PRESCRIBED BURNING IN SOUTH AUSTRALIA

Department of
Environment and
Natural Resources

Government of South Australia

PREPARE. ACT. SURVIVE. BUSHFIRE READY

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Summary

A set of interim burning prescriptions was compiled in 2002 as a result of a recommendation from the operational review of the Messent Conservation Park prescribed fire. The interim burning prescriptions were to be tested and validated in the field over time.

In 2010, the South Australian Department of Environment and Natural Resources initiated and conducted a review of the prescriptions for prescribed burning in South Australia.

Prescribed burning is the deliberate and safe application of fire under specified environmental conditions in a designated area for the purposes of fuel reduction objectives, ecological management objectives and/or woody weed management objectives.

The operational prescriptions are a guideline for conducting a prescribed burn safely and achieving the desired objectives. Specific fire prescriptions are based on the factors that influence fire behaviour: weather and fuel characteristics.

The revised prescriptions presented in this report aim to enhance the ability of fire management staff to conduct prescribed burning and achieve fire management objectives while also ensuring the burning is performed safely and the risks of adverse outcomes are minimised. This revision of the prescribed burning prescriptions has been based on an assessment of data on fuels, weather and fires, as well as information from scientific publications and other relevant documents.

The major changes in these revised prescriptions are the incorporation of fuel hazard rating and the linking of clearly defined objectives with measurable outcomes.

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1. Introduction

Fire should not be regarded as unnatural or catastrophic, but rather as a recurring event that influences the nature of the Australian landscape and the adaptations of its flora and fauna. The application of fire therefore offers enormous potential as a land management tool. The use of prescribed fire is one of a range of practices available to land managers for the manipulation of vegetation. This document summarises and explains the operational prescriptions knowledge underpinning the use of prescribed burning in South Australia.

Fire is a fundamental aspect of the Australian environment, with many vegetation types requiring periodic fire to maintain ecological values. However, not all fires are desirable. Fires may occur under conditions that threaten human life and property, be too frequent or intense, and cause temporary reductions to air quality and/or disruptions to the public.

Prescribed burning is an important tool in reducing adverse impacts to human values, but is not a panacea for all fire management problems. Prescribed burning can decrease bushfire risk by reducing fuel hazard; however this is not the only tool to reduce fuels. Furthermore, prescribed burning can enhance ecological management by increasing fire regime variability. However, it needs to be performed in conjunction with a wide range of risk management strategies including public education; management of the level of fuel hazard in areas adjacent to planned burns, especially where there are fire sensitive assets (including on both private and public land); effective training of personnel and resourcing of bushfire suppression; and the appropriate management of ecological values.

The use of operational prescriptions for prescribed burning activities should be undertaken by experienced and trained staff to ensure the safety of the community and fire crew as well as minimising the risk of fire escapes. It is essential for landholders looking to undertake prescribed burning operations to seek advice and guidance from the Department of Environment and Natural Resources, South Australian Country Fire Service, SA Water and/or Forestry SA.

The attached glossary covers the prescribed burning terminology used in this document.

2. Fire and the environment

Fire is a fundamental aspect of the Australian environment. It occurs in different vegetation types at different intervals and seasons with different intensities; it may burn above ground only or consume peat as well. In short, Australian plants and animals (biodiversity) are adapted to particular fire regimes – that is, the history of fires at any one place (Gill 2008). If fire regimes occur outside the domain to which they are adapted, extinction will occur. In contemporary landscapes, there are social and economic assets as well as environmental assets to be taken into account. These assets can be quite sensitive to fires, particularly fires of high intensity. If we can control fire intensity, we can reduce the risk to social and economic assets in particular: prescribed fire is one way of addressing this.

Prescribed burning is not without its limitations with respect to all types of assets – social, environmental and economic. Prescribed burning regimes are not the solution to all problems. There will be choices to be made by individuals, agencies and policy makers.

The last decade has seen several major bushfires in southern Australia, including the 2003 Canberra and alpine fires in New South Wales, ACT and Victoria, the 2005 Wangary fire on Eyre Peninsula in South Australia, the 2006/07 Great Divide fires in Victoria and the February 2009 fires in Victoria (VBRC 2010a). Projections for climate change suggest increases in the number and intensity of days of extreme fire danger across south-eastern South Australia (see Lucas *et al*. 2007).

Prescribed burning will not prevent all bushfires. If (or when) bushfires occur under extreme fire danger conditions, fires typically sustain burning (although with lower rates of spread, intensity and spot fire occurrence) even in recently prescribed burnt areas. This means that if fuel reduction has not been performed immediately adjacent to social, economic and environmental assets there is a high risk of adverse outcomes regardless of the amount of prescribed burning that is performed.

In the period from 1980 to 2001, levels of prescribed burning conducted in South Australia (particularly in growing areas of urban expansion) were low. This has resulted in many areas being long unburnt and at higher levels of fuel accumulation. The high proportion of areas in late successional stages leaves few areas of early stages in the landscape. Since 2004 the South Australian Government has increased the amount of prescribed burning performed and increased the level of bushfire suppression capacity. The amount of prescribed burning is proposed to increase to meet the major findings from the 2009 Victorian Bushfires Royal Commission (see VBRC 2010a).

Enhanced application and implementation of fire management in general, and prescribed burning specifically, is required if land management agencies and authorities are to address these issues. This enhanced fire management will require high level inter-agency cooperation as well as public education; improved understandings of the interactions between social, economic and environmental asset protection; community aspirations; fire management planning; fire risk assessment; fire behaviour and suppression; and the ecological management of fire prone areas.

In vegetation adapted to periodic fire (which includes most Australian native vegetation) the interactions between vegetation, fuel and fire occurrence cannot be ignored. In these vegetation types fuel hazard, fuel continuity and fuel load, rapidly increase to a maximum level, resulting in increased fire intensities. This increased flammability means that when ignitions occur, fires are typically high intensity and fast moving resulting in the potential to burn larger areas; increase the threat to social, economic and environmental assets; cause deaths and injuries; and leave few areas unburnt.

Therefore, in consultation with fire and land managers the community needs to make informed decisions as to the type of fire regime desired: a mixed regime of prescribed burning and some periodic bushfires, versus a regime dominated by infrequent, mostly high to extreme intensity bushfires. It is estimated that the immediate financial losses of the 1983 Ash Wednesday bushfire cost in excess of $200 million (Healey 1985). However, while the costs associated with such decisions will be significant and recurring, prescribed burning can be a cost effective way to reduce fuel loads and modify fuel structure compared to the alternative of unmanaged bushfires. This is especially the situation regarding threats to human life and property, as well as potentially adverse impacts to biodiversity from large-scale bushfires. The revised and updated prescriptions for prescribed burning developed by this review will form one aspect of this improved fire management.

The information in this review relies heavily on the Tasmanian review of prescribed burning (Marsden-Smedley 2009) with additional supporting information from literature.

3. Prescriptions for prescribed burning in South Australia

This review aims to revise and update the prescriptions used previously for performing prescribed burning in South Australia. The review is based on an assessment of data on fuels, weather and previous prescribed burns along with information from scientific publications and other relevant documents.

The revised prescriptions from this review are summarised in Appendix 2.

These prescribed burning prescriptions will supersede the previous draft prescriptions developed in a series of workshops in 2002. The review was undertaken to validate the previous interim prescriptions, update with recent research and incorporate prescribed burning experience gained since this time. The major changes in these revised prescriptions are the incorporation of fuel hazard rating and the linking of clearly defined objectives with measurable outcomes. Assessments will be made to evaluate the objectives the prescribed burn achieved.

These prescriptions will be updated and refined as new information and/or procedures become available using the principles of adaptive management. A critical requirement for updating and refining the prescriptions will be the collection of comprehensive data from prescribed burns as they are performed. This data will be used to indicate where the prescriptions are working as intended, where the prescriptions are unnecessarily restrictive (and hence can be extended to include a broader range of parameters), and/or where the prescriptions are not working and need to be updated.

This review does not, however, intend to be a comprehensive assessment of the relationships between different aspects of site conditions, vegetation type, weather and/or fuel on fire behaviour. If more information is required on these interactions, it can be obtained from the reviews in Tolhurst and Cheney (1999) and/or Marsden-Smedley (2009).

4. Prescribed burning objectives

A fundamental aspect of prescribed burning is the identification of clear objectives and targeted outcomes prior to the ignition of the burn. This means that pre- and post-burn surveys will be required in order to link the burn's objectives with post-burn outcomes.

The overall objectives of prescribed burning can include fuel reduction, ecological management, cultural management and woody weed management. These must be clearly stated in all burn plans.

4.1 Fuel reduction burning

Fuel reduction burning aims to reduce fuel loads and modify fuel structure in strategic locations to increase bushfire suppression potential and/or the likelihood that bushfires will self-extinguish. Fuel reduction burning needs to target reductions in the level of fuel hazard. In order to be effective this will require the prescribed burning to be applied in such a way that the fuel hazards immediately adjacent to assets, ignition sources and/or in fire corridor zones are prioritised (Luke and McArthur 1978).

Fuel reduction burning objectives include:

- conduct the burn safely
- minimise escapes
- reduce the level of fuel hazard (and in particular bark fuel hazard) to low or moderate
- burn a specified amount of the available fuel over a specified proportion of the site.

4.2 Ecological burning

The characteristics of prescribed burning for ecological outcomes will be dependent on the requirements of the species and/or vegetation associations being managed, and includes species and ecological community regeneration, habitat manipulation, and development of mosaics of burnt and unburnt areas. The review does not cover other aspects of burn planning such as burn season, size and intensity that need to be considered to ensure any specific ecological objectives are met. Ecological burning will aim to increase and/or promote fire-regime dependant species or associations, or reduce and/or remove unwanted species or associations.

Typical ecological burning objectives may include:

- species and ecological community regeneration (fire frequency used will vary between different species and ecological communities)
- habitat manipulation to increase native animal food and/or shelter availability
- management of mosaics of seral stages across a landscape. See Gill (2008) for further discussion.

4.3 Cultural management burning

The application of prescribed burning for the maintenance of cultural values will need to be driven by the requirements of the traditional owners. This burning will have a range of objectives, including looking after country, wildlife and vegetation management, access to and maintenance of cultural sites.

4.4 Woody weed management burning

Woody weed management burning is commonly targeted to removing abundant woody weeds. Effective use of fire for woody weed management requires integration with follow-up treatments due to the potential for fire to promote and expand weed populations (Swezy and Odion 1997; Baeza *et al*. 2003, 2006; De Luis *et al*. 2004, 2005).

The aim of burning during woody weed management is to remove adult plants to improve access for subsequent treatments, and to promote seedling germination so that seed banks are depleted, reducing subsequent seedling germination. Follow-up weed treatments will need to be completed prior to the weeds reaching reproductive maturity and replenishing seed banks.

Pre-burn herbicide spraying of weeds can be used during follow-up treatments to increase the proportion of dead fuel and consequently, weed flammability (DiTomaso *et al*. 2006). This spraying will be particularly useful where short inter-fire periods are targeted (and hence the fuel array consists of mostly live fuel) in order to prevent weeds flowering, setting seed and replenishing seed banks.

4.5 Bounded versus unbounded burning

Burns may be conducted as bounded or unbounded burns. Pre-specified control lines that are capable of containing the prescribed burn prior to ignition determine the entire area planned for a bounded burn. Pre-specified boundaries can be either constructed mineral earth control lines or natural barriers such as rocky outcrops or wet gullies. Three main strategies are utilised when performing bounded burning. The first strategy relies on existing and constructed mineral earth control lines. The second strategy utilises changes in the level of fuel hazard, where burns are lit so that they burn into areas of lower fuel hazard, such as recently burnt areas and/or less flammable vegetation types. The third strategy utilises slope and/or topographic position to extinguish fires, where fires may be lit along ridgelines and allowed to burn down slope until they self-extinguish in gullies

In contrast, unbounded burns are performed without relying on pre-specified boundaries but rely on fires self-extinguishing prior to burning to boundaries. As such, there will be uncertainty as to the location of the burn's final boundaries and its total size during unbounded burning. However, due to unbounded burning not requiring the construction of mineral earth control lines, it may have lower environmental, economic and resource costs than bounded burning. The main strategy when performing unbounded burning relies on fires self-extinguishing as a result of overnight decreases in wind speed, increases in humidity and/or increases in fuel moisture.

For example, fires in semi-arid mallee require high wind speeds and/or low fuel moistures (compared to many other vegetation types) to sustain burning, meaning that fires can be lit in the mid to late afternoon and, provided the wind speed and fuel moisture exceed critical thresholds, fires will self-extinguish overnight.

A major concern during unbounded burning is ensuring the weather, fuel hazard and/or site conditions are such that fires will self-extinguish. If the required conditions are not met there is a high potential for larger than desired fires to occur. Another concern is the risk of smouldering vegetation re-igniting at a later date. This means unbounded burning needs to be performed with care, especially when burn sites are surrounded by high value fire sensitive assets, such as urban areas and/or where there are species and/or ecological communities sensitive to fire regimes, or where areas are already close to or exceeding thresholds of potential concern.

4.6 Prescribed burning objectives

Prescribed burning objectives must be linked to measurable post-burn outcomes and, where practical, should target multiple objectives. Ecological management burning requires the identification of targeted outcomes and will require effective pre- and post-fire monitoring.

Examples of some prescribed burning objectives are in Table 1.

Table 1: Examples of potential prescribed burning objectives and outcomes.

Objective	*Target outcome*
All burns	
• burn performed safely • no escapes • fire outcomes and effects recorded • minimise adverse community impacts	• no reportable safety incidents • fire contained to planned area • fire data collected and recorded on databases • post-fire monitoring performed • effective community consultation and notification at planning, implementation and post-burn stages • smoke impacts minimised
Fuel reduction burning: Asset zone	
• reduce fuel hazards	• reduce elevated and bark fuel hazard to low and burn >70% of fuel across >70% of block within 250 m of the boundary • reduce overall fuel hazard rating to low across entire block
Fuel reduction burning: Buffer zone	
• reduce fuel hazards	• reduce overall fuel hazard rating to low or moderate • minimise impacts to community and ecological values
Ecological burning: broad-scale	
• manage for the full range of values	• ecological requirements of target associations recorded • area of target associations stable or increasing • 40–70% of block burnt, dependent on management aims • unburnt patches scattered throughout the block • burns conducted with a variable fire regime • effective pre- and post-burn monitoring and documentation
Ecological burning: species and ecological community management	
• maintain target species	• ecological requirements of target species documented • target species numbers stable or increasing • effective pre- and post-burn monitoring and documentation

5. Fire management zones

The fire management zone types will be determined by legal requirements and the aims and objectives of the land manager. In South Australia these zone types are, Asset zones, Buffer zones and Conservation zones (see Ellis *et al*. 2004; DENR 2011a).

The area immediately surrounding a high value asset, such as urban areas, buildings, ecological assets and/or communication infrastructure that require protection from bushfires would not normally be subjected to prescribed burning. In most situations, fire risk within the immediate surrounding area of the asset will be managed by the removal of fuel hazards and by requiring appropriate building designs.

Asset zones (also referred to as A zone) need to be located immediately adjacent to assets and/or ignition sources, with the primary objective being intensive fuel reduction to minimise bushfire risk. Within this zone, ecological values and/or recreational opportunities are of secondary importance and may be adversely impacted. As such, the area of the asset-protection zone needs to be kept as small as practical while still providing a buffer from radiant heat damage, flame contact and short-distance ember attack on assets.

The Buffer zone (also referred to as B zone) aims to provide broad-scale fuel reduction to increase bushfire suppression potential and reduce bushfire size while minimising adverse impacts to other values. This means that the Buffer zone needs to be of sufficient size and continuity to act as a barrier to fire spread by reducing rate of spread, intensity and spotting under a broad range of fire weather conditions and/or allow for effective fire suppression operations.

The Conservation zone (also referred to as C zone) aims to allow for land management in keeping with the land manager's requirements. This zone will aim to maintain appropriate fire regimes for vegetation management (eg species, ecological community and/or structural diversity), cultural heritage, catchment management, woody weed management and/or fire exclusion. This fire management zone should provide for a range of ecological objectives and requirements for both flora and fauna including, where appropriate, fire management for single species.

