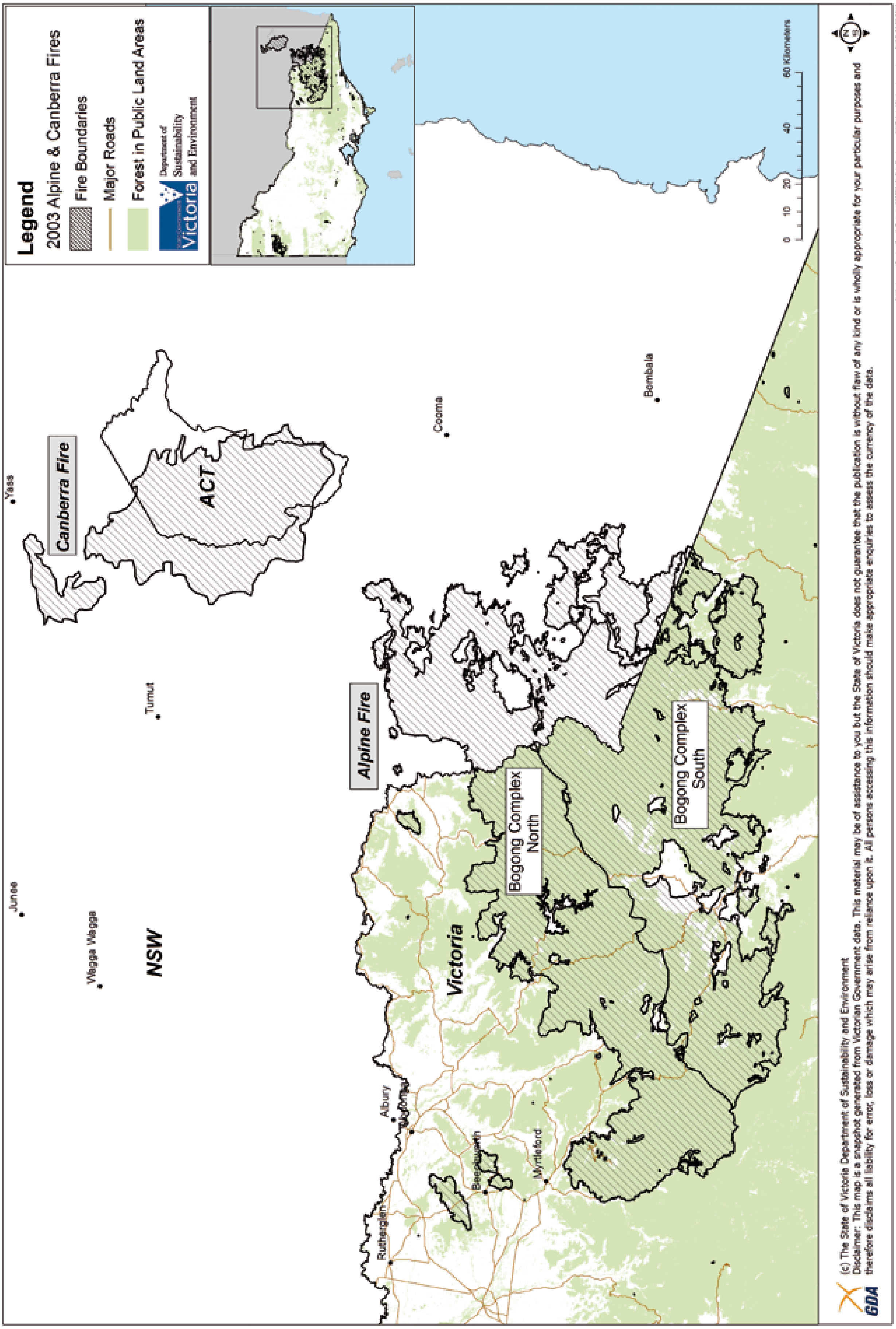
2003 Alpine Fires

Over 95% of Australia experienced below-average rainfall in the period of March to December 2002, and in Victoria, the highest seasonal mean maximum temperature was recorded for autumn, winter and spring (Sullivan 2004). Fires were ignited by a series of lightning strikes on the evening of 7 January and on 8 January. These strikes were created when a cold front and associated pre-frontal trough passed over south-eastern Australia, forming upper-level thunderstorms as the front passed over the Alpine region (Sullivan 2004). As a result, 87 fires were ignited in Victoria, and more than 40 in NSW and the Australian Capital Territory (ACT) (DSE 2005). Firefighters moved quickly to extinguish the fires; however, the large number of ignitions and difficult terrain meant that in Victoria, nine fires could not be brought under control and spread quickly, eventually merging to burn through approximately 1.1 million ha in 59 days (Sullivan 2004). For operational and administrative purposes, the Victorian Alpine Fires were divided into two complexes of approximately equal size: Bogong Complex North and Bogong Complex South (Figure 5).Fires ignited by the same thunderstorms also burned through approximately 600,000 ha of NSW vegetation and 160,000 ha of rural land, plantation forests and residential areas in the ACT (Canberra Fires) (Sullivan 2004) (Figure 5).

Five people died during the Alpine and Canberra Fires. A firefighter drowned during a flash flood in Victoria (DSE 2005), and four Canberra residents could not escape the fire when it raced into the outer suburbs on 18 January 2003 (McLeod 2003). The impacts to buildings and infrastructure were high in the ACT, in which approximately 800 homes and other buildings were either destroyed or damaged (McLeod 2003). Mount Stromlo Observatory, located in the hills overlooking Canberra, also suffered losses of great cultural significance, including six historically significant telescopes, the oldest of which dated back to 1911 (Orchiston 2003).

For Victoria and NSW, the fire was mainly restricted to the Alpine forests and grasslands. A DSE report (2005) highlighted that 60% of the Alpine National Park and 81% of the Mount Buffalo National Park were burnt to some degree. These impacts had large implications for the tourism industry and associated retail and accommodation industries.

Figure 5: Area burnt by the 2003 Alpine and Canberra Fires (DSE 2010)



2005–06 Grampians Fires

The Deep Lead Fire and Mount Lubra Fire were included in the Grampians Fires. The Deep Lead Fire primarily caused agricultural impacts, while the Mount Lubra Fire caused significant agricultural and natural vegetation losses. The Deep Lead Fire was detected from a fire tower at 1644 hrs on 31 December 2005 (Smith 2006). It was caused by lightning on private property, and with temperatures around 43°C, a relative humidity of 10% and a NNW wind of 65 km/hr, it expanded quickly (Smith 2006). By the time it was contained 49 hours later, it had burnt through approximately 7,500 ha of state forest and 6,100 ha of farmland (Figure 6). Eleven homes were also lost (Fleming et al. 2007).

The Mount Lubra Fire had already grown to 10 ha when spotted at 0745 hrs on 20 January 2006 inside the Grampians National Park (Fleming et al. 2007). It was assumed to have started at approximately 2300 hrs the previous night by lightning (Smith 2006). Steep terrain, extreme weather conditions, continually changing wind directions and short-distance fire spotting made it exceptionally difficult to contain the fire (Fleming et al. 2007). By the time it was contained on 3 February, it had burnt approximately 85,000 ha of the Grampians National Park and 45,000 ha of farmland (Figure 6) (Fleming et al. 2007). Losses were high, with two people dying while attempting to flee the fire in their car. As the fire burnt through 47% of the Grampians National Park, tourism was significantly affected. Agricultural losses were also high, with around 63,100 livestock (mostly sheep) killed, 2500 hives lost and 10,300 tonnes of hay destroyed (Fleming et al. 2007).

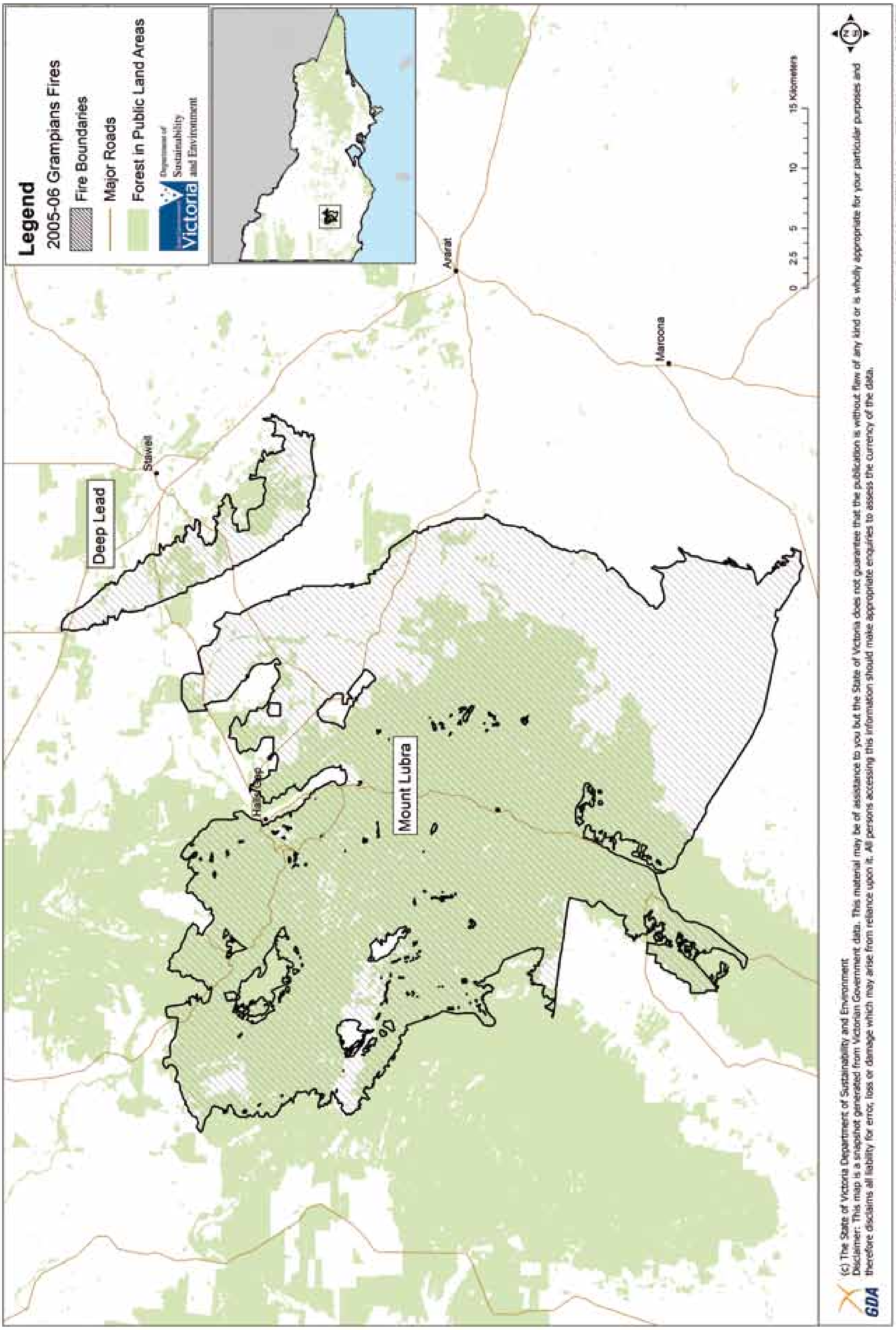


Figure 6: Area burnt by the 2005 Deep Lead and 2006 Mount Lubra Fires (DSE 2010)