6. Bushfire risk assessment

Risk assessment has an important role during prescribed burning. The South Australian Burn Risk Assessment Tool (BRAT SA) provides a standardised framework for assessing prescribed burning risks versus benefits. The BRAT SA is based on the Standards Australia Risk Management Standard AS/NZS ISO 31000 (Standards Australia 2009) and was developed from the BRAT Tas (Marsden-Smedley and Whight 2010; see also Slijepcevic *et al*. 2007). The BRAT SA assesses the risk of escapes (ie likelihood of impact), potential for damage (ie consequence), effect of mitigation strategies in reducing escape probability, and the burn's potential to meet fire management objectives (ie benefits).

Bushfire risk assessment can be used to identify areas with a high likelihood of being burnt. In doing so, it can predict the impacts (positive and negative) of different fire management strategies (eg changes in the amount and location of prescribed burning and/or changes in resource level and location).

The major advantages and disadvantages of bushfire risk assessment are:

Advantages:

- clarification and summarisation of bushfire risks
- display of the level of bushfire risk in an easily understood manner
- comparison of the effects of different strategies, including:
  - location and/or type of fuel reduction
  - resource allocation
  - visitor management
  - communication of risk levels to other personnel and the public.

Disadvantages:

- base information may be unclear and/or hidden
- parameter relationships in the system may be inappropriate.

The major benefit of the BRAT SA is its ability to provide an objective, consistent, standardised and repeatable process for ensuring that all of the major factors controlling fire risk have been assessed. By doing so, the BRAT SA allows the practitioner to identify the criteria having the greatest influence on risk level and, consequently, the parameters that could be modified to reduce risk levels. For example, if a burn has an unacceptable risk profile, such as a high risk of spot fires, the risk could be reduced by burning with higher fuel moistures (eg higher relative humidity and/or in a cooler season), increased resources could be used, additional boundary works could be completed, and/or the burn's boundaries could be moved to a lower risk location.

The fire behaviour during the burn and the fire behaviour in surrounding areas should the fire escape its boundaries are also predicted by the BRAT SA.

The BRAT SA is a mandatory component of prescribed burn planning and will be used as an important aid during the burn approval process. Prescribed burns with different burn overall risk rating profiles require different levels of sign-off and approval prior to undertaking the prescribed burn. The Department for Environment and Natural Resources *Fire Policy and Procedure Manual* (2011) sets out the approval process for the different burn overall risk rating categories.

In addition, prescribed burning forms only a minor component of the workload for the majority of managers who are required to approve prescribed burns. The BRAT SA provides a structured system by which these managers can ensure the critical factors controlling fire risk have been considered and the risk of adverse impacts has been minimised.

The final major advantage of the BRAT SA is that it provides a record of the risk assessment process, which can be used to assess operational performance and quantify improvements to fire management.

The strategy for using the BRAT SA is to determine the:

- main vegetation types within and adjacent to the prescribed burn area
- vegetation's time since fire, fuel hazard ratings and fuel heights
- block size, shape, slope, aspect and boundary characteristics
- suitable weather, fuel moisture and fire danger index
- ignition strategy
- resources required for performing the prescribed burn
- positive versus negative impacts to cultural, ecological, recreational and economic assets.

The BRAT SA then predicts and assigns a hazard rating to:

- fuel hazard
- weather conditions
- site factors
- ignition strategy
- resources used
- whether the burn's preparation has been performed prior to ignition.

The BRAT SA also predicts and assigns a rating to the consequences and benefits of performing the burn to asset types, including:

- cultural
- ecological
- recreational
- economic.

The fire behaviour during the burn along with the expected fire behaviour should the fire escape is predicted by the BRAT SA, including:

- rate of fire spread (km/hr)
- flame height (m)
- fire intensity (kW/m)
- fire danger index.

Finally, the BRAT SA assigns an overall hazard rating to the burn that can be used to assist with the burn's approval process.

The structure and relationships used in the BRAT SA are detailed in Appendix 1.

7. Fuel hazard rating

From a fire management perspective, prior to about 1996 the term fuel typically meant the total litter fuel load (eg see Luke and McArthur 1978). Since this time there has been a growing realisation that fire spread rate is poorly correlated with fuel load, but well correlated with fuel structure and composition (eg Gould 1993; Marsden-Smedley and Catchpole 1995; Gould *et al*. 2007a). As a result fuel hazard rating systems have been developed, initially for use in dry eucalypt forests (eg McCarthy *et al*. 1999; see also Gould *et al*. 2007a, 2007b; Hines *et al*. 2010), and more recently for a broader range of other vegetation types (eg DENR 2011; Hines *et al*. 2010).

The Victorian and South Australian overall fuel hazard rating systems are intended to be a guide to fire suppression operations and use different cover, height and continuity thresholds to the Project Vesta fuel hazard rating system, which is intended to provide information for fire behaviour prediction (Gould *et al*. 2007a, 2007b; DENR 2011; Hines *et al*. 2010).

Due to having been designed specifically for South Australian vegetation types, the South Australian overall fuel hazard rating system (DENR 2011) is recommended when doing prescribed burning and bushfire suppression operations in South Australia. This guide is summarised in Tables 2 and 3.

In native vegetation the main fuel strata are surface fuels, near-surface fuels, elevated fuels and bark fuels along with canopy height and density (Figure 1). Surface fuels strongly influence fire intensity due to frequently containing the majority of the fuel load, near-surface fuels are the most important stratum influencing the rate of fire spread, elevated fuels strongly influence the fire intensity and the potential for crown fires, and bark fuels strongly influence spotting (see reviews in Tolhurst and Cheney 1999; Marsden-Smedley 2009).

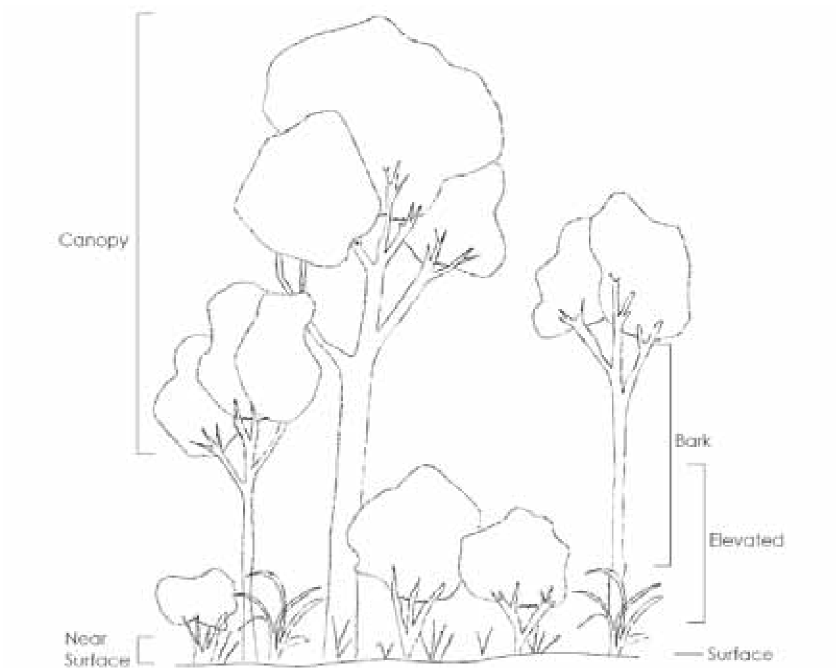

Figure 1. Fuel hazard strata. Figure taken from DENR (2011).

Fine fuels are assessed and include dead fuel up to 6 mm in diameter and live fuel up to two millimetres in diameter. All dead bark likely to be burnt in a fire is also included in the assessment (ie including bark more than six millimetres in diameter).

The surface fuel stratum consists of dead material made up of grass, leaves, bark and twigs that has a predominantly horizontal orientation and is either in contact or close to contact with the soil surface. Surface fuels often contain the majority of the fuel load, have higher fuel moisture and relatively low aeration resulting in typically minor influences on fire spread rate. However, because they frequently contain the majority of the fuel load, surface fuels may significantly influence fire intensity and flame height.

The near-surface fuel stratum consists of live and dead fuels above the surface fuel stratum and comprises a mixture of both vertical and horizontal material. In some sites, the surface and near-surface fuel strata intergrade with no clear break between them. Near-surface fuels are typically about 10 to 30 cm high, but may be as high as 60 cm in some situations. Due to their proximity to the surface fuels, near-surface fuels will always be burnt in a fire. Near-surface fuels consist of fine fuel including suspended bark, leaf litter, low shrubs, low bracken, tussock grasses, sedges and rushes.

The elevated fuel stratum consists of live and dead shrubs and tall bracken that have a largely vertical orientation and are typically about one to two metres tall.

The main bark types affecting fire behaviour are smooth or candle barks, platy bark and stringy bark. Candle bark consists of long, typically coiled bark strips which have the potential to be lofted by fire convection columns and remain burning for extended periods, resulting in their ability to facilitate long distance spotting (ie >2 km). Platy bark (ie the bark tends to form small 'plates') from peppermints, ironbarks and pines is characterised by layers of dead bark that can flake off and cause short to medium range spotting (ie up to about 2km). Stringy barks form fibrous wads, which can be removed by fire and can result in massive short to medium range spotting. Bark fuels are assessed for both overstorey and intermediate canopy strata.

The overall fuel hazard rating has been defined as the sum of the effects of surface, near-surface, elevated and bark fuel hazard (McCarthy *et al*. 1999; DENR 2011; Hines *et al*. 2010). Gould *et al*. (2007a) have derived a similar factor called the fuel combustibility score, which is defined as the sum of the product of the fuel hazard and fuel cover scores.

While the Project Vesta fuel hazard guide (Gould *et al*. 2007a, 2007b) will provide adequate predictions of fuel hazard in dry eucalypt forests, its use in other South Australian vegetation types is not recommended due to it not being designed to work in these fuel types.

The Victorian and South Australian dry eucalypt forest fuel hazard rating systems are intended to be a guide to fire suppression operations and use different cover, height and continuity thresholds than the Project Vesta fuel hazard rating system, which is intended to provide information for fire behaviour prediction (DENR 2011; Gould *et al*. 2007a, 2007b; Hines *et al*. 2010).

Davis (2010) researched the effects of prescribed burning on dry eucalypt forest fuel hazard in southeast Tasmania and found that prescribed burning was highly effective at reducing surface, near-surface and elevated fuel hazards, but ineffective at removing bark fuel hazard unless fires were conducted at moderate to high intensity and/or with low fuel moistures. This means that in order to be effective at removing bark fuel hazard, lighting patterns and weather conditions need to be considered to remove bark fuel.

Davis (2010) also examined the effectiveness of prescribed burning on the level of fuel hazard. This study found that following prescribed burning in heathy dry eucalypt forests surface, near-surface and elevated fuel hazard respectively reached equilibrium at about 20 to 30 years, about 15 to 20 years and about 13 years post fire. In grassy dry eucalypt forests following prescribed burning Davis (2010) also found that surface, near-surface and elevated fuel hazard respectively reached equilibrium at about 10 years, about 20 years and about 10 years post fire. The data collected by Davis (2010) indicates that in order to be effective in heathy and grassy dry eucalypt forests, prescribed burning in asset-protection zones needs to be conducted at four to eight year intervals, and in strategic management zones at four to 10 year intervals.

Table 2: Adjustment to the surface fuel hazard due to the characteristics of the near-surface fuel hazard rating in the South Australian fuel hazard rating system.

L=low, M=moderate, H=high, VH=very high, E=extreme; see DENR (2011).

Surface hazard		Near-surface fuel hazard rating				
Surface fuel hazard rating	**Litter Depth (mm)**	**L**	**M**	**M**	**H**	**VH**
L	<15	L	L	M	H	VH
M	15–<25	M	M	H	VH	E
H	25–<35	H	VH	VH	VH	E
VH	35–<50	VH	VH	E	E	E
E	>50	E	E	E	E	E

Table 3: South Australian fuel hazard ratings for different vegetation strata. See DENR (2011).

Hazard rating	*Description*
Surface fuel hazard	
Low	litter depth including duff: <15 mm, <4 t ha^{-1}
Mod	litter depth including duff: 15–25 mm, 4–8 t ha^{-1}.
High	litter depth including duff: 25–35mm, 8–12 t ha^{-1}
Very high	litter depth including duff: 35–50 mm, 12–20 t ha^{-1}
Extreme	litter depth including duff: >50 mm, >20 t ha^{-1}
Near-surface fuel hazard	
Low	• fuel cover <10%, little or no influence on fire behaviour
Mod	• 10–20% cover of tussock grasses, low sedges and rushes, hummock grasses and low shrubs • with little or no suspended bark and leaves
High	• 20–40% cover with >20% dead of tussock grasses, low sedges, rushes, ± suspended bark and twigs or • 30–50% cover with <20% dead of tussock grasses, low sedges and rushes, ± suspended bark and twigs • 20–35% cover of hummock grasses • 20–40% of low shrubs, ± suspended bark and twigs
Very high	• 40–60% cover with >20% dead of tussock grasses, low sedges, rushes or • 50–80% cover of tussock grasses, low sedges, rushes with <20% cover of dead grass, bark and twigs • 35–60% cover of hummock grasses • 40–60% of low shrubs.
Extreme	• >60% cover of tussock grasses, low sedges, rushes with >30% dead grass, leaves and bark or • >80% cover of tussock grasses, low sedges, rushes with <30% dead grass, leaves and bark • >60% cover of hummock grasses or low shrubs
Elevated fuel	
Low	• very little elevated fuel
Mod	• <20% cover or no fine fuel within 1 m of the ground, little or no dead material
High	• 20–50% cover or little fine fuel within 0.5 m of the ground, <20% dead material or • if the vegetation is 5+ m tall then it has little fine fuel within 2–4 m of the ground
Very high	• 20–50% dead material, high vertical and horizontal density and continuity, fuel particles mostly <1–2 mm • thick, average height >0.5 m and usually >1 m high, 50–80% of fuel >0.5 m and usually >1 m high
Extreme	• >20% dead material, high vertical and horizontal density and continuity and at least 2–3 m tall, >10 t ha^{-1}, • large amounts of suspended leaves, twigs and bark, >70% of fuel >1 m (and usually >2 m) tall.
Bark fuel	
Low	• stringy barks: 100% of trunk charred • platy/sub-fibrous barks: >90% of trunk charred • smooth/gum barks: no bark ribbons
Mod	• stringy barks: bark tightly held, >90% of trunk charred • platy/sub-fibrous barks: bark very tightly held onto trunk • smooth/gum barks: no long bark ribbons
High	• stringy barks: few pieces of loosely held bark, bark tightly held, 50–90% of trunk charred • platy/sub-fibrous barks: bark tightly held onto trunk, long unburnt • smooth/gum barks: long ribbons of bark but smooth trunk
Very high	• stringy barks: significant amounts of loosely held bark, 10–50% of trunk charred • platy/sub-fibrous barks: bark loosely held onto trunk • smooth/gum barks: long ribbons of bark hanging to ground level
Extreme	• stringy barks: outer bark weakly attached and easily dislodged, <10% of trunk charred • platy/sub-fibrous barks and smooth/gum barks: does not occur

8. Fuel moisture

Fuel moisture content, expressed as a percentage, is the proportion of free and absorbed water in vegetative fuels. Fuel moisture content influences fire behaviour by affecting the rate at which the fuel will burn as well as the amount of available fuel to burn. Consequently, the ability to assess and predict fuel moisture content is an important part of the success of prescribed burning operations. It is essential for fuels to be sampled and fuel moisture contents assessed to provide a measure of fire potential.