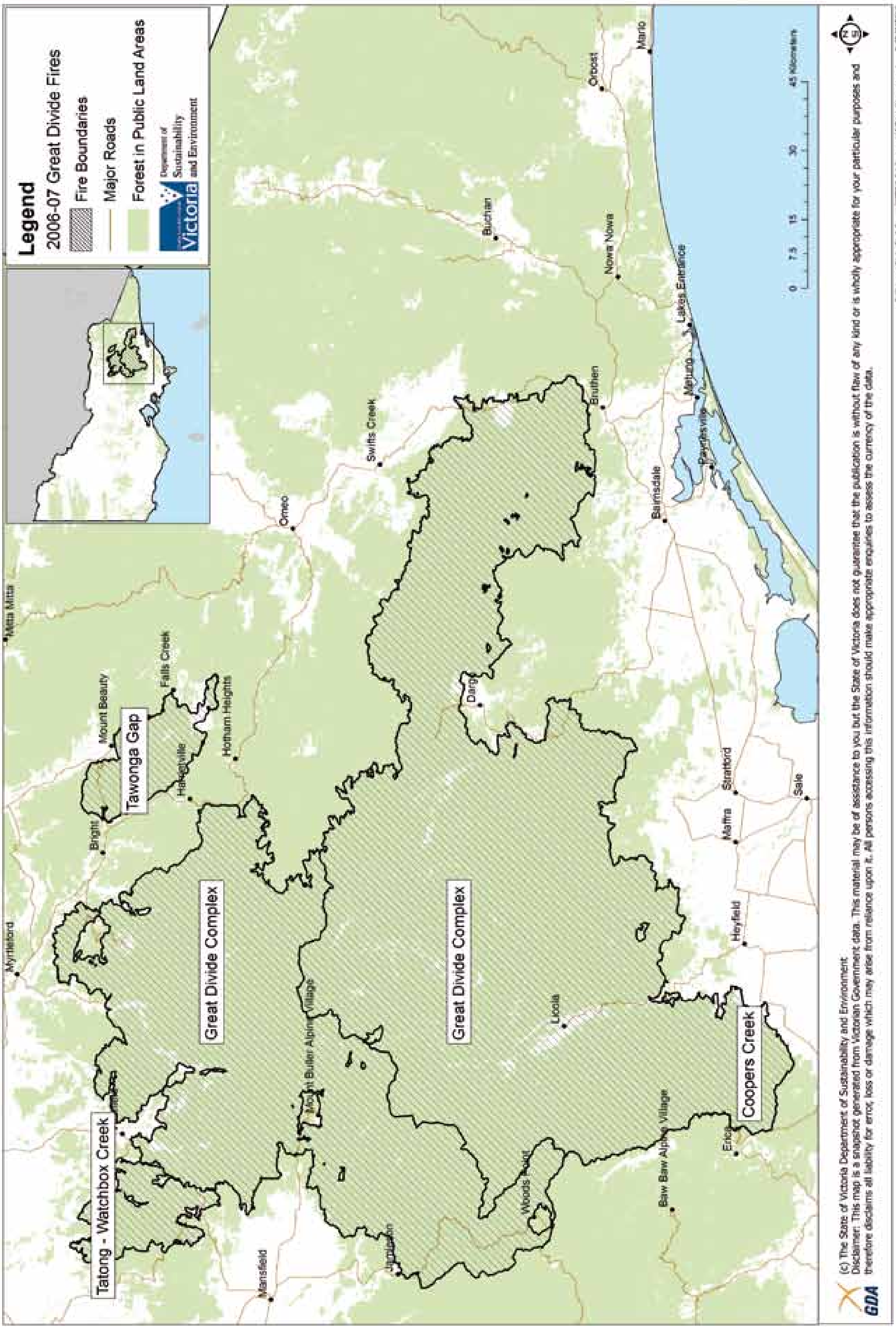
2006–07 Great Divide Fires

Like the 2003 Alpine and Canberra Fires, the 2006–07 Great Divide Fires were started by a series of dry lightning strikes from a thunderstorm passing over the Alpine area of Victoria on 1 December 2006 (Flinn, Wareing and Wadsley 2008). As a result, 70 separate fires were confirmed as going in extremely dry vegetation (Smith 2007). While many were extinguished quickly, some grew continually and eventually merged to become the Great Divide Complex North and Great Divide Complex South Fires. In addition, three other fires ignited within the Alpine area at later stages became part of the Great Divide Fires. The first was the Tawonga Gap Fire, which started on 10 December and was suspected to have been deliberately lit. Extensive fire suppression activities were used to contain the fire and stop it from merging with the large Complex Fires, as towns such as Mount Beauty, Falls Creek and Bogong Village were under threat. It was eventually contained on 27 December (Flinn, Wareing and Wadsley 2008). Another fire that was suspected of being deliberately lit was the Coopers Creek Fire, which started on 14 December. Extreme weather conditions and changing winds meant that this fire spread quickly and went on to destroy large areas of agricultural land and assets. This fire merged with the Great Divide Complex South Fire on 6 January (Flinn, Wareing and Wadsley 2008). The Tatong–Watchbox Creek Fire began on 11 January from lightning. Under extreme fire weather conditions, it spread quickly, growing to approximately 6,000 ha in the first 12 hours (Flinn, Wareing and Wadsley 2008). Like the Coopers Creek Fire, this fire merged with the main complex fires (Flinn, Wareing and Wadsley 2008).