A simple way for fire managers to assess fuel moisture content is using Fuel Moisture Index (FMI) (Sharples *et al*. 2009a). A direct estimate of the fuel moisture content is derived from the FMI equation below: subtract relative humidity from temperature, divide by four and then subtract from 10. For example, if temperature is measured to be 38°C and relative humidity is measured to be 22%, then FMI is calculated by subtracting 22% from 38°C to get 16, dividing by four to get four then subtracting from 10 to get an FMI of 6. It is important to note that this does not imply actual fuel moisture of 6% but an estimate of fuel moisture content (Sharples *et al*. 2009a).

$$\text{FMI} = 10 - \frac{\text{(Temperature (}^{\circ}\text{C) - Relative Humidity (\%))}}{4}$$

The estimates of the fuel moisture content can be combined with information on wind speed, vegetation type and drought effects to provide a simplified measure of fire danger index (FDI), equation below (Sharples *et al*. 2009b). Please note an assumption is made with the FDI relating to the maximum fuel available.

FDI = Drought Factor x (Wind Speed ÷ FMI)

When the humidity and temperature is constant and there is no precipitation, fuel moistures will reach equilibrium moisture content given sufficient time. Pippin (2007; see also King and Linton 1963) found that equilibrium moisture content will typically be about 0.5 to 1.5% lower when fuels are undergoing absorption (ie gaining moisture from the atmosphere) than when fuels are undergoing desorption (ie losing moisture to the atmosphere). However, under operational conditions, when it is not normally known if fuels are undergoing absorption or desorption, models that are applicable under both absorption and desorption conditions are required. The use of fuel level data for humidity, temperature and solar radiation may enhance predictions of fuel moisture (eg Matthews 2006). However, due to the difficulty of collecting fuel-level weather data, the low correlation between screen and fuel-level weather data and the poor performance of the available systems for predicting fuel-level weather (Pippin 2007), systems utilising fuel-level inputs are not practical.

Precipitation acts to elevate fuel moistures above those expected from the effects of temperature and humidity alone. The effect of precipitation on fuel moisture varies between vegetation types, mainly due to the influence of canopy interception, fuel structure, fuel particle diameter and rainfall duration (Plucinski 2003), with the amount of water required to saturate fine fuel particles of about one millimetre (Luke and McArthur 1978; Marsden-Smedley and Catchpole 2001). The drying rate once rainfall stops will be dependent on many factors, with the major factors being exposure to wind, solar radiation and humidity.

The Matthews (2006) fuel moisture model is probably the most robust model available for dry eucalypt forests. Comprehensive testing of this model has been undertaken within Project FuSE mallee heath vegetation and a range of eucalypt heathy open forest and woodland types (Pippin 2007; S Matthews personal communication) indicating that it has the potential to provide good fuel moisture predictions. However, the Matthews (2006) model is highly complex, requiring input data from about 26 factors, many of which are not available under operational conditions. As a consequence, the Matthews (2006) fuel moisture model has been simplified to only require screen level temperature, RH, wind speed and solar radiation (see Matthews *et al*. 2010). The Matthews (2006) model has also been extended and simplified for use in semi-arid mallee and mallee-heath fuels (Cruz *et al*. 2010).

Extensive testing by Pippin (2007) in New South Wales sedgy heathland and sedgy woodland (data in Pippin 2007) indicated that the buttongrass moorland fuel moisture model (Marsden-Smedley and Catchpole 2001) utilising relative humidity and temperature provided good predictions when fuels were undergoing absorption, but poor predictions when fuels were affected by recent precipitation. Additional analysis of the data in Pippin (2007) by Marsden-Smedley (2009) using the full buttongrass moorland model incorporating relative humidity, temperature, rainfall amount and time since the rain stopped suggested that this model should provide good predictions in coastal wet and damp mallee woodland, non-eucalypt woodland and heathland, heathland and weed vegetation types.

9. Weather parameters for prescribed burning

The main factors influencing fire behaviour are wind speed, fuel characteristics and fuel moisture, with wind speed being the most important factor (Sullivan 2009). However, the relative importance of these factors varies at different wind speeds. At low to moderate wind speeds (eg <25 km/h), wind speed and fuel characteristics have similar levels of influence on fire behaviour while at higher wind speeds (eg >25 km/h), wind becomes the dominant influence on fire behaviour (Marsden-Smedley and Catchpole 1995; Tolhurst and Cheney 1999; Gould *et al*. (2007); Marsden-Smedley 2009).

The major issues related to measuring wind speed are its highly changeable nature (Gould *et al*. 2007a), and the difficulty of measuring wind speed in many sites. For wind speeds to be measured correctly, large areas free of obstacles are required, with the width of the open area being at least 10 times the height of surrounding obstacles (Bureau of Meteorology (BoM) 1997). Where clearings of sufficient size are not available, the 10 metre wind speed can be estimated using the Beaufort scale, as described in Table 4.

Table 4: Beaufort wind scale.

Beaufort category	km/h	Description
0 calm	<1	smoke rises vertically
1 light air	1–5	smoke drifts slowly, slight leaf movements
2 light breeze	6–10	wind felt on face, leaves rustle
3 light wind	11–20	leaves and small twigs move
4 moderate wind	21–30	dust raised, small branches moved
5 fresh wind	31–40	small trees sway
6 strong wind	41–50	large branches moved, wires whistle
7 near gale	51–60	large trees sway
8 gale	61–75	twigs and small branches broken off
9 full gale	75–90	large branches broken off
10 storm	91–115	trees uprooted, severe building structural damage

Wind speed is strongly affected by friction from the ground surface (BoM 1997), which means it is also necessary to record the wind measurement height. Where possible, wind speed should be measured at a height of 10 metres above the ground surface, although the surface wind speed (ie the wind speed at 2 metres above the ground surface) may also be recorded. In open sites, the wind speed at 10 metres above the ground averages about 1.5 times the surface wind speed (Marsden-Smedley 1993; Tran 1999). In forested sites, Tran (1999) and Gould *et al*. (2007) found that wind speed at 10 metres above the ground averaged about 2.5 times the surface wind speed. Tran (1999) also found an approximately 50% reduction in the 10 metre wind speed between open versus forested sites (canopy densities of about 20 to 55%).

All the prescriptions detailed within this document use the wind speed measured at 10 metres above the ground surface. The wind speed predicted or measured by the Bureau of Meteorology forecasts and weather stations is the 10 metre wind speed. If the wind speed is being measured at 2 metres above the ground surface (eg by hand held anemometers) it needs to be transformed to the equivalent of the 10 metre wind speed by multiplying by 1.5 (eg a 20 km/h 2 metre wind speed is equivalent to a 30 km/hr 10 metre wind speed).

Wind speed measurements and predictions, from the Bureau of Meteorology forecasts and automatic weather stations, are 10 minute averages. This means that there will be gusts with considerably faster wind speeds (typically by about 30%) and lulls with lower wind speeds, along with periods when the wind direction will vary. These periods of higher wind speed can temporarily increase the potential for spotting, especially if they result in fires pulsing into the canopy. Changes in wind direction can also greatly decrease spot fire build up time by causing the fire to switch between head to flank, effectively increasing the effective fireline length (Cheney and Sullivan 2008).

The moisture content of the atmosphere is normally described using the relative humidity (RH) and the dew point temperature. Vapour pressure deficit is a major driver of fuel moisture, however, the most useful measure of moisture in the atmosphere for fire behaviour prediction is RH, since it reflects changes in the vapour pressure deficit (Tolhurst and Cheney 1999). Fire behaviour is influenced particularly when the RH is below about 30%. At low fuel moistures, fires burn with increased levels of fire behaviour and embers tend to stay alight for extended periods resulting in enhanced spot fire potential. When the dry-bulb temperature falls below the dew point temperature, dew typically forms resulting in rapid increases in fuel moisture along with decreased levels of fire behaviour and spot fire potential.

Other than through its influence on the saturation vapour pressure (and hence relative humidity), the dry-bulb temperature has very minor influences on fire behaviour. The dry-bulb temperature does, however, have major influences on fire crew fatigue and dehydration risk, and as a result, the ability of fire crews to perform fire management operations.

The stability of the atmosphere along with the presence or absence of inversion layers has major influences on weather and fire behaviour. This is mainly due to the likelihood that air from different altitudes will mix down to the ground surface and/or whether fires will form large convection columns. The Haines Index, which (Haines 1988) combines the effects of atmospheric stability and moisture content, can be incorporated into fire management operations. The Haines Index varies between a minimum of two and a maximum of six. The major advantages of the Haines Index are its simplicity and its capacity to provide information from higher altitudes above the ground surface. In doing so, the Haines Index overcomes a major shortcoming with the fire danger index, which only considers weather information from the ground surface.

The Haines Index does, however, have a major limitation in that it tends to saturate at ratings of five or six and so often poorly discriminates between periods with different levels of instability. In order to address this limitation, Mills and McCaw (2009) have extended the Haines Index into a continuous function called the Continuous Haines Index (C-HAINES), which varies between zero and a maximum of about 13. In their study of interactions between the C-HAINES and fire activity, Mills and McCaw (2009) found strong correlations between high values of the C-HAINES in the days leading up to and/or during days of high fire activity. However, C-HAINES is emerging research and will be verified as knowledge continues to improve. C-HAINES is not an input into the prescriptions.

The Soil Dryness Index (SDI, Mount 1972) estimates the amount of rainfall required to saturate the soil profile. The SDI is a useful indicator of fuel moisture, but must be used with caution. The SDI is predicted for a number of weather station sites and then extrapolated to the fireground. Due to these fireground sites typically having different precipitation amounts, aspects, altitudes, topography and/or vegetation type to the site for which it is predicted, the SDI may vary from the prediction and so needs to be used with caution and anchored with data collected from the fireground.

Due to being a bookkeeping system, the predicted SDI will be at its most accurate when soils are saturated and hence, the SDI is zero (eg in winter). As soils dry out following wet periods, errors may accumulate in the predicted SDI values and/or the SDI may lag behind the actual soil dryness. This means that, in general the SDI is more reliable in spring than in autumn.

In addition, the requirement for the SDI to periodically fall to zero in order for it to provide an accurate estimate of soil dryness means that the SDI is of limited utility in arid and semi-arid parts of South Australia and should only be used in coastal wet and damp mallee woodland and heathland, dry scrub, dry eucalypt forest and dry eucalypt woodland.

The Drought Factor (DF, McArthur 1967) combines the effects of recent precipitation, days since rain and the SDI to estimate the proportion of the fuel array's fine fuel that is dry enough to burn. The DF varies between 0 (all fine fuel is too wet to burn) and 10 (all fine fuel is dry enough to burn and will be consumed in a fire). The DF is normally only used as an input when calculating the Forest Fire Danger Index (McArthur 1973).

10. Effectiveness of prescribed burning

The utility of performing prescribed burning will need to be assessed at two levels: measures assessing the effectiveness of individual prescribed burns, and measures assessing the effectiveness of the prescribed burning process.

The effectiveness of individual prescribed burns will vary between different fuel reduction, ecological and cultural management burns. Therefore to evaluate effectiveness each prescribed burn will need to have specific requirements written into planning, and be assessed against the burn's objectives and fuel hazard loads. These objectives will need to be specified during the approval process with some potential examples detailed in Table 1.

The effectiveness of the prescribed burning process will be assessed by the prescribed burn's potential to increase fire suppression potential and the probability that fires will self extinguish.

These increases in fire suppression potential and the probability that fires will self-extinguish will mainly be achieved through reductions in the level of fuel hazard, and resultant reductions in the fire spread rate, intensity and/or number of embers produced. It also needs to be noted that under extreme and catastrophic levels of fire danger, bushfires will typically sustain burning (although at reduced rates of fire spread and intensity) within areas that have been recently prescribed burnt.

This means that prescribed burning is only one of the bushfire risk reduction strategies that needs to be implemented, and to be effective it must be integrated with other strategies such as appropriate land use planning, asset management (eg removal of flammable material from the immediate vicinity of assets) and control of ignition sources (eg management of arson risk). For example, recent research conducted by KG Tolhurst in the Otway Ranges using the Phoenix fire behaviour prediction system (see VBRC 2010b; see also Tolhurst *et al*. 2007, 2008) indicated that although prescribed burning can result in major reductions in bushfire risk and that the effectiveness of prescribed burning can be enhanced through the strategic placement of prescribed burning blocks, under catastrophic bushfire conditions the maximum reduction in level of impact that is possible is about 70%. This means that regardless of the level of prescribed burning performed there will a residual risk that has to be managed through other strategies (Esplin *et al*. 2003; Fernandes & Botelho 2003). It also indicates that if fuel reduction is not performed immediately adjacent to social and economic assets and/or ignition sources, at best only moderate levels of fire protection can be achieved through prescribed burning.

The critical aspects influencing the success or failure of fuel reduction burning includes the burn's:

- location relative to assets being protected and/or ignition sources
- size and width
- coverage
- proportion of the landscape treated
- fuel
- intensity
- frequency
- the weather conditions during subsequent bushfires.

Under extreme and catastrophic fire danger conditions (ie when the fire danger index is >75) bushfires will typically sustain burning (although at reduced rates of fire spread and intensity) even in areas were fuel hazard reduction has been recently undertaken (eg prescribed burnt less than one to two years previously). In addition, when bushfires burn into recently prescribed burnt areas they do not immediately reduce their rates of fire spread, intensity and numbers of embers, and instead can take up to several hundred metres and several minutes to drop down to the quasi-steady levels of fire behaviour appropriate to a recently burnt area (VBRC 2010b).

Burn coverage (ie the proportion of the block actually burnt, typically expressed as a percentage of the total area) has an important influence on the effectiveness of prescribed burns. Where burns have too low a coverage, bushfires may sustain with moderate to high rates of spread, intensity and ember numbers in the remaining fuels. Experience from dry eucalypt forests in Western Australia suggests that prescribed burns need to have a minimum coverage of about 60% to be effective in modifying the behaviour of an intense bushfire burning under dry conditions (VBRC 2010b). Conversely, burn coverage rates above 90% may be unnecessary for effective fuel reduction and can result in adverse impacts to ecological values due to the lack of unburnt areas.

In order to minimise both the risk of prescribed burns escaping and the level of resources required to perform the burn, low levels of fire danger are often utilised during prescribed burns. Provided these low intensity burns have adequate coverage rates (ie burn at least 60% of the block area) they are normally effective at reducing the level of surface and near-surface fuels. However, in dry eucalypt forests (and especially stringybark forests) bark hazard removal is a critical objective of fuel reduction burning and these low intensity fires frequently do not result in the effective removal of elevated and bark fuel hazard (see Davis 2010; Gould *et al*. 2007a). This means that in order to be effective at reducing dry eucalypt forest bark fuel hazard, flame height of at least two to four metres is required. It also needs to be noted that an outcome of performing prescribed burns with these levels of intensity will be increased levels of the scorch and potentially high levels of post-burn leaf fall which can result in increases in post-fire surface fuel hazard.

The frequency at which prescribed burns are performed will have an influence on their effectiveness for fuel reduction. Research in Victorian dry eucalypt forests by McCarthy and Tolhurst (2001), found strong correlations between the time since burning and the fire suppression potential, due to the influence of fuel age on the level of fuel hazard, which can be summarised as:

- highly effective
  - burning intervals of no more that 3 years
- moderate to highly effective
  - burning intervals of between 3 and 6 years
- minimally effective
  - burning intervals of 10 years or more

  (due to the recovery of near-surface, elevated and bark fuel hazard).

11. Predicting fire behaviour

Over the past three decades a number of models have been developed for predicting fire behaviour in semi-arid mallee and mallee-heath (McCaw 1998a, 1998b; Cruz *et al*. 2010), Spinifex grasslands (Burrows *et al*. 2006, 2009), dry eucalypt forests (McArthur 1962, 1967, Gould *et al*. 2007a, 2007b), heathlands (Catchpole *et al*. 1998, 1999; Plucinski 2003) and grasslands (McArthur 1966, Cheney and Gould 1995; Cheney *et al*. 1993, 1998; Cheney and Sullivan 2008; Leonard 2009).

The models of Allan McArthur (1962, 1967) were developed from experimental burns in litter dominated fuels of the ACT and Victoria, and are still valid for these fuel types where they occur (mostly in the Mt Lofty Ranges and the Lower South East). The Project VESTA models developed by CSIRO from experiments in south-west Western Australia (Gould 2007a, 2007b) incorporate the effects of additional shrub and bark fuel components in eucalypt forests. This model has not been validated in South Australian fuels yet, but is likely to be useful in these eucalypt forests.

Allan McArthur's grassland fire behaviour model (1966) has been modified several times. These models have now been superceded by the CSIRO Grassland models (Cheney and Sullivan 2008). Neil Burrows models for Spinifex grasslands (Burrows *et al*. 2006, 2009), developed from experiments in central WA, appear to apply well in South Australian Spinifex fuels (from limited validation).

None of the range of models that have been developed for shrubland, mallee and heath fuels has been extensively validated in South Australia. The significant work of Project FuSE (Cruz *et al*. 2010) using experiments in Ngarkat Conservation Park has produced fire behaviour models specifically for prescribed burning conditions in Mallee-heath vegetation. These models need to be tested in mallee vegetation and in other parts of South Australia, but appear to work well for at least other areas of drier mallee landscapes (e.g. Eyre Peninsula).

Most of these fire behaviour models have been designed for bushfire behaviour prediction (exceptions include McArthur 1962 and McCaw 1998b) and although the models provide predictions for fire behaviour under safe burning conditions, they are limited by the range of conditions to which they were exposed and thus implementing prescribed burning outside these parameters requires some caution. Furthermore, the fire behaviour models do not reflect the input of fuel moisture, slope and other variables specific to the prescribed burning operations. Implementing prescribed burning from these parameters of fire behaviour models should only be a used as a guide and requires further scientific validation and that models be reviewed as our knowledge continues to improve.

Despite these reservations, these models still provide the best practice for predicting fire behaviour and have been used, together with validation against actual prescribed burns from the last five years, as the basis for these revised burning prescriptions.

12. Prescribed burning prescriptions

Species and communities vary in their adaptations to, tolerance of, and reliance on fire. Vegetation types that are not readily flammable or contain species that are sensitive to burning are not suitable for prescribed burning.

The main vegetation (fuel) types in South Australia suitable for prescribed burning are:

- semi-arid mallee and mallee-heath
- Spinifex grassland
- eucalypt heathy open forest and woodland
- non-eucalypt woodland and heathland
- coastal mallee and mallee heathland
- native grasslands and grassy eucalypt woodlands
- woody weeds.

Each vegetation type has been allocated prescriptions with a series of parameters. The prescriptions for prescribed burning incorporate fuel hazard rating. This has the advantage of integrating the effects of time since fire, site productivity and seasonal conditions. For example, in Spinifex grasslands the rate at which fuel hazard increases with time since fire is dependent on not only the elapsed time but also the prevailing rainfall (eg see Latz 1990).

The integration of the different burning parameters is a critical component of prescribed burning. If burning is conducted with all of the parameters at their maximum values (eg highest wind speed, lowest relative humidity and highest fuel hazard) then fires will burn with rapid rates of spread, high intensities and a high risk of escapes. To minimise this risk, a maximum forward rate of spread has been included into all vegetation type's prescriptions, except for eucalypt heathy open forest and woodland.

Conversely, if burning is conducted with all of the parameters at their lowest values, then fires may fail to sustain, or if they do sustain, they may burn with insufficient intensity to meet the objectives of the burn.

In forest and grass vegetation types respectively the Forest Fire Danger Index (FFDI, McArthur 1973) and Grass Fire Danger Index (GFDI, McArthur 1966) can be used to integrate the different fuel and weather parameters and determine the upper limit of acceptable fire behaviour. In other vegetation types, the use of either the FFDI or GFDI is not recommended and the limits to acceptable fire behaviour can be estimated from a combination of the fuel hazard rating and wind speed.

Where prescribed burning is being performed in mixed vegetation types (eg dry eucalypt forest with dense weed understorey or Spinifex grassland with a mallee overstorey) the selection of appropriate burning prescriptions will need to be based on the most flammable component of the vegetation and/or the component with the highest fuel hazard.

For all vegetation types suitable for prescribed burning in South Australia, the BRAT SA can be used to predict the forward rate of spread rate, flame height and intensity.

The ignition pattern and techniques chosen for the prescribed burn will influence the fire behaviour and in particular the fire intensity. The speed at which the head of the fire forms and the fire shape vary depending on the ignition of the prescribed burn. The ignition pattern often needs to be varied according to weather, fuel and topographic conditions within the burn area.

The characteristics of the control lines utilised during prescribed burning will depend on the type of prescribed burning and anticipated level of fire behaviour. If prescribed burns are performed in dry eucalypt forests which have very high or extreme bark hazards then the burn should be resourced to a higher level, wider boundaries used and/or the burn undertaken at lower levels of fire danger (eg higher relative humidity, higher fuel moisture and/or lower wind speed).

The recommended process for selecting appropriate burning parameters is:

1. Specify the burn's objectives.
2. Determine the vegetation type/s and the level of fuel hazard within and adjacent to the prescribed burning area.
3. Determine the minimum and maximum fire intensity to achieve objectives, fuel modification required, and likely fire behaviour during the burn.
4. Determine whether the burn's risk profile is acceptable using the BRAT SA.
5. If necessary, modify the weather and site parameters to reduce the level of fire risk while maintaining acceptable levels of fire intensity to achieve the burn's objective.
6. Undertake the burn within the prescription parameters.
7. Undertake post-burn assessments to determine if burn objectives have been met (and develop strategies to address the issue if the objectives have not been met), and record the burn outcomes on appropriate databases.

Figure 2. Semi-arid mallee.

12.1 Semi-arid mallee and mallee-heath

Semi-arid mallee (see Figure 2) and mallee-heath normally consist of low open eucalypt and/or shrub dominated vegetation in central and northern South Australia (SA veg 2007). The understorey normally consists of smaller shrubs, grasses and herbs. The fuel array in these vegetation types is typically highly discontinuous with the majority of the fuel occurring under patches of overstorey mallee and heath.

Under comparable conditions, fires in semi-arid mallee-heath spread faster but with lower intensities than fires in semi-arid mallee (Sandell *et al*. 2006; Cruz *et al*. 2010).

Fires are most common in these vegetation types when either above average rainfall conditions results in ephemeral species (particularly Austrostipa spp.) filling in the gaps between clumps of perennial species and/or when sites are long unburnt and have accumulated sufficient fuel to carry fires (Bradstock and Cohn 2002).

A characteristic of fire in semi-arid mallee and mallee-heath is the high wind speeds and/or low fuel moistures (compared to other vegetation types) required for fires to sustain burning. The level of fuel hazard has significant but smaller influences (McCaw 1998b; Cruz *et al*. 2010). This means that fire occurrence in semi-arid mallee and mallee-heath is strongly linked to the ability of fires to spread and/or spot across fuel discontinuities. In addition, flank and back fires in these vegetation types typically do not sustain burning, frequently resulting in long, narrow wind-driven fires.

This requirement for high levels of fire potential in order for fires to sustain burning can, however, be utilised during prescribed burning. Fires may only sustain for a period during the day (typically mid morning to late afternoon) and self-extinguish overnight when the surface wind speed reduces and/or the humidity increases.

Another feature of fires in semi-arid mallee and mallee-heath is that often only the head fire sustains with flank and back fires self-extinguishing.

Fire behaviour in semi-arid mallee and mallee-heath can be predicted using the fire prediction models in Cruz *et al*. (2010).

The boundary type surrounding the burn will have major influences on the overnight conditions required to safely stop fires, with higher fire potential conditions being acceptable when burns are bounded (ie have boundaries capable of stopping a fire) than when burns are unbounded (ie do not have boundaries capable of stopping a fire).

Along with wind speed and fuel moisture, fuel hazard rating influences the level of fire behaviour in semi-arid mallee and mallee-heath. The *Overall Fuel Hazard Guide for South Australia* (2011) can be used to estimate the combined fuel hazard of surface and near-surface fuels.

The prescriptions for conducting semi-arid mallee and mallee-heath prescribed burning are in Table 5.

Table 5: Semi-arid mallee and mallee-heath prescribed burning prescriptions.

Parameter	*Units*	*Range*
Adjusted surface fuel hazard rating: L or M		
Maximum Forward Rate of Spread	**km/h**	**1.5**
Wind speed at 10 m	km/h	25 to 50
Relative humidity	%	10 to 60
Temperature	°C	20 to 40
Dead fuel moisture content, near-surface fuel	%	5 to 10
Adjusted surface fuel hazard rating: H		
Maximum Forward Rate of Spread	**km/h**	**1.5**
Wind speed at 10 m	km/h	20 to 45
Relative humidity	%	20 to 70
Temperature	°C	20 to 40
Dead fuel moisture content, near-surface fuel	%	7 to 12
Adjusted surface fuel hazard rating: VH or E		
Maximum Forward Rate of Spread	**km/h**	**1.5**
Wind speed at 10 m	km/h	15 to 35
Relative humidity	%	20 to 70
Temperature	°C	20 to 40
Dead fuel moisture content, near-surface fuel	%	8 to 13
Overnight weather conditions required: bounded burns		
(surrounded by tracks or areas with L or M fuel hazard rating)		
Wind speed at 10 m	km/h	<25
Relative humidity	%	>60
Dead fuel moisture content, near-surface fuel	%	>15
Overnight weather conditions required: unbounded burns		
(no surrounding tracks or areas with L or M fuel hazard rating)	<15	
Wind speed at 10 m	km/h	<15
Relative humidity for at least 5 hours	%	>85
Dead fuel moisture content, near-surface fuel	%	>15

The major influences on fire behaviour are wind speed and fuel moisture, according to fire behaviour prediction models for semi-arid mallee originally developed by McCaw (1998a, 1998b). Further fire research conducted by CSIRO in association with the South Australian Department of Environment and Natural Resources has seen the development of a range of fuel moisture and fire behaviour models (see Cruz *et al*. 2010). These studies have found that semi-arid mallee and mallee-heath fires respectively, failed to sustain burning when the elevated fuel moistures were above about 9% and 13% (Cruz *et al*. 2010).

The research conducted by Cruz et al. (2010) was performed during a period of below average rainfall. It is possible the amount and cover of near-surface fuels was lower than is normal. The models may under-predict the probabilities of fires sustaining burning, the rates of fire spread and fire intensities at other times. This needs to be tested when implementing this guide.

Figure 3. Prescribed burning in a Spinifex grassland.

12.2 Spinifex grassland

Spinifex grasslands occur across a broad belt in central and northern South Australia and consist of hummock grasslands dominated by *Triodia* spp. with a variable density overstorey of *Acacia* spp., shrubs and/or mallee (Figure 3; SA veg 2007). While fires in Spinifex grasslands may occur as frequently as every three years following above average rainfall periods, inter-fire periods of more than 10 to 15 years are more common (eg see: Latz 1990; Craig 1999; Allan and Southgate 2002).

The critical factor controlling fire propagation in Spinifex grasslands is the ability of flames to cross fuel discontinuities (Griffin and Allen 1984; Bradstock and Gill 1993; Allan and Southgate 2002; Burrows *et al*. 2006, 2009). In common with semi-arid mallee and mallee-heath, relatively high wind speeds and low humidity are required for fires to sustain burning in Spinifex grasslands. The near-surface fuel hazard rating provides an effective system of estimating fire potential in these grasslands.

Fire behaviour in Spinifex grasslands can be predicted using the fire prediction models in Burrows *et al*. (2006, 2009).

Fuel hazard ratings in Spinifex grasslands should be estimated from the near-surface fuel stratum using the *Overall Fuel Hazard Guide for South Australia* (2011) due to most fuel in Spinifex grasslands being in this stratum.

The prescriptions for conducting Spinifex grassland prescribed burning are in Table 6.

Table 6: Spinifex grassland prescribed burning prescriptions.

Parameter	*Units*	*Range*
Adjusted surface fuel hazard rating: L or M		
Maximum Forward Rate of Spread	**km/h**	**1**
Wind speed at 10 m	km/h	20 to 50
Dead fuel moisture content, near-surface fuel	%	12 to 30
Adjusted surface fuel hazard rating: H		
Maximum Forward Rate of Spread	**km/h**	**0.9**
Wind speed at 10 m	km/h	10 to 40
Dead fuel moisture content, near-surface fuel	%	12 to 30
Adjusted surface fuel hazard rating: VH or E		
Maximum Forward Rate of Spread	**km/h**	**1.3**
Wind speed at 10 m	km/h	10 to 30
Dead fuel moisture content, near-surface fuel	%	12 to 30
Overnight weather conditions required:		
Bounded burns (surrounded by tracks or areas with L or M fuel hazard rating)		
Wind speed at 10 m	km/h	<15
Relative humidity	%	>60
Fuel moisture	%	>15
Overnight weather conditions required:		
Unbounded burns (no surrounding tracks or areas with L or M fuel hazard rating)		
Wind speed at 10 m	km/h	<15
Relative humidity for at least five hours	%	>85
Fuel moisture	%	>15

Using a complex relationship between vegetation cover versus fuel load, prediction equations for Spinifex fuel loads were first published by Griffin and Allan (1984). More recently, Burrows *et al*. (2006, 2009) published data on the accumulation of Spinifex fuel with increasing time since fire (see also: Walker 1981; Suijdendorp 1981; Griffin *et al*. 1983; Burrows *et al*. 1991; Allan and Southgate 2002). Burrows *et al*. (2006, 2009) also developed the concept of the profile fuel moisture, which is similar in concept to the degree of curing. The models in Burrows *et al*. (2006, 2009) predict the Spinifex grassland fire danger index and the fire spread index, which are used to predict the fire spread rate.

Figure 4. Eucalypt heathy open forest.

12.3 Eucalypt heathy open forest and woodland

South Australian Eucalypt heathy open forest and woodland occur as a fragmented belt through south-eastern South Australia, including in some areas in close proximity to semi-urban areas and/or forest plantations. Many of these forests and woodlands are dominated by Stringybark (also called messmate or *Eucalyptus obliqua*). These forests and woodlands are typically 10 to 30 metres tall and range from open forests to open woodlands (Figure 4; SA veg 2007) with understoreys ranging from litter, sedgy, heathy and/or bracken (Specht 1972).

The variation in eucalypt heathy open forest and woodland fuel hazard can be assessed using the *Overall Fuel Hazard Guide for South Australia* (2011) with the McArthur Forest Fire Danger Index (McArthur 1973), which is used to predict the fire danger index, and the *Project Vesta Field Guide* (Gould *et al*. 2007a, 2007b), which is used to predict rates of fire spread and intensity.

In eucalypt heathy open forest and woodland the burn's objectives will have a major influence on the fire intensity targeted during the burn.

When prescribed burning is conducted in asset-protection zones for the purpose of fuel reduction, the fire's intensity will need to be high enough to reduce the bark hazard rating to low or moderate within about 250 metres of the burn's boundary (Davis 2010). In order to achieve this reduction in bark hazard, fires will need to be conducted with flame heights in excess of two metres and/or with relatively dry fuels (eg fuel moistures between about 10% and 16%). Where fires are conducted for ecological management, the level of fire intensity targeted will be dependent on the species and/or vegetation community being managed and the objectives of the burn.

The height and density of trees at a site will influence the effective wind speed, with taller and/or denser sites having lower wind speeds on the fireline. This means that wind will have greater influences in woodland than in forest. The effects of variation in tree density on fire rate of spread, flame height and intensity can be predicted using the BRAT SA.

The overall fuel hazard ratings should be assessed using the *Overall Fuel Hazard Guide for South Australia* (2011).

The prescriptions for conducting eucalypt heathy open forest and woodland prescribed burning are in Table 7.

Table 7: Eucalypt heathy open forest and woodland prescribed burning prescriptions.