The total area burnt was just over 1.1 million hectares in 69 days (Figure 7).Tragically, a CFA volunteer was killed in a motor vehicle accident while trying to help a Seaton property owner defend his property in the Coopers Creek Fire (Flinn, Wareing and Wadsley 2008). Even though the fires threatened many towns and agricultural properties, losses to the immediate area were relatively low. This was attributed to some breaks in the extreme weather that the firefighters could take advantage of and the tireless efforts of the DSE and CFA.

One major indirect impact was the tripping of the key powerline connecting Victoria to NSW when fire entered the easement on 16 January during the Tatong–Watchbox Creek Fire (The Nous Group 2007). As a result, large areas of Victoria, including Melbourne, lost supply for up to 4.5 hours. In total, 685,000 residential, commercial and industrial customers lost power. Problems were further exacerbated because it occurred at 1600 hrs on a weekday, leaving 175,000 peak-hour train commuters stranded as a result of delays and cancellations (The Nous Group 2007). Although the fire was too intense for firefighters to control on this occasion, they successfully prevented the fire from entering the Victorian Thompson Dam catchment. Recognising the impacts on Melbourne's long-term water supply if the fire did enter this catchment, i.e. more then 250 years in the worst-case scenario (assuming 100% tree mortality in the catchment) (Feikema, Lane and Sherwin 2008), fire personnel constructed a 107-km control line using backburning operations and bulldozers between the fire and the catchment (Flinn, Wareing and Wadsley 2008).

Figure 7: Area burnt by the 2006–07Great Divide Fires (DSE 2010)



2009 Black Saturday Fires

The weather during January and February 2009 was extreme. Even though many parts of Victoria experienced near-average to above-average rainfall during the last three months of 2008, January 2009 was characterised by below-average to record-low rainfall (Teague, McLeod and Pascoe 2009). Making the landscape even more conducive to fires was the onset during the last week of January of the most severe, prolonged heat-waves in south-eastern Australia's history (Teague, McLeod and Pascoe 2009). A new record was set in Melbourne with three consecutive days over 43°C (Teague, McLeod and Pascoe 2009).

In the days leading up to Black Saturday (7 February 2009), fire activity was very high. The Delburn Complex fire began on 29 January (Figure 8), burning 30 homes and approximately 6,500 ha of forested and agricultural land before being contained on 3 February (A. Haywood, Policy Officer, Land and Fire Management Division, Department of Sustainability and Environment, Victoria, pers. comm. 2009). One day later, the Bunyip Ridge Track Fire began in the Bunyip State Park. This fire could not be contained before 7 February, sweeping through the forest into cleared land and heading for the towns of Bunyip, Drouin and Warragul (Teague, McLeod and Pascoe 2009). This fire was largely controlled by the night of 7 February, and by the time it was contained on 4 March (A. Haywood, pers. comm. 2009), 26,500 ha of forested and agricultural land (including a large amount of stock, pasture and feed) had been destroyed (DSE 2009, Victorian February 2009 Fire Severity Area Statements, unpub.[11]).

Much hardship had already been felt throughout many communities this fire season; however, Saturday 7 February 2009, 173 people lost their lives in what will forever be known as Black Saturday (Franklin 2009). Hundreds of fires were reported to fire authorities on this day, with the CFA recording 592 grass and bushfires (Teague, McLeod and Pascoe 2009). Many of these were extinguished or brought under control while still small, but some became major fires, causing widespread destruction and chaos that directly impacted on 78 communities and left entire towns unrecognisable (DSE 1996). The major fires beginning on 7 February studied in this assessment were (in order of when they were reported to authorities and using the fire names recorded by DSE) the Kilmore East–Kinglake Complex, Horsham–Remlaw Road, Coleraine–Glenelg Highway, Weerite–Danedite Road, Churchill–Jeeralang, Murrindindi Mill–Marysville Complex, Redesdale–Coliban Park Road, Maiden Gully–Bracewell Street (Bendigo) and Beechworth–Murmungee Fires. The locations of these fires are shown in Figure 8.

The Kilmore East–Kinglake Complex and Murrindindi Mill–Marysville Complex were the most destructive by all measures (Figure 9). One hundred and twenty-one people died in the Kilmore East–Kinglake Complex. In addition, 1,244 homes, many other buildings, including community centres, schools, shops and emergency facilities, and hundreds of farms and their infrastructure and stock were destroyed (Teague, McLeod and Pascoe 2009). The total area burnt was 86,500 ha (DSE 2009, Victorian February 2009 Fire Severity Area Statements, unpub.). During the Murrindindi Mill–Marysville Complex, there were 38 fatalities, with an ACT firefighter also losing his life on 17 February from a falling tree branch (Teague, McLeod and Pascoe 2009). Again, many hundreds of buildings and farms were destroyed, including 590 homes. In all, approximately 171,600 ha were burnt (DSE 2009, Victorian February 2009 Fire Severity Area Statements, unpub.).

While authorities were still battling these fires, another large fire was started by lightning on 8 February on the western side of Wilsons Promontory National Park (PV 2010a). As the fire could not be easily accessed by fire crews and there was a chance of winds bringing the fire to a major holiday destination, all campers at Tidal River (camping grounds on the east side of the Promontory) were evacuated on 9 February (ABC News 2009). The fire was difficult to control, but was eventually contained on 14 February. It had burnt through 24,500 ha (DSE 2009, Victorian February 2009 Fire Severity Area Statements, unpub.), or almost 50% of the park, and came very close to Tidal River in the process (PV 2010b).

Overall, these fires burnt approximately 388,000 ha (DSE 2009, Victorian February 2009 Fire Severity Area Statements, unpub.). A majority of the fires were not declared safe until March and April, with the Bunyip Ridge Track Fire and Kilmore East–Kinglake Complex the last to be declared safe on 15 May 2009 (A. Haywood, pers. comm. 2009).

11 This document is believed to give the most accurate area for each fire, as it used post-fire aerial imagery interpretation to map the exact boundary.