Parameter	*Units*	*Range*
Overall fuel hazard rating: L or M		
Wind speed at 10 m	km/h	20 to 40
Relative humidity	%	10 to 60
Temperature	°C	20 to 40
Fuel moisture within the burning block	%	5 to 15
Forest Fire Danger Index - fuel reduction	dimensionless	7 to 15
Overall fuel hazard rating: H		
Wind speed at 10 m	km/h	10 to 35
Relative humidity	%	20 to 60
Temperature	°C	15 to 40
Fuel moisture within the burning block	%	7 to 15
Forest Fire Danger Index - fuel reduction	dimensionless	5 to 12
Overall fuel hazard rating: VH or E		
Wind speed at 10 m	km/h	5 to 20
Relative humidity	%	20 to 80
Temperature	°C	15 to 40
Fuel moisture within the burning block	%	10 to 15
Forest Fire Danger Index - fuel reduction	dimensionless	4 to 10
Overall fuel hazard rating: VH or E		
Fire frequency - fuel reduction	years	4 to 10
Flame Height - asset protection	m	2 to 4

Prior to 2009, the McArthur Forest Fire Danger Meter was the most widely utilised fire behaviour prediction model used in Australia (Luke and McArthur 1978). The McArthur Forest Fire Danger Meter was designed primarily for use in dry eucalypt forests with a litter understorey. While the meter has been used in a wide range of other fuel types, including sedgy, heathy and shrubby dry eucalypt forests and wet eucalypt forests, its reliability has not been systematically tested in these other vegetation types.

More recently, the Project Vesta fire behaviour model has been developed by the CSIRO and the Department of Conservation and Land Management in Western Australia (Gould *et al*. 2007a, 2007b). This model was intended to address some of the concerns with the McArthur Forest Fire Danger meter using data from experimental fires. For example, suggestions have been made that the McArthur Forest Fire Danger Meter under-predicts dry eucalypt forest fire spread rates at moderate or higher levels of fire danger (Gould *et al*. 2007a; McCaw *et al*. 2008). A major change between the McArthur Forest Fire Danger Meter and the Vesta Fire Model is the changeover from using fuel load to fuel hazard.

The Vesta Fire Model uses as inputs the wind speed, fuel hazard and fuel moisture (which can be predicted from the RH and temperature) and predicts the rate of fire spread, flame height and spotting distance.

Figure 5. Grassy eucalypt woodland.

12.4 Native grasslands and grassy eucalypt woodlands

Native grasslands and grassy eucalypt woodlands occur throughout South Australia, ranging from arid tussock grasslands in the north of the state, temperate grasslands in central and south-eastern areas through to grassy eucalypt woodlands (along river channels often with a red gum, *Eucalyptus camaldulensis*, overstorey) along drainage channels (Figure 5; SA Veg 2007).

Fuel hazard in these grasslands can be assessed using a combination of the DENR fuel hazard rating system (DENR 2011) and curing (ie percentage dead grass), with fire behaviour being predicted using the CSIRO grassland fire spread model (Cheney and Gould 1995; Cheney *et al*. 1993, 1998; Cheney and Sullivan 2008).

The critical factors influencing fire behaviour in native grassland burning are wind speed and curing (ie percentage of dead fuel).

In grassy eucalypt woodlands, tree height and density will influence the effective wind speed, with taller and/or denser sites having lower wind speeds on the fireline. The effects of variation between grassland and grassy eucalypt woodland on fire rate of spread, flame height and intensity can be predicted using the BRAT SA.

The prescriptions for conducting native grassland and grassy eucalypt woodland prescribed burning are in Table 8.

Table 8: Native grassland and grassy eucalypt woodland prescribed burning prescriptions.

Parameter	*Units*	*Range*
Adjusted surface fuel hazard rating: L or M		
Maximum Forward Rate of Spread	**km/h**	**1.5**
Wind speed at 10 m	km/h	10 to 40
Relative humidity	%	20 to 80
Temperature	°C	15 to 40
Curing (percentage dead fuel)	%	90 to 100
Grassland Fire Danger Index	dimensionless	≤5
Adjusted surface fuel hazard rating: H		
Maximum Forward Rate of Spread	**km/h**	**1.5**
Wind speed at 10 m	km/h	5 to 20
Relative humidity	%	20 to 80
Temperature	°C	15 to 40
Curing (percentage dead fuel)	%	80 to 90
Grassland Fire Danger Index	dimensionless	≤5
Adjusted surface fuel hazard rating: VH or E		
Maximum Forward Rate of Spread	**km/h**	**1.5**
Wind speed at 10 m	km/h	0 to 10
Relative humidity	%	20 to 80
Temperature	°C	15 to 40
Curing (percentage dead fuel)	%	60 to 80
Grassland Fire Danger Index	dimensionless	≤5

Cheney and Gould (1995), Cheney *et al*. (1993, 1998) and Cheney and Sullivan (2008) have developed models predicting grassland fire behaviour. These models use wind speed, fuel moisture, curing (ie percentage of dead fuel) and grassland state (eg natural, cut-over or eaten out) to predict the fire spread rate, flame height and intensity. The prescriptions have been developed for a natural grassland state.

The thresholds between sustaining versus non-sustaining grassland fires have been modelled by Leonard (2009). This study found that native grasslands sustained burning when the dead fuel moisture was <24% and the fuel load was greater than two tonnes per hectare (or if the fuel load was between one and two tonnes per hectare, the wind speed must be >2.5 km/h).

12.5 Coastal mallee and mallee-heathland, non-eucalypt woodland and heathland and woody weeds

The same prescriptions for prescribed burning are recommended for coastal mallee and mallee-heathland, non-eucalypt woodland and heathland, and woody weed vegetation types. These vegetation types, however, will typically have different levels of fuel-hazard rating and fuel height.

A major issue in achieving prescribed burn objectives for coastal mallee and mallee-heathland, non-eucalypt woodland and heathland, and woody weed management burning is the tight threshold between sustaining and non-sustaining fires.

When conditions are close to this threshold, minor increases in wind speed and/or slope, along with decreases in fuel moisture can transform low intensity fires that require intensive lighting, into easy to over-light, high intensity, fast moving fires. This tight sustaining versus non-sustaining threshold mainly results from the typically low levels of surface and near-surface fuels meaning that moderate levels of fire activity are required before fires propagate through the elevated fuel stratum. This means that the critical fuel hazard factor is the combined surface and near-surface fuel hazard rating (assessed using the *Overall Fuel Hazard Guide for South Australia* (2011).

12.5.1 Coastal mallee and mallee-heathland

Mallee woodland and heathland occur in higher rainfall parts of South Australia (particularly on Kangaroo Island) and consist of dense shrub, heath and mallee vegetation about one to four metres tall (Figure 6; SA veg 2007).

In common with non-eucalypt woodland and heathland, variation in non-eucalypt woodland and heathland fuel hazard can be assessed using the DENR fuel hazard rating system (DENR 2011), while fire behaviour can be predicted using the heathland fire model (Catchpole *et al*. 1998, 1999). The average height of the elevated layer should be used as an input into this model. In the absence of actual measures a height of 1.5 metres should be measured.

The prescriptions for conducting coastal wet and damp mallee woodland prescribed burning are in Table 9.

Figure 6. Coastal mallee heathland.

12.5.2 Non-eucalypt woodland and heathland

Non-eucalypt woodland and heathland vegetation consisting of tea-tree, paperbark, heath, and *Callitris* occur in a broad belt across southern and central South Australia from the southeast of the state across to west of Ceduna (Figure 7; SA veg 2007). Vegetation height is typically about one to three metres tall.

Variation in non-eucalypt woodland and heathland fuel hazard can be assessed using the DENR fuel hazard rating system (DENR 2011) while fire behaviour can be predicted using the heathland fire model (Catchpole *et al*. 1998, 1999).

The prescriptions for conducting non-eucalypt woodland and heathland prescribed burning are in Table 9.

Figure 7. Tea-tree non-eucalypt woodland and heathland.

12.5.3 Woody weeds

The main woody weed species where fire is used for management are gorse (*Ulex europeaus*), broom (*Genista* spp. and *Cytisus* spp.), olives (*Olea* spp.), *Erica* spp., horehound (*Marrubium vulgare*), boneseed (*Chrysanthemoides monilifera* ssp. *monilifera*), Aleppo pine (*Pinus halepensis*), *Polygala* spp. and/or blackberry (*Rubus* spp.) (Figure 8).

Fire behaviour in areas dominated by these woody weeds can be predicted using the heathland fire behaviour model (*Catchpole et al*. 1998, 1999), with additional information from the gorse fire modelling by Anderson and Anderson (2010) and the heathland and gorse fire prediction models by Fernandes (2001) and Baeza *et al*. (2002).

The most flammable of the woody weed species where fire is used for management is gorse. Fire is a major issue in areas dominated by gorse due to its ability to sustain burning over a wide range of conditions, and its rapid post-fire regeneration. Therefore, integrated pre- and post-fire treatments are essential. Treatment effectiveness can be enhanced by pre-burning herbicide spraying, scrub rolling and/or slashing to maximise burn intensity, which increases biomass consumption (to kill shallowly buried seeds and/or enhance seedling germination of deeper buried seeds) and improves post-fire access for follow-up treatments. Pre-burn treatment can also be used to broaden the burning window by increasing the weed's flammability and allowing the fire to be performed under higher fuel moisture conditions, thus reducing the risk of fires spreading to other vegetation types.

The prescriptions for conducting woody weed management prescribed burning are in Table 9.

Figure 8. Gorse prescribed burning.

Table 9: Costal mallee and heathland, non eucalypt woodland and heathland and woody weed prescribed burning prescriptions.

Parameter	*Units*	*Range*
Elevated fuel height 0 – 0.5m		
Maximum Forward Rate of Spread	**km/h**	**0.9**
Wind speed at 10 m	km/h	15 to 40
Relative humidity	%	10 to 70
Temperature	°C	20 to 40
Dead fuel moisture content, near-surface fuel	%	7 to 10
Elevated fuel height 0.5 – 2m		
Maximum Forward Rate of Spread	**km/h**	**1.5**
Wind speed at 10 m	km/h	5 to 30
Relative humidity	%	25 to 75
Temperature	°C	15 to 40
Dead fuel moisture content, near-surface fuel	%	10 to 15
Elevated fuel height >2m		
Maximum Forward Rate of Spread	**km/h**	**1.2**
Wind speed at 10 m	km/h	0 to 15
Relative humidity	%	25 to 75
Temperature	°C	15 to 40
Dead fuel moisture content, near-surface fuel	%	10 to 20

The Heathland Fire Model was developed as part of a cooperative project between land management agencies in Australia and New Zealand. The Heathland Fire Model uses as inputs wind speed and fuel height and does not incorporate fuel moisture. The issue of the heathland model not incorporating fuel moisture is a major problem during prescribed burning, as burning is normally conducted under higher fuel moisture conditions than typically occur during bushfires.

The normal situation is that when conditions are below the sustaining versus non-sustaining threshold, fires will only burn within individual bushes and fail to form sustaining fires. The Heathland Fire Model strongly suggests that this threshold corresponds to a surface wind speed of about 10 km/h. Fires also appear to burn poorly when the dead fuel moisture is above about 20% (JB Marsden-Smedley unpublished data). This threshold means that minor changes in environmental conditions (eg minor increases in wind speed, increases in slope or decreases in fuel moisture) can result in fires rapidly transforming from very low intensity fires requiring intensive lighting into high intensity fires with moderate spread rates.

Fernandes (2001) and Baeza *et al*. (2002) have developed heathland and gorse fire prediction models, which incorporate the influence of fuel moisture and wind speed (and fuel height in the case of the Fernandes 2001 model). Due to the small number of fires, the very limited range of wind speeds and fuel moistures, and the short fireline lengths used in the development of the models, the utility of their systems for predicting fire behaviour is uncertain. However, these models do provide some insights into the likely fire behaviour during low intensity weed (ie gorse) management burns and have been used in the development of the prescribed burning prescriptions.

Anderson and Anderson (2010) examined the threshold between sustaining versus non-sustaining fires in gorse in New Zealand. This study found a clear difference between the conditions that would support ignition only (fuel ignites but does not spread beyond a single bush or clump) and conditions that are conducive to fire spread (fuel ignites and develops into a spreading fire), with the critical factor being the moisture content of the elevated dead fuel. Fires failed to ignite when the moisture content was >36% and sustained ignition only occurred when the moisture content was <19%.

13. Information used for the revision of the prescribed burning prescriptions

Information for the revision and updating of the prescriptions used for prescribed burning in South Australia was obtained from the literature along with fuel and fire data supplied by the Department of Environment and Natural Resources.

The methodology used to develop these revised prescribed burning prescriptions was to:

- review the available literature on fuel and fire dynamics
- use the published fuel and fire prediction models to determine likely fire behaviour under prescribed burning conditions
- use the BRAT SA to examine the relative risk of different burning prescriptions
- compare the proposed burning prescriptions against data collected during the prescribed burns
- present and discuss the proposed prescriptions at a workshop held in Adelaide in September 2010
- incorporate input and corrections received from the workshop and on the draft report.

13.1 Expert opinion workshop

As part of this review of prescribed burning in South Australia, a workshop was held in Adelaide in September 2010 with personnel experienced in performing prescribed burning under South Australian conditions. The workshop was facilitated by Mike Wouters (Department of Environment and Natural Resources). The aim of the workshop was to obtain expert opinion about where the previous prescriptions were working, where they needed revising and updating, and to present draft prescriptions for prescribed burning for review. Consideration was also given to any other factors that were restricting the application of prescribed burning in South Australia. The highly constructive input arising from this workshop resulted in significant improvements to this review.

The workshop attendees were:

South Australia Department of Environment and Natural Resources
Ross Allen, Ross Anderson, Stuart Beinke, Robert Ellis, Tim Groves, Tim Hall, Robert Laver, Rob McGuiness, Ron Saers, Sam Sanderson, Brett Stephens, Ian Tanner, Joe Tilley, Michael Wigg, Mike Wouters and Shane Wiseman

Forestry SA
Dave Stevens

SA Water
Dani Boddington, Richard Munn and David Loveder

Country Fire Service
Malim Watts

Prescribed burn review consultant
Jon Marsden-Smedley

13.2 Previous prescriptions for conducting prescribed burning in South Australia

The previous South Australian prescribed burning prescriptions were developed during a series of workshops, which commenced in October 2002. These workshops were intended to identify the range of vegetation types suitable for prescribed burning along with suitable conditions to conduct the burning. The previous prescriptions for South Australian prescribed burning are summarised in Table 10.

Table 10: Previous South Australian prescribed burning prescriptions.

Vegetation Type	FDI max	Temp °C	RH %	Wind km/h at 10 m
Riverine open forest	5	16–20	60–80	0–5
Shrublands	12	24	35–70	5–15
Callitris woodland (regrowth)	12	23–27	35–50	10–20
Sedge dominated communities	18	15–25	30–70	0–10
Open grassland (modified pasture)	20	15–25	30–50	5–15
Stringybark forest and woodland	8	15–24	35–65	5–15
Heath dominated mallee and woodland	8	15–25	40–75	5–15
Open woodland	10	18–25	40–60	5–15
Mallee with Spinifex	12	18–25	40–80	0–15

Prescriptions for performing prescribed burning in Victorian semi-arid mallee and mallee-heath were also assessed. Sandell *et al*. (2006; see also: Billings 1981; Grant and Wouters 1993) published these prescriptions, which cover weather, lighting patterns and fire behaviour.

13.3 Assessment of fire behaviour data collected before, during and after prescribed burning

The available data on prescribed burns conducted in South Australia was compared against the revised burning prescriptions in this review in order to test the utility of the revised prescriptions. This data comprised information on sites, weather and fire behaviour in semi-arid mallee and mallee-heath, eucalypt heathy open forest and woodland, and heathlands.

As a high priority, the available information on prescribed burns should be collated for future reference. In addition, when prescribed burns are conducted in the future comprehensive data should be collected, including:

Before

vegetation:

- vegetation type(s) including proportion covered by each type
- surrounding vegetation type(s)
- key species and structure
- signs of time since last fire
- fuel hazard rating of surface, near-surface, elevated and bark fuels
- fuel cover, height and continuity
- weed infestations
- objectives

site:

- location (grid reference and datum)
- slope and aspect
- block size and shape
- altitude

During

weather:

- methodology used to collect weather data
- nearest Bureau of Meteorology weather station
- wind speed and direction
- wind gust speed
- relative humidity, dew-point temperature, dry-bulb temperature;
- cloud cover and/or solar radiation, atmospheric stability

fire ignition and behaviour:

- ignition method, strategy and intensity of lighting
- ignition time, fire duration and time at which fire behaviour data was collected
- rate of fire spread, flame height and intensity
- fire danger index (forest or grass)

After

fire behaviour

- ROS for head, flank and backfire
- post-fire assessment
- proportion of vegetation burnt within burn area
- objectives met
- fuel hazard rating of surface, near-surface, elevated and bark fuels
- monitoring
- weed infestations and control.