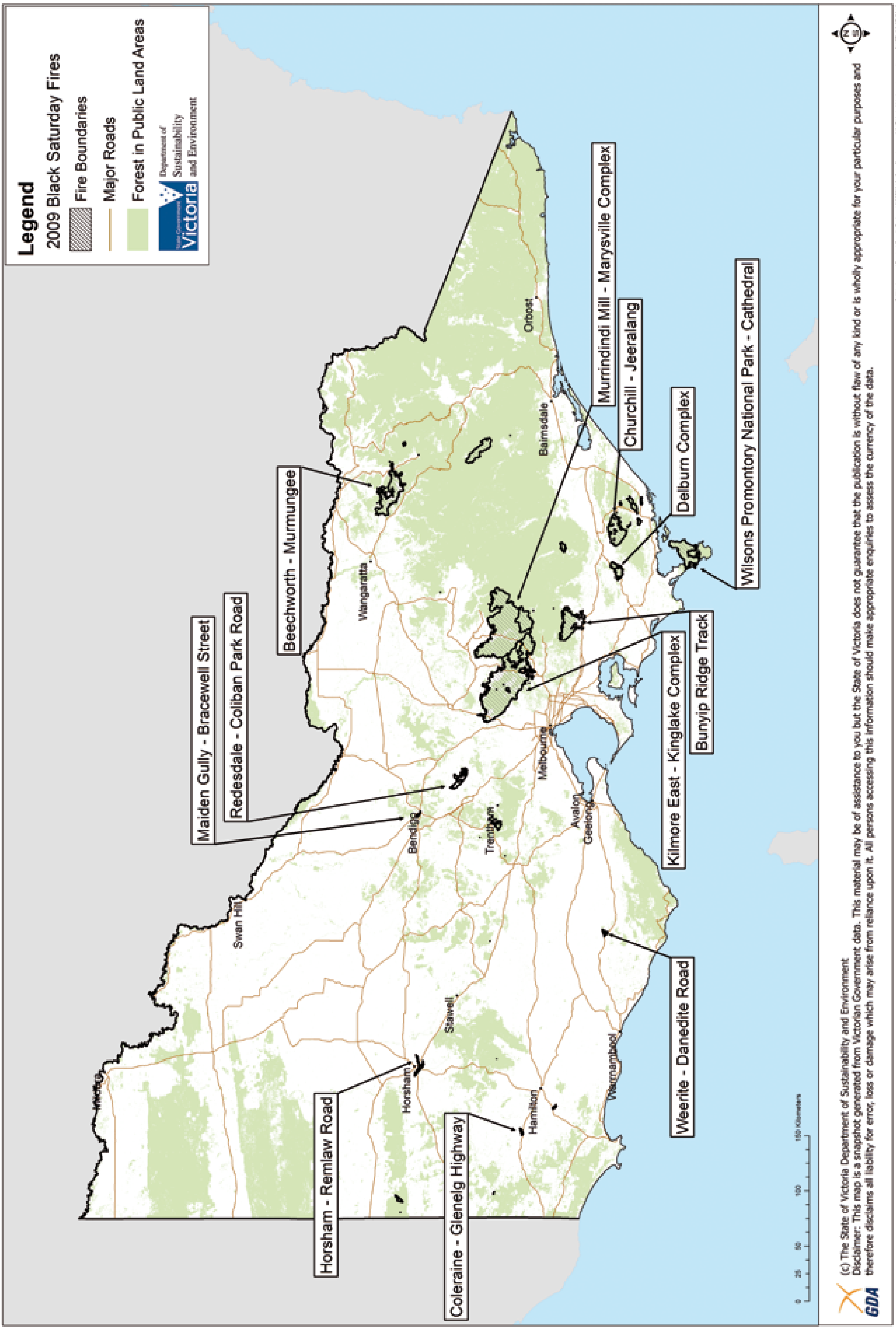