14. Conclusion

The Department of Environment and Natural Resources will adopt these prescriptions for South Australian conditions. These revised guidelines aim to minimise the risk of adverse outcomes from prescribed burning while also ensuring that burning is performed safely and meets land management objectives. The guidelines and methodologies for the operational prescriptions for prescribed burning outlined in this review should be reassessed no later than 10 years or earlier if significant circumstances arise.

The Department of Environment and Natural Resources *Fire Policy and Procedure Manual* (2011) specifies the use of Burn Risk Assessment Tool SA for all prescribed burns. Furthermore, the Policy and Procedure Manual states the BRAT SA will determine the required level of approval based on the burn overall risk rating.

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16. Glossary

The aim of the glossary is to promote an exchange of information between fire and land managers on terminology used specifically in prescribed burning. The definitions of this glossary have been taken from the Australasian Fire and Emergency Service Authorities Council Bushfire Glossary 2010.

Term	Definition
Assets	Anything valued by people which includes houses, crops, forests and, in many cases, the environment.
Atmospheric stability	The degree to which the atmosphere resists turbulence and vertical motion.
Available fuel	The portion of the total fuel that would actually burn under various environmental conditions.
Backburn	A fire started intentionally along the inner edge of a fireline during indirect attack operations to consume fuel in the path of a bushfire (Australia).
Bark fuel	The flammable bark on tree trunks and upper branches.
Basal accumulation	Bark fallen from a tree and forming a relatively high and localised accumulation of fine fuel.
Beaufort wind scale	A system for estimating wind speeds based on observation of visible wind effects. A series of descriptions of visible wind effects upon land objects or sea surfaces is matched with a corresponding series of wind speed ranges, each being allocated a Beaufort number.
Buffer	A strip or block of land on which the fuels are reduced to provide protection to surrounding lands.
Burn plan	The plan that is approved for the conduct of prescribed burning. It contains a map identifying the area to be burnt and incorporates the specifications and conditions under which the operation is to be conducted.
Burning conditions	The state of the combined components of the fire environment that influence fire behaviour and fire impact in a given fuel type. Usually specified in terms of such factors as fire weather elements, fire danger indices, fuel load and slope.
Burning off	Generally setting fire – with more or less regard to areas carrying unwanted vegetation such as rough grass, slash and other fuels.
Burning out	To intentionally light fires to consume islands of unburned fuel inside the fire perimeter.
Burning program	A program of prescribed burns scheduled for a designated area over a nominated time, normally looking ahead over one fire season (for the coming spring to the following autumn), but can also look ahead five years or more.
Burning rotation	The period between reburning a prescribed area for management purposes.
Burning unit	A specified land area for which prescribed burning is planned.
Bushfire	A general term used to describe a fire in vegetation.
Bushfire danger period	A period of the year either established by legislation or declared by the relevant agency, when restrictions are placed on the use of fire due to dry vegetation and the existence of conditions conducive to the spread of fire.
Candle (Candling)	A tree (or small clump of trees) is said to candle when its foliage ignites and flares up, usually from the bottom to top.
Candlebark	Long streamers of bark that have peeled from some eucalypt species that form fire bands conducive to very long distance spotting.
Canopy	The crowns of the tallest plants in a forest – the overstorey cover.
Canopy cover	Canopy cover refers to two dimensions (ie plan view, area coverage)
Canopy density	Canopy density refers to three dimensions (ie mass/volume)
Central ignition	A method of prescribed burning in which fires are set in the centre of an area to create a strong convective column. Additional fires are then set progressively closer to the outer control lines causing indraft winds to build up. This has the effect of drawing the fires towards the centre.
Climate	The atmospheric conditions of a place over an extended period of time.
Coarse fuels	Dead woody material, greater than 25 mm in diameter, in contact with the soil surface (fallen trees and branches). Some researchers categorise forest fuels as: fine <6 mm diameter; twigs 6–25 mm diameter; coarse >25mm diameter.

Term	Definition
Combustion	Rapid oxidation of fuels producing heat, and often light.
Control line	See: Fireline
Convection	1. As applied in meteorology, atmospheric motions that are predominantly vertical, resulting in vertical transport and mixing of atmospheric properties; distinguished from advection. 2. As applied in thermodynamics convection, along with conduction and radiation, is a principal means of energy transfer.
Convection column	The rising column of smoke, ash, burning embers and other particle matter generated by a fire.
Crown fire	A fire that advances from top to top of trees or shrubs.
Crowning	A fire ascending into the crowns of trees and spreading from crown to crown.
Curing	Drying and browning of herbaceous vegetation due to mortality or senescence.
Dead fuel	Fuels with no living tissue in which moisture content is governed almost entirely by absorption or evaporation of atmospheric moisture (relative humidity and precipitation).
Dew	The moisture that collects in small droplets on the surface of substances and vegetation by atmospheric condensation, chiefly at night.
Dew point temperature	This is a measure of the moisture content of the air and is the temperature to which air must be cooled in order for dew to form. The dew-point is generally derived theoretically from dry and wet-bulb temperatures, with a correction for the site's elevation.
Dominant height	The average of the height of the three largest diameter trees selected on a plot by a technique of variable probability sampling.
Drought	Prolonged absence or marked deficiency of precipitation (rain).
Drought index	A numerical value reflecting the dryness of soils, deep forest litter, logs and living vegetation.
Dry-bulb temperature	Technically, the temperature registered by the dry-bulb thermometer of a psychrometer. However, it is identical to the temperature of the air. (Degrees Celsius).
Ecological burning	A form of prescribed burning. Treatment with fire of vegetation in nominated areas to achieve specified ecological objectives.
Edge burning	A term used to describe perimeter burning of an area in mild conditions prior to large scale prescribed burning. This practice is used to strengthen buffers and to reduce mop-up operations.
Elevated fuel	The standing and supported combustibles not in direct contact with the ground and consisting mainly of foliage, twigs, branches, stems, bark and creepers.
Embers	Glowing particles cast from the fire (as 'showers' or 'storms').
Equipment	All material supplied to an incident excluding personnel and vehicles.
Extreme fire behaviour	A level of bushfire behaviour characteristics that ordinarily precludes methods of direct suppression action. One or more of the following is usually involved: • high rates of spread • prolific crowning and/or spotting • presence of fire whirls • a strong convective column. Predictability is difficult because such fires often exercise some degree of influence on their environment and behave erratically, sometimes dangerously.
Fine fuel	Fuel such as grass, leaves, bark and twigs less than 6 mm in diameter that ignite readily and are burnt rapidly when dry.
Fire	The chemical reaction between fuel, oxygen and heat. Heat is necessary to start the reaction and once ignited, fire produces its own heat and becomes self-supporting.
Fire access track	A track constructed and/or maintained expressly for fire management purposes.
Fire behaviour	The manner in which a fire reacts to the variables of fuel, weather and topography.
Fire behaviour prediction	Prediction of probable fire behaviour usually prepared by a fire behaviour analyst in support of fire suppression or prescribed burning operations.
Fire behaviour model	A set of mathematical equations that can be used to predict certain aspects of fire behaviour.

Term	Definition
Fire climate	The composite pattern or integration over time of the fire weather elements that affect fire occurrence and fire behaviour in a given area.
Fire danger	Sum of constant danger and variable danger factors affecting the inception, spread, and resistance to control, and subsequent fire damage; often expressed as an index.
Fire danger index (FDI)	A relative number denoting the potential rates of spread, or suppression difficulty for specific combinations of temperature, relative humidity, drought effects and wind speed.
Fire danger rating	A relative class denoting the potential rates of spread, or suppression difficulty for specific combinations of temperature, relative humidity, drought effects and wind speed, indicating the relative evaluation of fire danger.
Fire ecology	The study of the relationships between fire, the physical environment and living organisms.
Fire edge	Any part of the boundary of a going fire at a given time. NOTE: The entire boundary is termed the 'fire perimeter'.
Fire effects	The physical, biological and ecological impact of fire on the environment.
Fire environment	The surrounding conditions, influences, and modifying forces of topography, fuel, and weather that determine fire behaviour.
Firefighting operations	Any work or activity directly associated with control of fire.
Fire frequency	A general term referring to the recurrence of fire in a given area over time (NWCG). Also see: Fire regime.
Fire front	The part of a fire within which continuous flaming combustion is taking place. Unless otherwise specified, the fire front is assumed to be the leading edge of the fire perimeter. In ground fires, the fire front may be mainly smouldering combustion.
Fireground	The area in the vicinity of a fire suppression operation, and the area immediately threatened by the fire. It includes burning and burnt areas; constructed and proposed fire lines; the area where firefighters, vehicles, machinery and equipment are located when deployed; roads and access points under traffic management control; tracks and facilities in the area surrounding the actual fire; and may extend to adjoining area directly threatened by the fire.
Fire hazard	A fuel complex, defined by volume, type condition, arrangement, and location, that determines the degree of ease of ignition and of resistance to control.
Fire intensity	See: Fireline intensity.
Fireline	A natural or constructed barrier, or treated fire edge, used in fire suppression and prescribed burning to limit the spread of fire.
Fireline intensity	The rate of energy release per unit length of fire front usually expressed in kilowatts per metre (Kw/m). The rate of energy release per unit length of fire front, defined by the equation I=Hwr, where I = fireline intensity (kW/m) H = heat yield of fuel (kJ/kg) - 16,000 kJ/kg w = dry weight of fuel consumed (kg/m2) (mean total less mean unburnt) r = forward rate of spread (m/s) The equation can be simplified to I = w r/2 where I = fireline intensity (kW/m) w = dry weight of fuel consumed (tonnes/ha) r = forward rate of spread (m/hr)
Fire management	All activities associated with the management of fire prone land, including the use of fire to meet land management goals and objectives.
Fire potential	The chance of a fire or number of fires occurring of such size, complexity or impact that requires resources (both a pre-emptive management and suppression capability) from beyond the area of the fire origin.
Fire prevention	All activities concerned with minimising the incidence of bushfire, particularly those of human origin.
Fire regime	The history of fire in a particular vegetation type or area including the frequency, intensity and season of burning. It may also include proposals for the use of fire in a given area.
Fire risk	Processes, occurrences or actions that increase the likelihood of fires occurring.

Term	Definition
Fire season	The period during which bushfires are likely to occur, spread and do sufficient damage to warrant organised fire control.
Fire spread	Development and travel of fire across surfaces.
Fire suppression	The activities connected with restricting the spread of a fire following its detection and before making it safe.
Fire threat	The impact a fire will have on a community.
Fire weather	Weather conditions that influence fire ignition, behaviour, and suppression.
Flame angle	The angle of the flame in relation to the ground, caused by wind direction or the effect of a slope.
Flame depth	The depth of the zone within which continuous flaming occurs behind the fire edge.
Flame height	The average maximum vertical extension of flames at the leading edge of the fire front. Occasional flashes that rise above the general level of flames are not considered. This distance is less than the flame length if flames are tilted due to wind or slope.
Flame length	The distance between the flame tip and the midpoint of the flame depth at the base of the flame (generally the ground surface), an indicator of fire intensity.
Flammability	The ease with which a substance is set on fire.
Flammable	Capable of being ignited and of burning with a flame.
Forest	An area, incorporating all living and non-living components, that is dominated by trees having usually a single stem and a mature or potentially mature stand height exceeding 2 metres and with existing or potential crown cover of overstorey strata about equal to or greater than 20%. This definition includes Australia's diverse native forests, woodlands and plantations, regardless of age.
Forest fire	A fire burning mainly in forest and/or woodland.
Forward rate of spread (FROS)	The speed with which a head fire moves in a horizontal direction across the landscape.
Fuel	Any material such as grass, leaf litter and live vegetation which can be ignited and sustains a fire. Fuel is usually measured in tonnes per hectare. Related Terms: Available fuel, Coarse fuel, Dead fuel, Elevated dead fuel, Fine fuel, Ladder fuels, Surface fuels, and Total fine fuel.
Fuel age	The period of time lapsed since the fuel was last burnt.
Fuel arrangement	A general term referring to the spatial distribution and orientation of fuel particles or pieces.
Fuel array	The totality of fuels displayed in a location: fine and coarse, live and dead.
Fuel assessment	The estimation or calculation of total and available fuel present in a given area.
Fuel bed depth	Average height of surface fuels contained in the combustion zone of a spreading fire front.
Fuelbreak	A natural or manmade change in fuel characteristics that affects fire behaviour so that fires burning into them can be more readily controlled.
Fuel continuity	The degree or extent of continuous or uninterrupted distribution of fuel particles in a fuel bed thus affecting a fire's ability to sustain combustion and spread. This applies to aerial fuels as well as surface fuels.
Fuel depth	The average distance from the bottom of the litter layer to the top of the layer of fuel, usually the surface fuel.
Fuel load	The oven-dry weight of fuel per unit area. Commonly expressed as tonnes per hectare. (AFAC). (Also known as fuel loading).
Fuel management	Modification of fuels by prescribed burning, or other means.
Fuel modification	Manipulation or removal of fuels to reduce the likelihood of ignition and/or to lessen potential damage and resistance to control (eg lopping, chipping, crushing, piling and burning). (NWCG)
Fuel moisture content	The water content of a fuel expressed as a percentage of the oven-dry weight of the fuel particle. (%ODW)
Fuel moisture differential	A term used to describe the situation where the difference in the moisture content between fuels on adjacent areas results in noticeably different fire behaviour on each area.
Fuel profile	The vertical cross section of a fuel bed down to mineral earth.
Fuel reduction burning	The planned application of fire to reduce hazardous fuel quantities; undertaken in prescribed environmental conditions within defined boundaries.
Fuel reduction	Manipulation, including combustion, or removal of fuels to reduce the likelihood of ignition and/or to lessen potential damage and resistance to control.

Term	Definition
Fuel separation	The action of separating fuel for the purpose of providing a mineral earth firebreak. Also, the actual gap between fuel layers or particles, for example the gap between individual hummock grasses or between the surface and canopy fuels.
Fuel type	An identifiable association of fuel elements of distinctive species, form, size, arrangement, or other characteristics that will cause a predictable rate of spread or difficulty of control under specified weather conditions. (AFAC).
Grassland curing	The proportion of dead material in grasslands – usually increases over summer as tillers die off and dry out, increasing the risk of grassland fire.
Grid ignition	A method of lighting prescribed fires where ignition points are set individually at a predetermined spacing through an area.
Ground fuels	All combustible materials below the surface litter, including duff, roots, peat and saw dust dumps that normally support a glowing combustion without flame. Synonym: Subsurface Fuels. Note: Aerial, Surface and Ladder Fuels.
Habitat	The local environment of conditions in which an animal or plant lives.
Hazard	A source of potential harm or a situation with potential to cause loss.
Hazard reduction	See: Fuel management
Head fire	The part of a fire where the rate of spread, flame height and intensity are greatest, usually when burning downwind or upslope.
Heavy fuels	See: Coarse fuels
High intensity fire	Fires with an average intensity greater than 3000 kW.m-1 and flame heights greater than 3 metres, causing complete crown scorch or possibly crown fires in forests. Uncontrollable by direct attack. The term is also applied to stationary fires burning in very high fuel loads (such as logging slash).
Ignition pattern	The manner in which a prescribed burn, backburn, or burnout is set, determined by weather, fuel, ignition system, topographic and other factors having an influence on fire behaviour and the objective of the burn.
Ignition source	A source of energy sufficient to initiate combustion.
Inversion	A layer of the atmosphere in which temperature increases with increasing elevation. A condition of strong atmospheric stability.
Isobar	Lines on weather maps joining places which have the same air pressure. (BOM).
Keetch-Byram Drought Index (KBDI)	A numerical value reflecting the dryness of soils, deep forest litter, logs and living vegetation, and expressed as a scale from 0–200 where the number represents the amount of rainfall (mm) to return the soil to saturation.
Ladder fuels	Fuels that provide vertical continuity between strata. Fire is able to carry surface fuels into the crowns of trees with relative ease.
Light fuel	An assessment of fuel quantity indicating a low weight.
Line ignition	See: Strip burning
Litter	The top layer of the forest floor composed of loose debris of dead sticks, branches, twigs, and recently fallen leaves and needles, little altered in structure by decomposition.
Litter bed fuel	Dead fine fuel, including surface fuel and fuel lower in the fuel profile.
Living fuels	Fuels made up of living vegetation.
Low intensity fire	A fire that travels slowly and only burns lower storey vegetation, like grass and lower tree branches, with an average intensity of less than 500 kW.m-1 and flame height less than 1.5 metres. Usually causes little or no crown scorch and is easily controlled.
Mineral earth	When used in the context of fire control refers to a non-flammable surface (either natural or prepared), which provides a break in understorey, litter and humus fuels and hence a barrier (of varied effectiveness depending, among other things, on its width and the intensity of the approaching fire) to fire travelling on or near the ground surface.
Mosaic	Used in reference to the spatial arrangement of burnt and unburnt fuels at either a local or a landscape scale.
Natural barrier	Any area where lack of flammable material obstructs the spread of vegetation fires.
Near surface fuels	Fuels above surface fuels with a vertical component to their structure and are generally less than about 30 centimetres above the ground, but may be as high as 60 centimetres.