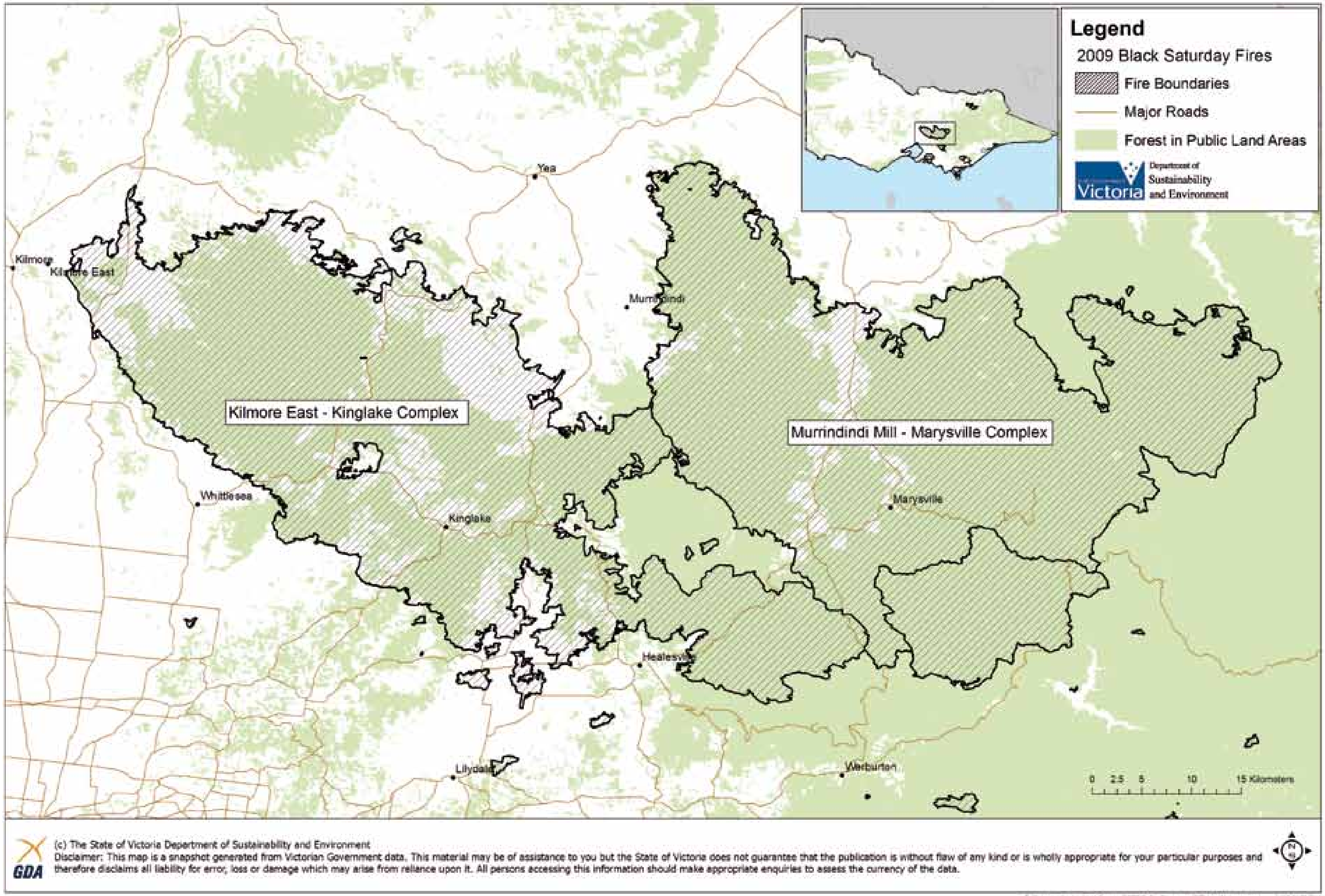