Term	Definition
Peat	An amorphous organic material formed by anaerobic decomposition that usually means the area is seasonally or permanently inundated with water. Peat fires burn by smouldering combustion and generate very high amounts of energy per unit area.
Peri urban interface	See: Urban rural interface
Predicted rate of spread	The rate of spread predicted by the application of fire spread models utilising appropriate inputs of fuel conditions, topography and weather. Also see Rate of Spread.
Preparedness	All activities undertaken in advance of the occurrence of an incident to decrease the impact, extent and severity of the incident and to ensure more effective response activities.
Prescribed burn	A fire utilised for prescribed burning.
Prescribed burning	The controlled application of fire under specified environmental conditions to a predetermined area and at the time, intensity, and rate of spread required to attain planned resource management objectives. It is undertaken in specified environmental conditions.
Prescribed fire	Any fire ignited by management actions to meet specific objectives. A written, approved burn plan must exist, and approving agency requirements (where applicable) must be met prior to ignition.
Prescription	A written statement defining the objectives to be attained during prescribed burning.
Prevention	All activities concerned with minimising the occurrence of incidents, particularly those of human origin.
Profile litter moisture content	The moisture content, expressed as a percentage of oven-dry weight, of the entire leaf litter bed above the mineral soil surface.
Rakehoe (McLeod tool)	A hand tool used for bushfire fighting, consisting of a combination of a heavy rake and hoe.
Rate of spread (ROS)	The speed with which a fire moves in a horizontal direction across the landscape at a specified part of the fire perimeter. See also Forward rate of spread.
Regeneration burn	A burn lit under prescribed conditions for the purpose of achieving regeneration of a particular vegetation type.
Relative humidity (RH)	The amount of water vapour in a given volume of air, expressed as a percentage of the maximum amount of water vapour the air can hold at that temperature.
Resources	All personnel and equipment available, or potentially available, for incident tasks.
Risk analysis	A systematic use of available information to determine how often specific events may occur and the magnitude of their likely consequences.
Risk	The exposure to the possibility of such things as economic or financial loss or gain, physical damage, injury or delay, as a consequence of pursuing a particular course of action. The concept of risk has two elements, i.e. the likelihood of something happening and the consequences if it happens. (AS4360).
Scorch height	1. The height above ground level up to which foliage has been browned by a fire. 2. A measurement for determining the acceptable height of flame during prescribed burning.
Scrub	Refers to vegetation, such as heath, wiregrass and shrubs, which grows either as an understorey or by itself in the absence of a tree canopy.
Slash	Accumulated fuel resulting from such natural events as wind, fire, snow breakage, or from such human activities as logging, cutting or road construction.
Soil Dryness Index (SDI)	A form of drought index, usually with slightly more detailed inputs than the Keetch-Byram Drought Index. May be on a scale of 0–200 like the KBDI, but some versions have different scales (for example, Western Australia: 0–2000).
Spot fire	1. Isolated fire started ahead of the main fire by sparks, embers or other ignited material, sometimes to a distance of several kilometres. 2. A very small fire that requires little time or effort to extinguish.
Spot ignition	An ignition pattern using a series of spaced points of ignition.

Term	Definition
Spotting	Behaviour of a fire producing sparks or embers that are carried by the wind and start new fires beyond the zone of direct ignition by the main fire. (NWCG).
Strip burning	1. An ignition pattern using lines of continuous fire. 2. In hazard reduction, burning narrow strips of fuel and leaving the rest of the area untreated by fire. (NWCG).
Strip ignition	See: Strip burning
Surface fuel	Fuels lying on or near the surface of the ground, consisting of leaf and needle litter, dead branch material, downed logs, bark, tree cones, and low stature living plants. (NWCG).
Temperature (dry-bulb)	The ambient air temperature recorded by an exposed thermometer.
Temperature (wet bulb)	Wet bulb temperature is measured by placing a moist, single-layer, muslin sleeve over the bulb of a dry-bulb thermometer. The difference between dry and wet bulb readings is used to determine relative humidity and dewpoint values.
Test fire	A controlled fire ignited to evaluate fire behaviour.
Topography	The surface features of a particular area or region. It may include mountains, rivers, populated areas, roads and railways, and fuel types.
Under storey	The lowest stratum of a multi-storeyed forest.
Urban rural interface (URI)	The line, area, or zone where structures and other human development adjoin or overlap with undeveloped bushland.
Values at risk	The natural resources or improvements that may be jeopardised if a fire occurs.
Wind direction	The direction from which the wind blows.
Wind speed	The rate of horizontal motion of the air past a given point expressed in terms of distance per unit of time. In the New Zealand Fire Danger Rating System, wind speed is measured at the standard height of 10 metres in the open, averaged over a 10-minute interval and in kilometres per hour.
Woodland	A subset of forest plant communities in which the trees form only an open canopy (between 20% and 50% crown cover), the intervening area being occupied by lower vegetation, usually grass or scrub.

17. Appendix 1: BRAT SA - relationships used to estimate fire risk, impacts and consequences

The main components of the BRAT SA are its data input and risk output forms.

The BRAT SA's data input form is divided into six sections:

- vegetation type burnt
- fuel characteristics in and adjacent to the burning block
- burning block type and boundary security
- weather and fuel moisture
- ignition strategy
- resources available to perform the burn.

The BRAT SA's risk output form is divided into three main sections:

- risks associated with performing the burn
- consequences and benefits arising from the burn
- predicted fire behaviour during the burn and the fire behaviour if the fire escapes.

The strategy for using the BRAT SA is to determine the:

- main vegetation types within and adjacent to the prescribed burn area
- vegetation's time since fire, fuel hazard ratings and fuel heights
- block size, shape, slope, aspect and boundary characteristics
- suitable weather, fuel moisture and fire danger indexes
- ignition strategy
- resources required for performing the prescribed burn
- positive versus negative impacts to cultural, ecological, recreational and economic assets.

The BRAT SA then predicts and assigns a hazard rating to:

- fuel hazard
- weather conditions
- site factors
- ignition strategy
- resources used
- whether the burn's preparation has been performed prior to ignition.

The BRAT SA also predicts and assigns a rating to the consequences and benefits of performing the burn to asset types, including:

- cultural
- ecological
- recreational
- economic.

The fire behaviour during the burn along with the expected fire behaviour should the fire escape is predicted by the BRAT SA, including:

- rate of fire spread (km/hr)
- flame height (m)
- fire intensity (kW/m)
- fire danger index.

Finally, the BRAT SA assigns an overall hazard rating to the burn that can be used to assist with the burn's approval process.

The BRAT SA uses drop down tables and range limited numerical values to control the allowable inputs.

In the impact and consequence categories, the *factors* are the numerical values used to assign the different *rating* classes. The rating classes are then used to multiply the relevant risk weightings (Table 11) to predict the overall level of risk.

Table 11: Percentage risk weightings applied to the different factors when estimating prescribing burning risk.

Risk Factors			Df	Mw	Ds, We	Sm	Gr	Sp
Fuel	Inside burn block	Fuel hazard	20	20	20	20	11	20
		Spotting	10	10	10	5	1	10
	Adjacent to burn block	Fuel hazard	10	10	10	10	10	10
Weather	FFDI	Max on day of burn	10	7	12	8.5	16	12
		Max day after burn	2	2	2	2	2	2
		Max next 3 days	1	0.5	1	0.5	1	0.5
	Stability	Day of the burn	2	2	2	2	2	2
		Preceding 2 days	1	1	1	1	1	1
	Fuel moisture	Inside burn block	2	5	5	0.5	6	3
		Adjacent to block	2	5	5	8	2	4
Burning block	Inside burn block	Aspect	1	0.5	1	0.5	1	1
		Slope	3	3	3	4.5	5	3
		Position	1	1	1	1	1	1
	Adjacent to burn block	Aspect	0.5	0.5	0.5	0.5	0.5	0.5
		Slope	1	1	0.5	0.5	2	0.5
		Position	0.5	0.5	0.5	0.5	0.5	0.5
	Block type and boundary	Type	3	3	3	5	5	2
		Accessibility	3	1	1	2	4	2
	Block	Shape	0.5	0.5	0.5	0.5	1	0.5
		Size	0.5	0.5	0.5	0.5	1	0.5
		Fall back boundary	1	1	1	2	2	1
Burning	Lighting	Pattern	3	3	1	3	3	2
		Technique	1	1	0.5	1	1	0.5
		Duration	1	1	0.5	1	1	0.5
Resources	Personnel	Number	5	5	3	5	5	5
	Machines/Aircraft	Number	2.5	2.5	2.5	2.5	2.5	2.5
	Additional resources	Response time	2.5	2.5	2	2.5	2.5	2.5
Preparation completed prior to burn ignition			10	10	10	10	10	10
TOTAL			**100**	**100**	**100**	**100**	**100**	**100**

Note: Df = dry forest, Mw = coastal mallee and mallee heathland, Ds = non-eucalypt woodland and heathland, We = weeds, Sm = semi-arid mallee and mallee-heathland, Gr = native grassland and grassy eucalypt woodland, Sp = Spinifex grassland.

17.1 Data input form: impacts arising from the burn

Vegetation type

The following vegetation types are considered suitable for prescribed burning and have been included using a drop-down list in the BRAT SA:

- semi-arid mallee and mallee-heath
- Spinifex grassland
- eucalypt heathy open forest and woodland
- non-eucalypt woodland and heathland
- coastal mallee and mallee heathland
- native grasslands and grassy eucalypt woodlands
- woody weeds.

The following additional vegetation and land-use types have been included for areas surrounding the prescribed burning block:

- urban areas and farmland
- plantations
- low and/or non-fuel areas.

Fuel hazard

The values for time since fire, fuel hazard rating and the height of surface, near-surface, elevated and bark fuels are entered from drop-down lists.

The fire risk associated with fuel hazard and spotting is based on the overall fuel hazard score.

Fuel hazard and spotting

Eucalypt heathy forest and eucalypt heathy woodland

Based on the overall fuel hazard rating.

Overall fuel hazard rating:

Low	=	0.25
Mod	=	0.5
High	=	0.75
Very high	=	0.9
Extreme	=	1

Coastal mallee and mallee heathland, non-eucalypt woodland and heathland, and woody weeds

Based on the addition of the influences of elevated fuel hazard and height.

For coastal mallee and mallee heathland:

Age factor:

<2 years	=	0.25
2 to <5 years	=	0.5
5 to <10 years	=	1
10 to <15 years	=	2
15 to <25 years	=	3
>25 years	=	4

Elevated fuel height factor:

<0.5 m	=	0.5
0.5 to 1 m	=	1
1 to 2 m	=	2
2 to 4 m	=	3
>4 m	=	4

Age and height rating:

<3	=	0.1
3	=	0.25
4	=	0.5
5	=	0.75
6	=	0.9
>6	=	1

For non-eucalypt woodland and heathland and weeds:

Age factor:

<2 years	=	0.5
2 to <5 years	=	1
5 to <10 years	=	3
10 to <15 years	=	4
15 to <25 years	=	4.5
>25 years	=	5

Elevated fuel height factor:

<0.5 m	=	1
0.5 to 1 m	=	2
1 to 2 m	=	3
2 to 4 m	=	4
>4 m	=	5

Age and height rating:

<3	=	0.1
3	=	0.25
4	=	0.5
5	=	0.75
6	=	0.9
>6	=	1

For native grassland:

Curing:

<60%	=	0.1
60 to 70 %	=	0.25
70 to 80 %	=	0.5
80 to 90 %	=	0.75
90 to 95 %	=	0.9
>95 %	=	1.0

Fuel moisture rating

Mf: >24%	=	0.1
Mf: 21 to 24%	=	0.25
Mf: 18 to 20%	=	0.5
Mf: 15 to 17%	=	0.75
Mf: 11 to 14%	=	0.9
Mf: <14%	=	1

For Spinifex grassland:

Age rating:

<2 years	=	0.25
2 to <5 years	=	0.5
5 to <10 years	=	1
10 to <15 years	=	2
15 to <25 years	=	3
>25 years	=	4

Near-surface fuel hazard rating:

Low	=	1
Mod	=	2
High	=	3
Very high	=	3.5
Extreme	=	4

Age and fuel hazard rating:

<3	=	0.1
3	=	0.25
4	=	0.5
5	=	0.75
6	=	0.9
>6	=	1

For semi-arid mallee and mallee-heath:

Near-surface fuel hazard rating:

Low	=	1
Mod	=	2
High	=	3
Very high	=	3.5
Extreme	=	4

Fuel moisture rating

Mf: >19%	=	0.1
Mf: 14 to 19%	=	0.25
Mf: 12 to 13%	=	0.5
Mf: 10 to 11%	=	0.75
Mf: 6 to 9%	=	0.9
Mf: <6%	=	1

Weather and fuel moisture

Weather parameters

The values for wind speed, relative humidity, temperature, last rainfall amount, time since rain and Drought Factor are used to predict fire behaviour and are entered into the BRAT SA as range limited numerical values. Data for season, fuel moisture, stability and fire danger index are entered from drop-down lists.

Fire behaviour potential

The fire behaviour potential in eucalypt heathy open forest and woodland is predicted from the Forest Fire Danger Index. The fire danger index on the day of the burn is predicted from the weather data, while for the following three days the fire danger index is entered using a drop-down table. For all other vegetation types the fire behaviour potential is predicted from the predicted rate of fire spread.

Eucalypt heathy forest and woodland: burn day, following day and next 3 days

Fire Danger Index:

0 to 5	=	0.1
6 to 10	=	0.25
11 to 20	=	0.5
21 to 30	=	0.75
31 to 50	=	0.9
>50	=	1

All other vegetation types: burn day, following day and next 3 days

Rate of fire spread

<0.15 km/hr	=	0.1
0.15 to 0.3 km/hr	=	0.25
0.3 to 0.9 km/hr	=	0.5
0.9 to 1.5 km/hr	=	0.75
1.5 to 2.4 km/hr	=	0.9
>2.4 km/hr	=	1

Stability

All burn types and times: burn day, preceding 2 days

Continuous Haines Index rating:

Very low - 2 or 3	=	0.1
Low - 4	=	0.25
Mod - 5	=	0.5
High - 6	=	0.75
Very high - 7 or 8	=	0.9
Extreme - >8	=	1

Fuel moisture

Semi-arid mallee and mallee-heathland, and Spinifex grassland

Measured fuel moisture is used if available, otherwise fuel moisture is estimated from models.

Fuel moisture content rating:

>15%	=	0.1
11 to 15%	=	0.25
8 to 10%	=	0.5
6 to 7%	=	0.75
<6%	=	1

All other vegetation types

Measured fuel moisture is used if available, otherwise fuel moisture is estimated from models.

Fuel moisture content rating:

>20%	=	0.1
16 to 20%	=	0.25
11 to 15%	=	0.5
8 to 10%	=	0.75
6 to 7%	=	0.9
<6%	=	1

Burning block type and boundary security

The values for burning block shape, size, slope, position in the landscape, aspect and boundary type are entered from drop-down lists.

Aspect

All vegetation types

Aspect rating:

SE to SW	=	0.1
flat	=	0.25
variable	=	0.5
NE to SE, SW to NW	=	0.75
NW to NE	=	1

Slope steepness

All vegetation types

Slope steepness rating:

flat to 5°	=	0.1
6 to 10°	=	0.25
11 to 20°	=	0.5
>20°	=	1

Slope position

All vegetation types

Slope position rating:

base of slope	=	1
mid slope	=	0.5
top of slope	=	0.25
flat	=	0.1

Boundary type

The boundary types are divided into four groups: mineral earth, vegetation with an overall L fuel hazard rating, vegetation with an overall M fuel hazard rating, vegetation with an overall H, VH or E fuel hazard rating. For fallback boundaries, the factor for distance to the fallback line is added to boundary type. There is also an option to select 'none', which results in the overall risk presented by boundary factors to go straight to extreme.

Mineral earth boundary types

Mineral earth boundary factor:

mineral earth or water: >250 m wide	=	1
mineral earth or water: 25 to 250 m wide	=	4
mineral earth, road or water: 5 to <25 m wide	=	6
mineral earth, road or water: <5 m wide	=	7
handline/wetline <2 m wide	=	8

Vegetation overall fuel hazard rating boundary types

Vegetation overall fuel hazard:

L factor

boundary >250 m wide	=	1
boundary 25 to 250 m wide	=	2
boundary <25 m wide	=	3

Vegetation overall fuel hazard:

M factor

boundary >250 m wide	=	2
boundary 25 to 250 m wide	=	4
boundary <25 m wide	=	6

Vegetation overall fuel hazard:

H, VH or E factor

boundary >250 m wide	=	5
boundary 25 to 250 m wide	=	7
boundary <25 m wide	=	9

Fallback boundary type and distance

Fall back distance factor:

>10 000 m	=	0.1
1001 to 10 000 m	=	0.25
501 to 1000 m	=	0.5
101 to 500 m	=	0.75
<100 m	=	1

Overall boundary type rating

Boundary rating:

1	=	0.1
3	=	0.25
5	=	0.5
7	=	0.75
9	=	0.9
11	=	1

Boundary accessibility

All vegetation types

Boundary accessibility rating:

all weather road	=	0.1
2wd track	=	0.25
4wd: all tankers	=	0.5
4wd: class 14 or QRV tankers only	=	0.75
foot only	=	0.9
inaccessible	=	1

Block size

All vegetation types

Block size rating:

<1 ha	=	0.1
1 to 25 ha	=	0.25
26 to 100 ha	=	0.5
101 to 500 ha	=	0.75
501 to 1000 ha	=	0.9
>1000 ha	=	1

Block shape

All vegetation types

Block shape rating:

regular shape with slopes ≤5°	=	0.1
regular shape with slopes 6 to 10°	=	0.5
regular shape with slopes >10°	=	0.75
long and narrow with slopes ≤5°	=	0.25
long and narrow with slopes 6 to 10°	=	0.5
long and narrow with slopes >10°	=	0.75
irregular shape with slopes ≤5°	=	0.75
irregular shape with slopes 6 to 10°	=	0.9
irregular shape with slopes >10°	=	1
irregular shape with slopes >10°	=	1

Ignition strategy

Drop-down lists are used to enter values for lighting pattern, technique and duration.

Lighting pattern

All vegetation types

Lighting pattern rating:

lines or spots <50 m apart	=	0.1
lines or spots 50 to 100 m apart	=	0.25
lines or spots 100 to 300 m apart	=	0.5
lines or spots >300 m apart	=	0.75
edge lighting only, block <300 m wide	=	0.9
edge lighting only, block >300 m wide	=	1

Ignition technique

All vegetation types

Ignition technique rating: hand lighting	=	0.1
hand lighting and aerial ignition combined	=	0.25
aerial incendiary capsule	=	0.5
vehicle flame thrower	=	0.5
aerial driptorch	=	1

Ignition duration

All vegetation types

Ignition duration rating:

<1 day	=	0.1
1 day	=	0.25
2 days	=	0.5
>2 days	=	1

Resources

The values for personnel, resources, response time for additional resources and burn preparation are entered from drop-down lists.

Number of personnel per km of boundary requiring lighting or support

All vegetation types

Personnel rating:

>20 people	=	0.1
11 to 20 people	=	0.25
5 to 10 people	=	0.5
<5 people	=	1

Resources available per 1000 m of burning block boundary

All vegetation types

Resources rating:

>5 fire vehicles onsite	=	0.1
1 to 5 fire vehicles and aircraft onsite	=	0.25
1 to 5 fire vehicles onsite	=	0.5
max 1 fire vehicle and aircraft onsite	=	0.75
max 1 fire vehicle onsite	=	0.9
no fire vehicles onsite, aircraft only onsite	=	1

Aerial resources available

All vegetation types

Resources rating:

fixed wing 802 bomber (3200l)	=	0.1
fixed wing 602 bomber (2450l)	=	0.25
helicopter with 1250l belly tank	=	0.5
helicopter with 600l water hog	=	0.75
helicopter with 400l bambi bucket	=	0.9
ignition aircraft only without water bombing capability	=	1
no aircraft available	=	1

Response time for additional resources

All vegetation types

Response time rating:

<30 min	=	0.1
30 to 60 min	=	0.25
1 to 3 hours	=	0.5
3 to 6 hours	=	0.75
6 to 24 hours	=	0.9
next day	=	1

Preparation completed prior to burn day

All vegetation types

Burn preparation performed rating:

yes	=	0
unbounded burn	=	0.5
no	=	1

17.2 Data input form: burn consequences and potential benefits

The potential consequences of performing the burn on cultural, ecological, recreational and/or economic assets are assessed for both within and adjacent to the prescribed burning block along with the potential protection (ie benefit) that the burn may provide for nearby assets. When the consequences and/or benefits on assets adjacent to the burn are assessed, the effect of distance to these assets is added to the final rating.

Burn consequence

All vegetation types

Cultural asset rating:

no cultural assets known	=	0
wells, mines, quarries	=	0.25
tracks, drainage lines, retaining walls	=	0.25
wooden huts and bridges	=	0.9
gardens and planted vegetation	=	0.75
middens	=	0.5
artefact scatters, stone arrangements	=	0.75
axe grinding groves	=	0.75
rock paintings	=	0.75
rock engravings	=	0.9
scarred trees and/or carved trees	=	1

Ecological asset rating:

no ecological assets	=	0
old-growth fire dependent vegetation	=	0
regrowth or mature fire dependent vegetation	=	0.25
EPBC issue	=	0.5
Regrowth *Callitris* pines	=	0.5
Mature *Callitris* pines	=	0.75
Fire sensitive species	=	1

Recreational asset rating:

no visitor facilities	=	0
minor visitor site or walking track	=	0.5
major visitor site; high use walking track	=	1

Economic asset rating:

no economic assets	=	0
other infrastructure present	=	0.1
regrowth production forest	=	0.25
farms, mature production forest	=	0.5
major developments, plantations	=	0.75
urban interface	=	0.9
high value built assets, eg schools, hospitals	=	1

Distance to asset factor:

>1000 m	=	0.1
501 to 1000 m	=	0.25
101 to 500 m	=	0.5
<100 m	=	1

17.3 Risk output form: burn impact and consequence scores

The risk output form predicts the risk of adverse impacts associated with the different parameters, consequences of the fire escaping, benefits of performing the burn, the fire behaviour during the burn and the likely fire behaviour should the fire escape.

The risks associated with each of the different parameters are allocated a score between low and extreme based on the percentage of the maximum value possible for that parameter.

This risk score has been developed using a risk level matrix using the following risk level thresholds:

- Low 0 to 25%
- Moderate 26 to 50%
- Significant 51 to 75%
- High 76 to 90%
- Extreme >90%

The risk of adverse impacts are calculated for the following parameters:

- Fuel hazard
  - inside block
  - adjacent to block
- Weather
  - fire behaviour potential: day of the burn
  - fire behaviour potential: next day
  - fire behaviour potential: following 3 days
  - stability: day of the burn
  - stability: max over preceding 2 days
  - fuel moisture
- Site factors
  - inside block
  - adjacent to block
  - boundary factors
- Ignition strategy
  - lighting pattern, technique and duration
- Resources
  - personnel and equipment
  - response time for additional resources
- Preparation works completed
- Overall risk, consequence and benefit ratings

The consequences of the burn being performed are calculated for the following areas:

- adverse consequences inside burning block
- adverse consequences outside burning block
- benefits from the burn.

For assets outside the prescribed burning block the distance from the block's boundary to the asset's location is incorporated in the consequence rating.

For each of these areas – inside the burning block, outside the burning block and the benefits from performing the burn – the potential for adverse consequences or benefits are calculated for the following asset types:

- cultural assets
- ecological assets
- recreational opportunities
- economic assets.

The ratings for cultural, ecological, recreational and economic asset types are presented in the BRAT SA as separate ratings.

17.4 Risk output form: predicted fire behaviour

The predicted fire behaviour during the prescribed burn and the fire behaviour should the fire escape are predicted from the weather, fuel and site conditions. The following fire behaviour parameters are predicted using the indicated models:

eucalypt heathy open forest and woodland

- ROS, F_H Vesta dry eucalypt model
- I_B Byram's Intensity
- FDR McArthur Forest Fire Danger Meter

non-eucalypt woodland and heathland, woody weeds

- ROS, F_H Heathland fire model
- I_B Byram's Intensity

coastal mallee woodland and coastal mallee heathland

- ROS Heathland fire model

semi-arid mallee woodland and semi arid heathland

- ROS Cruz *et al*. (2010)

Spinifex grassland

- ROS Burrows *et al*. (2006, 2009)

native grassland, grassy eucalypt woodland

- ROS CSIRO grass fire model

The wind speed used to predict fire behaviour has been corrected where applicable for the effects of measurement height and forest density. In non-eucalypt woodland and heathland, coastal mallee woodland, semi-arid mallee, Spinifex grassland and native grassland the 10 metre wind speed has been multiplied by 0.66 to reduce it to the surface wind at 2 metres.

In mallee woodland, non-eucalypt woodland and heathland and dry forest vegetation types the wind speed has been corrected using a formula developed from McArthur (1967).

The wind speed correction formula used is:

factor = (1.48-0.237*veg type+0.00463*wind10m)*wind10m

where veg type:

non-eucalypt woodland and heathland, mallee woodland, semi-arid mallee, dry woodland	= 2
dry forest	= 3
plantation	= 4

18. Appendix 2: South Australian prescribed burning prescriptions

The main vegetation groups (fuel types) suitable for prescribed burning are:

- semi-arid mallee and mallee-heath
- Spinifex grassland
- eucalypt heathy open forest and woodland
- non-eucalypt woodland and heathland
- coastal mallee and mallee heathland
- native grasslands and grassy eucalypt woodlands
- woody weeds.

The prescribed burning parameters need to be integrated when conducting prescribed burning. If burning is conducted with all of the parameters at their maximum values (eg highest wind speed, lowest relative humidity and highest fuel hazard) then fires will burn with rapid rates of spread, high intensities and a high risk of escapes. Conversely, if burning is conducted with all of the parameters at their lowest values, then fires may fail to sustain, or if they do sustain they may burn with insufficient intensity to meet objectives.

All of the prescriptions detailed below use the wind speed measured at 10 metres above the ground surface. If the wind speed is measured at 2 metres above the ground surface it needs to be transformed to the equivalent of the 10 metre wind speed by multiplying by 1.5.

The recommended process for selecting appropriate burning parameters is:

1. Specify the burn's objectives.
2. Determine the vegetation type/s and the level of fuel hazard within and adjacent to the prescribed burning area.
3. Determine the minimum and maximum fire intensity to achieve objectives, fuel modification required, and likely fire behaviour during the burn.
4. Determine whether the burn's risk profile is acceptable using the BRAT SA.
5. If necessary, modify the weather and site parameters to reduce the level of fire risk whilst maintaining acceptable levels of fire intensity to achieve the burn's objective.
6. Undertake the burn within the prescription parameters.
7. Undertake post-burn assessments to determine if burn objectives have been met (and develop strategies to address the issue if the objectives have not been met), and record the burn outcomes on appropriate databases.

The prescriptions for conducting prescribed burning in South Australia are summarised in Table 12.

Table 12: South Australian prescribed burning prescriptions.

Parameter	Units	Vegetation types for prescribed burning				
		Semi-arid mallee woodland and mallee heath[1]	Spinifex grassland[1]	Eucalypt heathy open forest and woodland[2]	Native grasslands and grassy eucalypt woodlands[1]*	Coastal mallee and mallee heathland, non-eucalypt woodland and heathland and woody weeds[3]
Adjusted surface fuel hazard rating: L or M[1] Overall fuel hazard rating[2] Elevated fuel height 0–0.5 m[3]						
Maximum forward rate of spread	**km/h**	**1.5**	**1**	**-**	**1.5**	**0.9**
Wind speed at 10 m	km/h	25 to 50	20 to 50	20 to 40	10 to 40	15 to 40
Relative humidity	%	10 to 60	-	10 to 60	20 to 80	10 to 70
Temperature	°C	20 to 40	-	20 to 40	15 to 40	20 to 40
Fuel moisture content, near-surface fuel	%	5 to 10	12 to 30	5 to 15	-	7 to 10
Fire Danger Index			-	7 to 15	≤5	-
Curing (percentage dead fuel)	%	-	-	-	90 to 100	-
Adjusted surface fuel hazard rating: H[1] Overall fuel hazard rating[2] Elevated fuel height 1–2 m[3]						
Maximum forward rate of spread	**km/h**	**1.5**	**0.9**	**-**	**1.5**	**1.5**
Wind speed at 10 m	km/h	20 to 45	10 to 40	10 to 35	5 to 20	5 to 30
Relative humidity	%	20 to 70	-	20 to 60	20 to 80	25 to 75
Temperature	°C	20 to 40	-	15 to 40	15 to 40	15 to 40
Fuel moisture content, near-surface fuel	%	7 to 12	12 to 30	7 to 15	-	10 to 15
Fire Danger Index		-	-	5 to 12	≤5	
Curing (percentage dead fuel)	%	-	-	-	80 to 90	-
Adjusted surface fuel hazard rating: VH or E[1] Overall fuel hazard rating[2] Elevated fuel height >2 m[3]						
Maximum forward rate of spread	**km/h**	**1.5**	**1.3**	**-**	**1.2**	**1.5**
Wind speed at 10 m	km/h	15 to 35	10 to 30	5 to 20	0 to 10	0 to 15
Relative humidity	%	20 to 70	-	20 to 80	20 to 80	25 to 75
Temperature	°C	20 to 40	-	15 to 40	15 to 40	15 to 40
Fuel moisture content, near-surface fuel	%	8 to 13	12 to 30	10 to 15	-	10 to 20
Fire Danger Index		-	-	4 to 10	≤5	-
Curing (percentage dead fuel)	%	-	-	-	60 to 80	-
Overnight weather conditions required: bounded burns (surrounded by tracks or areas with L or M fuel hazard rating)						
Wind speed at 10 m	km/h	<25	<15	-	-	-
Relative humidity	%	>60	>60	-	-	-
Fuel moisture content, near-surface fuel	%	>15	>15	-	-	-
Overnight weather conditions: unbounded burns (no surrounding tracks or surrounded by areas with L or M fuel hazard rating)						
Wind speed at 10 m	km/h	<15	<15	-	-	-
Relative humidity	%	>85	>85 for 5+hrs	-	-	-
Fuel moisture content, near-surface fuel	%	>15	>15	-	-	-

*Grassland Fire Danger Index is used for native grassland and grassy eucalypt woodland vegetation type. The prescriptions for native grassland and grassy eucalypt woodland vegetation type have been developed for a natural grassland state. Use Forest Fire Danger Index for all other vegetation types where Fire Danger Index is required.

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