Figure 8: Area burnt by the 2009 Black Saturday Fires (DSE 2010)

Figure 9: Area burnt by the Kilmore East–Kinglake and Murrindindi Mill–Marysville Complexes (DSE 2010)



Appendix 2: Methods for Estimating Ecosystem Service Values

Table 6 highlights some of the methods used to find the financial values of environmental impacts (Pagiola, von Ritter and Bishop 2004, p. 11). The first five methods are known as revealed preference methods because they use data from related markets to estimate the value. The last two are known as stated preference methods, as they use questionnaires to value changes in environmental quality and are the only method that can be used to estimate non-use (i.e. existence) values (Morrison, In press). Morrison (In press) also discusses a number of these methods within the specific context of bushfire management.

Table 6: Summary of methods commonly used to estimate ecosystem service values

Method	Approach	Data requirements	Applications	Limitations
Travel Cost Method *	Derive demand curve from data on actual travel costs	Survey to collect monetary and time costs of travel to destination, distance travelled	Recreation	Limited to recreational benefits; hard to use when trips are to multiple destinations
Hedonic Price Method	Extract effect of environmental factors on price of goods that include those factors	Prices and characteristics of goods	Air quality, scenic beauty, cultural benefits	Requires vast quantities of data; very sensitive to specification
Production Function (also known as Change in Productivity)	Trace impact of change in ecosystem services on produced goods	Change in service; impact on production; net value of produced goods	Any impact that affects produced goods	Data on change in service and consequent impact on production often lacking
Replacement Cost (and variants such as Relocation Cost)	Use cost of replacing the lost good or service	Extent of loss of goods or services, cost of replacing them	Any loss of goods or services	Tends to overestimate actual value; should be used with caution
Cost of Illness, Human Capital	Trace impact of change in ecosystem services on morbidity and mortality	Change in service; impact on health (dose–response functions); cost of illness or value of life	Any impact that affects health (e.g. air or water pollution)	Dose–response functions linking environmental conditions to health often lacking; underestimates, as omits preferences for health; value of life cannot be estimated easily
Contingent Valuation Method	Ask respondents directly their willingness to pay for a specified service	Survey that presents scenario and elicits willingness to pay for specified service	Any service (including environmental hazards)	Many potential sources of bias in responses; guidelines exist for reliable application
Choice Modelling	Ask respondents to choose their preferred option from a set of alternatives with particular attributes	Survey of respondents	Any service (including environmental hazards)	Similar to the contingent valuation method; analysis of the data generated is complex

* Morrison (In press) further divides the Travel Cost Method into the Zonal, Individual and Random Utility.

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